Text—Denson and Gill—URANIUM-BEARING LIGNITE AND CARBONACEOUS SHALE IN WILLISTON BASIN—Geological Survey Professional Paper 463

# Uranium-Bearing Lignite and Carbonaceous Shale in the Southwestern Part of the Williston Basin— A Regional Study

GEOLOGICAL SURVEY PROFESSIONAL PAPER 463

*Prepared on behalf of the*
*U.S. Atomic Energy Commission*

# Uranium-Bearing Lignite and Carbonaceous Shale in the Southwestern Part of the Williston Basin— A Regional Study

*By* N. M. DENSON *and* J. R. GILL

*With a section on*

HEAVY MINERALS IN CRETACEOUS AND TERTIARY ROCKS ASSOCIATED WITH URANIUM OCCURRENCES

*By* W. A. CHISHOLM

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## CONTENTS

# ILLUSTRATIONS

[Plates are in plate volume]

# TABLES

# URANIUM-BEARING LIGNITE AND CARBONACEOUS SHALE IN THE SOUTHWESTERN PART OF THE WILLISTON BASIN—A REGIONAL STUDY

By N. M. Denson and J. R. Gill


## ABSTRACT

Uranium in carbonaceous shale and lignite occurs at many horizons throughout 2,500 feet or more of Upper Cretaceous and lower Tertiary (Paleocene and Eocene) rocks in the southwestern part of the Williston basin. The uranium occurrences extend northward 150 miles or more in general alinement with the structurally lowest part of the basin from Harding and Perkins Counties in northwestern South Dakota to the western part of Dunn County in southwestern North Dakota. The carbonaceous host rocks containing the higher grade occurrences range from 6 inches to 2 feet or more in thickness and are characterized by lenticularity, relatively high ash contents (35 to 40 percent), and low heating values.

Although small amounts of uranium occur sporadically in carbonaceous rocks over a wide area along the southwestern part of the Williston basin, the important reserves of ore-grade uraniferous lignite and carbonaceous shale containing greater than 0.1 percent uranium are present in the North Cave Hills and Slim Buttes areas of Harding County, S. Dak., and in the Little Missouri River escarpment area (Rocky Ridge and Saddle Butte localities) in eastern Billings and northwestern Stark Counties, N. Dak. In these areas blanket-type deposits, containing in excess of 150,000 tons of ore-grade material, and lentil-type deposits of higher grade material, containing a few hundred pounds to as much as 1,500 tons, have been reported. Some of the deposits in the Cave Hills and Little Missouri River escarpment areas are overlain by relatively thin overburden which make them amenable to strip mining. Inferred reserves of ore-grade material in the region exceed 1 million tons.

Chemical analyses of 10 large samples of uranium-bearing lignite and carbonaceous shale collected by the Atomic Energy Commission from Billings County, N. Dak., indicate an average content of 0.18 percent uranium, 0.3 percent molybdenum, 0.09 percent phosphorus, and 0.01 percent vanadium. Only 2 of the 10 large samples analyzed contained less than 0.1 percent uranium.

Primary structural and stratigraphic controls affecting the localization of uranium appear to be shallow troughs superimposed on the flanks of the basin by late Tertiary tectonic movements and by the proximity of the host rocks to the pre-Oligocene erosion surface. The localization of uranium in the Williston basin, as in the Colorado Plateau and Texas Coast Plain, is remarkably influenced by the presence of carbon, which has an affinity for uranium and which is effective as a reducing agent in causing the precipitation of uranium and associated metals from solution. Porosity of the lignitic host materials and the enclosing rocks are important secondary controls of mineralization.

From a study of the spectrographic, chemical, and mineralogic data and of the principal structural and topographic relations of the deposits, we conclude that uranium, arsenic, molybdenum, selenium, vanadium, and some other elements were introduced into the lignite by ground water. Mineralization was probably continuous from Miocene to present. The abundance of these elements in samples of ground water draining the middle and upper Tertiary tuffaceous rocks in the region and their presence in only minor amounts in ground water draining the underlying lignite-bearing sequence in unmineralized areas suggest an origin by leaching from the volcanic constituents composing the tuffaceous rocks. Other evidence supporting this mode of origin is the fact that all significant occurrences of uranium in the region fall to within about 200 feet stratigraphically of the base of the tuffaceous sequence or to its projected base in areas where erosion has removed the tuffaceous sequence.

Microscopic studies of 135 grab samples from the continental basin-fill sedimentary rocks comprising the Hell Creek, Fort Union, Chadron, Brule, and Arikaree Formations reveal a characteristic heavy-mineral assemblage for each formation that differs from the assemblage in the adjacent formation. No relation was found between any of these assemblages and the occurrence of uranium.


## INTRODUCTION

### PURPOSE AND SCOPE

During the field seasons of 1955 and 1956, reconnaissance and detailed studies were made of uranium-bearing lignite and carbonaceous shale of Late Cretaceous and early Tertiary age in eastern Montana and adjacent parts of western North and South Dakota. These studies were a part of the U.S. Geological Survey's investigations of uranium-bearing carbonaceous rocks on behalf of the Division of Raw Materials of the U.S. Atomic Energy Commission. They included compilation and synthesis of all available published and unpublished data, both surface and subsurface, that might have a bearing on the distribution of uranium in the region.

The purpose of the investigation was to determine the relation of the higher grade deposits of uranium-bearing lignite and carbonaceous shale to major regional structures, to stratigraphic position, and to possible source areas.

Elevations were determined for most of the known uranium-rich deposits and for the pre-Oligocene erosion surface which truncates 2,500 feet or more of potential ore-bearing rocks of Late Cretaceous and early Tertiary age in the region studied. Regional and local maps were prepared to show principal structural features and to aid in interpreting the possible influence of post-Oligocene folding on uranium localization.

Spectrographic and chemical analyses of about 300 samples of lignite and carbonaceous shale from various parts of the region were studied to identify those elements concentrated or introduced into the lignite and shale during the period of uranium mineralization, and to ascertain whether there were differences in composition of carbonaceous host materials resulting from possible variations in environments of deposition. Most of the uranium in the region occurs as a finely disseminated amorphous constituent intimately associated with the organic fraction of the lignite and carbonaceous shale. Yellow fluorescent and nonfluorescent uranium minerals, however, do occur in carbonaceous rocks at many widely scattered areas within the basin, and these minerals have been studied and identified in the laboratories of the U.S. Geological Survey and private organizations by optical and X-ray methods.

Heavy-mineral studies of 135 grab samples from 30 measured sections throughout the region were made to determine differences in mineral suites between the lignite-bearing rocks that contain the uranium and the overlying tuffaceous sequence from which the uranium was probably leached.

Detailed basic analytical and drill-hole data supplemental to this report were compiled in 28 tables that have been placed in open file by the Geological Survey. These tables, which are in five groups according to subject matter, are listed in the bibliography at the end of this report and cited at appropriate places in the text. (See Denson and Gill, 1965a, b, c, d, e.) The tables are available for public inspection or may be purchased through the Geological Survey libraries in Washington, D.C., Denver, Colo., and Menlo Park, Calif.

## LOCATION AND EXTENT OF AREA

The area covered by this report is bounded on the north and south by the 49th and 45th parallels, on the east by the 102d meridian, and on the west by the 106th and 107th meridians. These boundaries delimit about 55,000 square miles in an area about 280 miles long and 195 miles wide. The southern boundary is 80 miles north of the central part of the Black Hills in western South Dakota and the northern boundary is the Saskatchewan, Canada, border. The area includes most of the southwestern part of the Williston basin and the northern part of the Black Hills uplift. All the uranium-rich deposits studied are in the unglaciated part of the Missouri River Plateau area of the northern Great Plains province (Fenneman, 1931, pl. 1 and p. 63 and 72). Within this area detailed geologic investigations and mapping were conducted in the Slim Buttes and Short Pine Hills in northwestern South Dakota, in the Finger Buttes, Ekalaka Hills, and Long Pine Hills in southeastern Montana, and in the Little Badlands and Chalky Buttes and along the Little Missouri River escarpment in southwestern North Dakota (fig. 1). The uranium deposits in the Cave Hills area, Harding County, S. Dak., were studied in detail by Pipiringos, Chisholm, and Kepferle (1964).

## PREVIOUS INVESTIGATIONS FOR URANIUM

Uranium-bearing lignite was discovered in southwestern North Dakota by D. G. Wyant and E. P. Beroni (1950) in the summer of 1948 and in northwestern South Dakota and eastern Montana by Beroni and Bauer (1952) in 1949. The uranium deposits discovered in carbonaceous rock of the region from 1948 through 1952 were largely of low grade. A carnotite-bearing sandstone at Slim Buttes in northwestern South Dakota discovered in 1953 (Gill and Moore, 1955, p. 249) and relatively high-grade uranium-bearing lignite and carbonaceous shale in the North Cave Hills discovered in 1954 by the Homestake Mining Co. stimulated considerable interest in the lignite and associated shale in the region as potential sources of uranium. As a result, much geologic work has been done in the region by the Federal and State geological surveys, by independent organizations under contract to the U.S. Atomic Energy Commission, and by private industry.

Geologic relationships, theories of origin, and the nature and extent of many of these occurrences are described in reports by Bergstrom (1956), Curtiss (1955), Denson and Gill (1956), Everhart (1956), Denson, Bachman, and Zeller (1959), Schopf and Gray (1954), Gruner (1956), Petsch (1955a, 1955b), White (1958), King and Young (1956), Osterwald and Dean (1957a, 1957b, 1958), Gill, Zeller, and Schopf (1959), Moore, Melin, and Kepferle (1959), Pipiringos, Chisholm, and Kepferle (1964), Vine (1962), Zeller and Schopf (1959), and the U.S. Geological Survey semiannual reports (1953–1958). This report summarizes and integrates much of the information made available by these investigations.

## ACKNOWLEDGMENTS

The authors are indebted to many colleagues in the U.S. Geological Survey for aiding in the compilation and interpretation of data presented in this report, but particular thanks are due the following: Leonard B. Riley for helpful criticism and suggestions relating to the presentation of analytical data on lignites; Roger B. Colton for copies of unpublished maps of the geol-

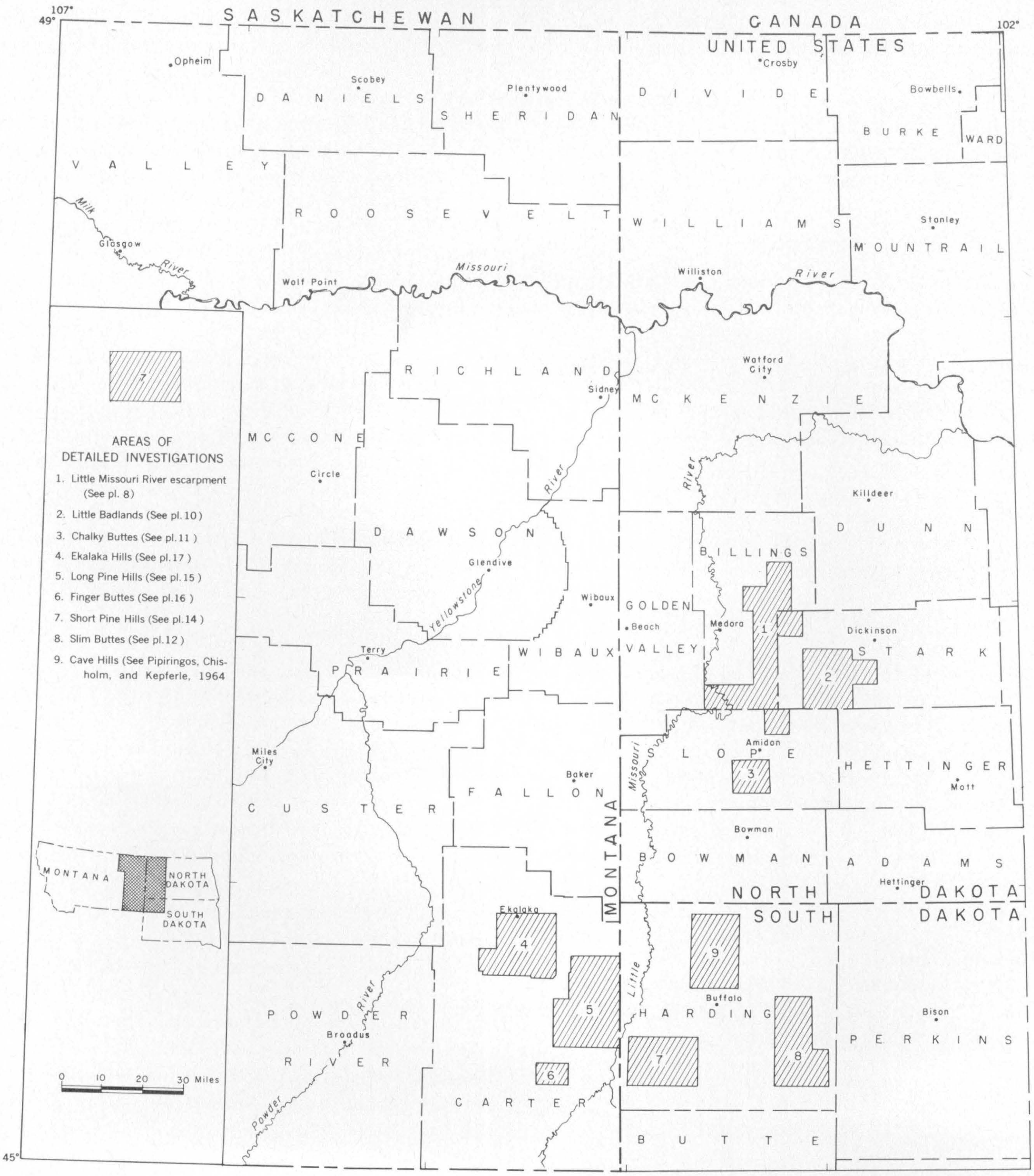


FIGURE 1.—Location of areas of detailed investigations for uranium described in this report.

ogy of northeastern Montana; Charles Sandberg for critical review of thickness maps and assistance in correlating key horizons on radioactivity well logs; George N. Pipiringos for the use of spectrographic and chemical analyses of samples from the Cave Hills uranium deposits in northwestern South Dakota; and Mortimer Staatz for identifying and describing thin sections of volcanic rocks.

## METHODS

Geologic mapping in the areas of detailed studies (fig. 1) was done at the scale of 1:20,000 on aerial photographs taken by the Agriculture Adjustment Administration. The geology and culture were later transferred by Saltzman projector to planimetric bases at the scale of 1:31,680 prepared from Bureau of Land Management township plats. Elevations were determined on the base of the Oligocene and Miocene tuffaceous rocks in each of these areas, as well as on isolated outcrops in intervening areas. From these data contour maps were compiled to show possible influence of post-Oligocene movements on uranium mineralization.

Federal and State highway bench marks, Army Map Service control points, and triangulation stations and bench marks of the U.S. Coast and Geodetic and the U.S. Geological Surveys were used in establishing vertical control throughout the region. Single base altimeter methods described by Lahee (1941, p. 467) were employed in determining elevations on selected geologic contacts and on the important uranium occurrences. Elevations determined by this method were checked at various times during the investigation and found to be correct to within about 10 feet.

Oil fields, selected dry holes, culture, and geology shown on the regional map (pl. 1) were originally plotted on maps at a scale of 1:200,000 compiled by the Army Map Service. These maps were reduced photographically to a scale of 1:500,000, and the data were transferred by direct tracing to a Lambert conformal conic projection base prepared by the Geological Survey.

## STRATIGRAPHY

### GENERAL DISCUSSION

The Williston basin in North and South Dakota and Montana is largely covered by a few feet to as much as 2,700 feet of interbedded drab-colored sandstone, siltstone, shale, and claystone dominantly of continental origin and of Late Cretaceous and early Tertiary age (pls. 1 and 2). These deposits are thickest near the center of the basin and thin, as a result of erosion, to a featheredge along the flanks of the Poplar dome, Cedar Creek anticline, and the north end of the Black Hills uplift. The sequence contains many beds of lignite and carbonaceous shale, some of which are remarkably persistent and can be traced with certainty over wide areas. In the area of the uranium deposits, the sequence can be subdivided in descending order into the Golden Valley Formation of Eocene age, the Fort Union Formation of Paleocene age comprising the Sentinel Butte, Tongue River, Cannonball, and Ludlow Members, and the Hell Creek Formation of Late Cretaceous age. Directly underlying the Hell Creek Formation with apparent conformity is the Fox Hills Sandstone, which is in turn underlain by Pierre Shale or its upper lateral equivalent, the Bearpaw Shale; all are of Late Cretaceous age. These units of marine origin are present in the subsurface throughout most of the region, and occur at the surface along the Cedar Creek anticline, the Poplar dome, and the north end of the Black Hills uplift. They are the oldest rocks exposed in the area of this report, except for a small area in southeastern Montana where the underlying Colorado Group of Late Cretaceous age and Mowry Shale of Early Cretaceous age are exposed along the north flank of the Black Hills uplift.

Unconformably overlying the tilted and beveled edges of each of the units previously mentioned is a thick sequence of tuffaceous sandstone, siltstone, claystone, bentonite, and volcanic ash of middle and late Tertiary age which at one time extended over southeastern Montana and adjoining parts of western North and South Dakota. This sequence comprises the Arikaree Formation of Miocene age and the underlying Brule and Chadron Formations of the White River Group of Oligocene age. These rocks have been removed by erosion throughout most of the region, but remnants are preserved on many of the principal drainage divides in widely separated areas in the southwestern part of the Williston basin. Excellent exposures are present in the Slim Buttes and Short Pine Hills in northwestern South Dakota, the Ekalaka and Long Pine Hills in eastern Montana, and the Little Badlands, Chalky Buttes, and Killdeer Mountains in western North Dakota. The rocks of the Chadron, Brule, and Arikaree Formations have a combined thickness of about 600 feet and contain vertebrate fossils at many localities throughout the basin.

The erosion surface on which the upper Tertiary tuffaceous rocks were deposited has a local relief of 150 feet, a regional relief of about 2,500 feet, and an average slope of about 12 feet per mile to the northeast (pl. 1). At many places the rocks beneath the erosion surface are highly oxidized (fig. 2) and are readily recog-

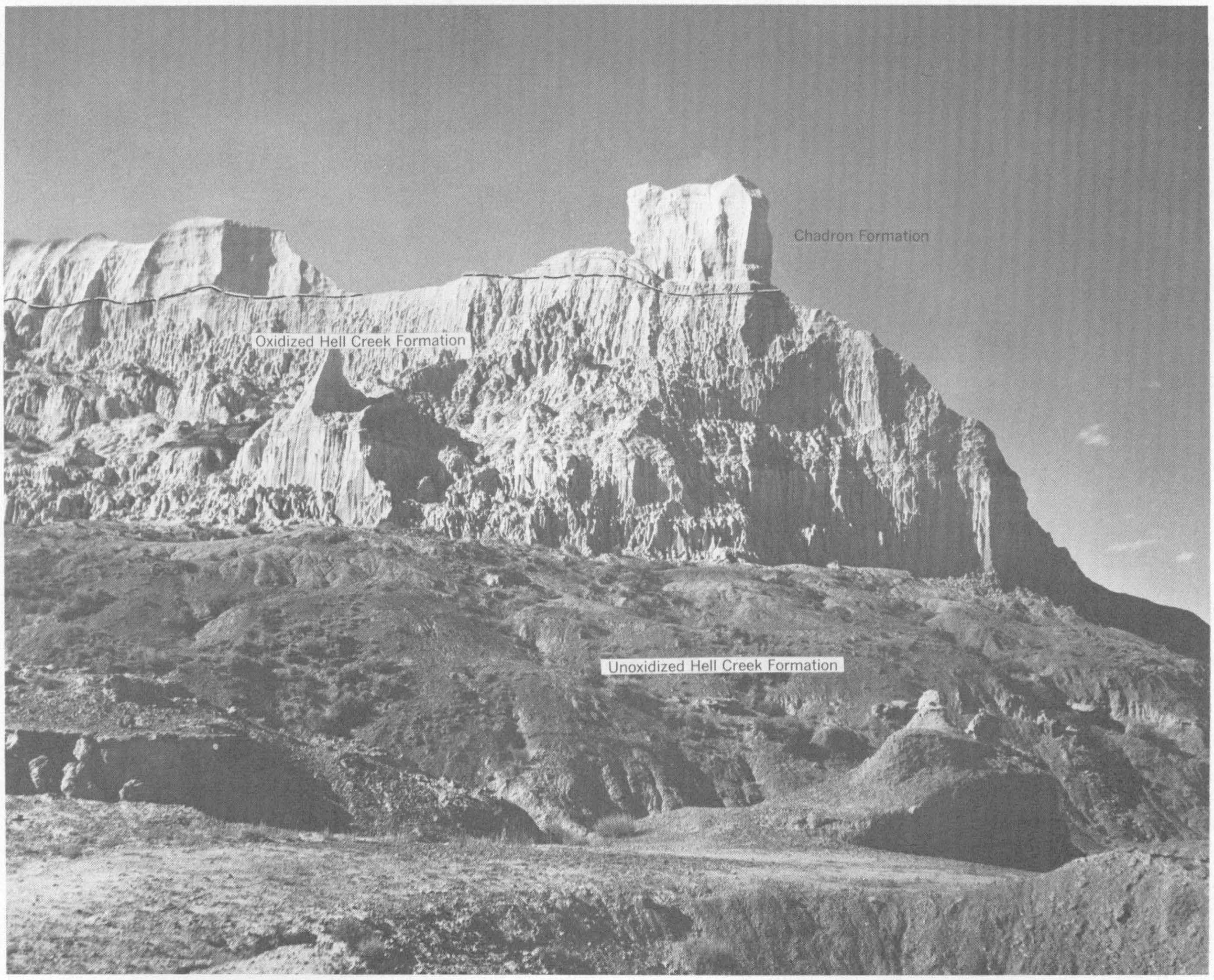


FIGURE 2.—Oxidized beds in the upper part of the Hell Creek Formation (Upper Cretaceous) directly underlying the pre-Oligocene erosion surface in the SW¼ sec. 26, T. 17 N., R. 3 E., Short Pine Hills, S. Dak.

nizable by their pale pastel shades of orange, red, yellow, and brown that contrast with the darker brown and buff of the unoxidized rocks below. Analcite rosettes, averaging 1 to 3 mm in diameter and derived from leaching of tuffaceous constituents in the overlying beds, are commonly present in the rocks at or just below the erosion surface. Angular blocks of locally derived quartzite (fig. 3), chert, ironstone, and other resistant rock debris are common constituents which accumulated on the surface prior to deposition of the White River Group and Arikaree Formation. This surface and its relation to attendant geologic features in the northern Black Hills and adjacent areas in the northern Great Plains region of western South Dakota and Nebraska are described by Vickers (1957), Tourtelot (1956, p. 80), and Dunham (1955, p. 8).

In northeastern Montana, the Chadron, Brule, and Arikaree Formations are not present. The upper Tertiary rocks there consist of a widespread pediment deposit of poorly cemented sand and gravel overlain at some places by beds of volcanic ash and white chalky marlstone which are referred to as the Flaxville Formation. Vertebrate fossils from these rocks indicate a late Miocene or Pliocene age. These beds range from a few feet to 180 feet or more in thickness. In the area studied, the Flaxville Formation caps a series of even-topped plateaus along the Montana-North Dakota State line. The Flaxville has not been recognized in southeastern Montana and northwestern South Dakota, but local sand and gravel deposits along the flanks of the major buttes in these areas may be partial correlatives of the Flaxville Formation. These deposits are com-

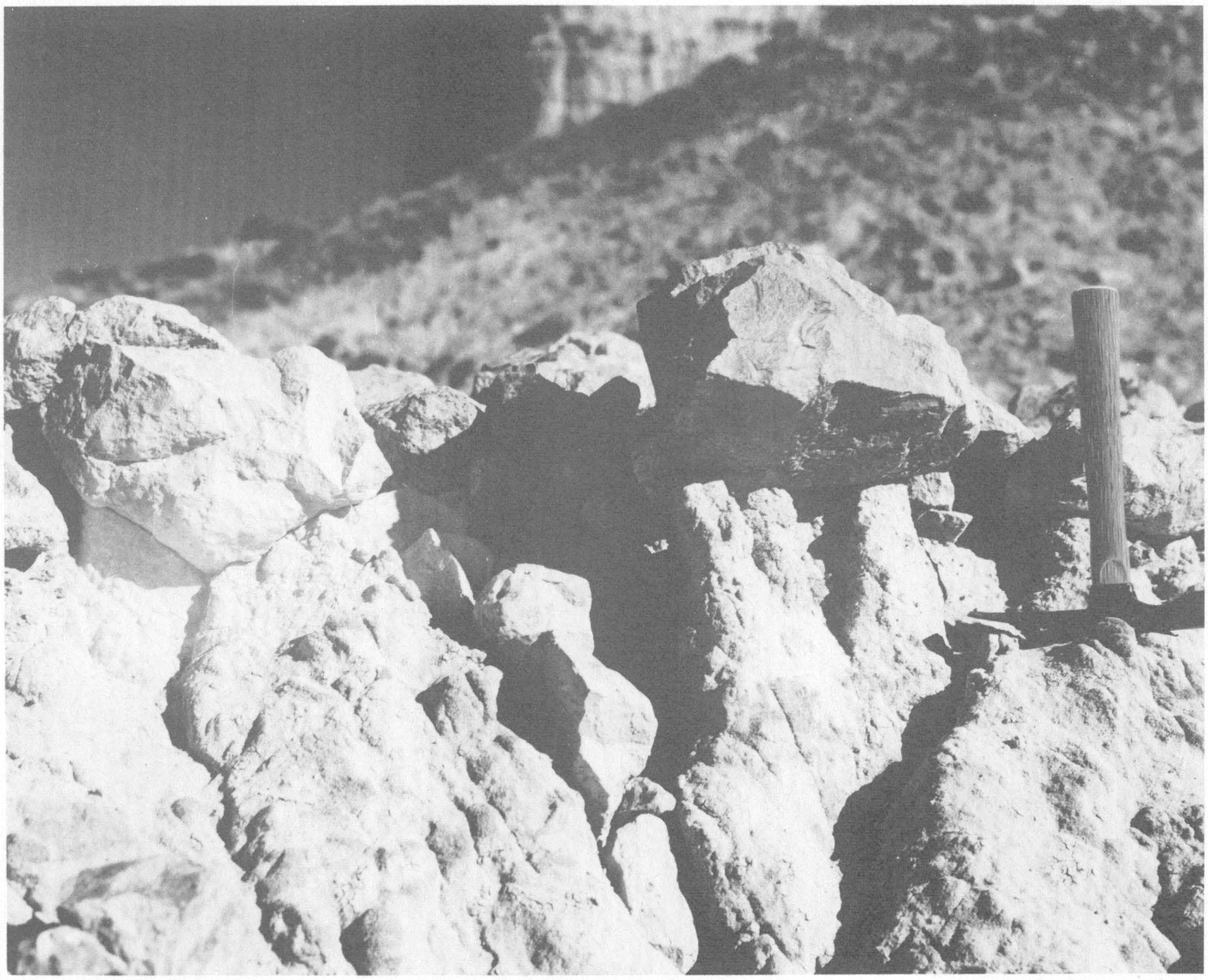

FIGURE 3.—Angular blocks of locally derived quartzite at the erosion surface between the Fort Union (Paleocene) and Arikaree (Miocene) Formations, (in the NE¼ sec. 20, T. 2 S., R. 61E., Long Pine Hills, Carter County, Mont.

posed of clayey siltstone, fine-grained sandstone, and gravel derived and reworked from the Arikaree and older formations. Vertebrate fossils from these deposits in the Ekalaka Hills in southeastern Montana are of pliocene(?) age.

From 100 to 400 feet below the base of the Flaxville in northeastern Montana are extensive areas capped by poorly stratified gravel and silt which at some places have been loosely cemented to a conglomerate. This gravel superficially resembles the Flaxville Formation from which it has been derived and with which, at some places, it has been incorrectly correlated (Ross and others, 1955). The erosion of these extensive areas below the Flaxville level has been assigned by Collier and Thom (1918, p. 182 and pl. 62) to the late Pliocene or early Pleistocene on the basis of physiographic and paleontologic evidence.

Glacial till, sand, and gravel of Pleistocene age mantles much of the region north of the Missouri River in northwestern North Dakota and northeastern Montana (Alden, 1932, pl. 1). Except where streams have cut through them, these deposits effectively mask the underlying rocks.

Table 1 gives the general lithologic characteristics of the rocks exposed in the region. Although rocks of the Colorado Group and Mowry Shale are exposed in a small area in southeastern Montana, they were not differentiated from the Pierre Shale and are not described in table 1.

TABLE 1.—*Generalized section of formations exposed in eastern Montana and adjoining parts of North and South Dakota* [1]

| System | Series | Group, formation, member | Thickness (feet) | Lithologic characteristics |
|---|---|---|---|---|
| Quaternary | Recent and Pleistocene | | 0–250 | Silt, sand, and gravel in dunes, terraces, and alluvial fans along main stream channels south of the Missouri River. Pleistocene deposits, glacial and glaciofluviatile in origin, cover a large part of the region north of the Missouri River; deposits include alluvium, eskers, kames, and glacial outwash sand and gravel. |
| Tertiary | Pliocene or upper Miocene | Flaxville Formation and probable correlatives | 0–180 | Sandstone and conglomerate, poorly cemented, overlain at some places by beds of volcanic ash and white marlstone. Basal unit is widespread pediment deposit that caps eventopped plateaus ranging in altitude from 3,600 ft on Sheep Mountain in northeastern Montana to about 2,500 ft along the Montana-North Dakota State line. Not recognized in southeastern Montana and northwestern South Dakota, but may be a partial correlative in these areas to local pediment deposits along the flanks of the major buttes. These deposits are composed of clayey siltstone, fine-grained sandstone, and gravel derived and reworked from the Arikaree and older formations. Vertebrate fossils in the Ekalaka Hills indicate a Pliocene(?) age. |
| | | Unconformity | | |
| | Miocene | Arikaree Formation | 260+ | Massive greenish-white to light-gray tuffaceous sandstone and siltstone and a few thin beds of quartzite, dolomite, and volcanic ash. Local occurrences of carnotite in dolomite in the West Short Pine Hills, S. Dak. |
| | | Unconformity | | |
| | Oligocene | White River Group: Brule Formation | 0–250+ | Massive buff to pinkish-tan tuffaceous siltstone, nodular claystone, and channel sandstone. Contains abundant vertebrate remains. Well exposed in Chalky Buttes and Little Badlands of North Dakota. Preserved in pre-Arikaree landslide blocks in the Slim Buttes and Short Pine Hills of South Dakota. Absent or poorly represented in southeastern Montana. |
| | | White River Group: Chadron Formation | 0–190 | Dark-gray bentonite and light-gray tuffaceous claystone, siltstone, sandstone, and arkose at many places interbedded with thin beds of lenticular limestone. Lower part at many places weathers golden yellow. |
| | | Unconformity | | |
| | Eocene | Golden Valley Formation | 0–175 | Gray to yellow sandstone, siltstone, and purplish-gray to white kaolinitic clay. Contains a few thin lenticular beds of lignite and carbonaceous shale. |
| | Paleocene | Fort Union Formation: Sentinel Butte Member | 600–950 | Dark-gray bentonitic claystone and shale, and buff to brown sandstone. Many beds of lignite are radioactive in H T, Sentinel, Bullion, and Chalky Buttes in North Dakota. Contains relatively high-grade uranium deposits in lignite and carbonaceous clay in the Little Missouri River escarpment area, North Dakota. |
| | | Fort Union Formation: Tongue River Member | 650 | Massive gray to tan sandstone, siltstone, and shale. Contains many lenticular beds of quartzite and thick persistent beds of lignite. Large deposits of uranium-bearing lignite in the Medicine Pole Hills, N. Dak., and at Cave Hills and Lodgepole Buttes, S. Dak. Relatively high-grade uranium deposits in lignite in the Cave Hills area, South Dakota. |
| | | Fort Union Formation: Cannonball Member | 0–300 | Cannonball Member: marine dark-gray and brown sandstone and shale. Contains large limy concretions. Extends from the east into northern Perkins and northeastern Harding Counties, S. Dak., and southern Adams and southeastern Bowman Counties, N. Dak. Thins to the west and intertongues with the Ludlow Member. Not recognized west of R. 8 E., northeastern Harding County, S. Dak. |
| | | Fort Union Formation: Ludlow Member | 0–400 | Ludlow Member: gray to light yellow-tan sandstone, gray shale, and thick lenticular beds of lignite. Uranium-bearing lignite deposits in the Slim Buttes and Cave Hills, S. Dak., and the Long Pine and Ekalaka Hills, Mont. Local deposits of uranophane-bearing sandstone and relatively high-grade uranium deposits in lignite and carbonaceous shale in the Slim Buttes, S. Dak. |
| Cretaceous | Upper Cretaceous | Hell Creek Formation | 400–575 | Dark-gray bentonitic claystone and gray-brown lenticular sandstone. Many concretions and thin lenses of iron carbonate. Contains thin lenses of lignite in upper part. Local occurrence of carnotite and becquerelite in carbonaceous clay and sandstone in the Long Pine Hills, Mont.; one relatively high-grade uranium deposit in lignite in East Short Pine Hills, S. Dak. |
| | | Fox Hills Formation | 25–300 | Marine grayish-white to brown and ocherous-yellow glauconitic sandstone and interbedded greenish-gray marine shale. |
| | | Pierre Shale | 1,700–2,500 | Marine dark-gray to brownish-black bentonitic claystone and shale containing large limestone concretions and thin beds of bentonite. |

[1] Not including Colorado Group and Mowry Shale locally exposed in small area in southern Carter County, Mont.

## EXPOSED ROCKS

### CRETACEOUS SYSTEM

#### PIERRE SHALE

The Pierre Shale was named by Meek and Hayden (1862) for exposures along the Missouri River, 95 miles southeast of the area of this report, in the vicinity of old Fort Pierre in Stanley County, S. Dak. The Pierre Shale occurs at the surface along the Cedar Creek anticline, the Poplar dome, and the north end of the Black Hills uplift; it is present in the subsurface throughout eastern Montana and adjoining parts of North and South Dakota.

Studies of electric and radioactivity logs of wells drilled for oil and gas in the region indicate that the Pierre thins progressively northeastward from 2,300 feet in southern Wibaux and northern Fallon Counties in eastern Montana to 1,700 feet in northeastern Burke County, N. Dak.

The Pierre is a seemingly homogeneous unit of dark-gray to brownish-black bentonitic claystone and shale containing large limestone concretions and thin beds of bentonite. These shales and associated fine-grained rocks are of marine origin and contain numerous invertebrate fossils of Late Cretaceous age. In normal succession the Pierre Shale is conformably overlain by the

Fox Hills Sandstone and conformably underlain by the Niobrara Formation, both of Late Cretaceous age.

Inasmuch as the Pierre Shale does not contain beds of lignite or carbonaceous shale which might contain uranium, it was not studied or mapped in detail. The general areal distribution of the rocks assigned to the Pierre in this report is shown on plate 1.

#### FOX HILLS SANDSTONE

The Fox Hills Sandstone was named by Meek and Hayden (1862) for exposures on Fox Ridge, about 50 miles east of the area of this report, in southwestern Dewey County, S. Dak. The unit rests conformably on the Pierre Shale, and its outcrop surrounds the outcrop of the Pierre along the Cedar Creek anticline, the Poplar dome, and the north end of the Black Hills uplift.

The rocks composing the Fox Hills are marine grayish-white to brown and ocherous-yellow glauconitic sandstone and interbedded greenish-gray marine shale which at many places grade into the overlying continental deposits of the Hell Creek Formation and into the underlying marine shales of the Pierre. The unit ranges from 25 to 300 feet in thickness, but because its upper and lower contacts are gradational, its thickness in the subsurface is difficult to determine from electric and gamma-ray logs.

At many places the formation contains an abundant marine invertebrate fauna of Late Cretaceous age. Lithologic similarity and the stratigraphic position of the formation above the Pierre and below the Hell Creek make correlation of the Fox Hills with the rocks at the type locality in southwestern Dewey County reasonably certain. The Fox Hills Sandstone was not studied or examined in detail.

#### HELL CREEK FORMATION

The Hell Creek Formation of Late Cretaceous age was named by Barnum Brown (1907, p. 829) for rocks typically exposed on Hell Creek and nearby tributaries of the Missouri River in Garfield County in northeastern Montana. The Hell Creek conformably overlies the marine Fox Hills Sandstone and underlies the lignite-bearing Ludlow Member of the Fort Union Formation (Paleocene). The formation has an average thickness of about 500 feet and is composed of rocks of fluviatile and possibly brackish-water origin. In the Williston basin the formation is exposed over wide areas along the flanks of the Poplar dome, the Cedar Creek anticline, and north end of the Black Hills uplift.

The Hell Creek Formation is characterized by the drab, somber hues of the bentonitic silty shale and claystone that compose most of the formation. Dark purplish-black manganosiderite concretions that weather with a metallic luster and thin beds of medium-grained sandstone cemented by lime and iron carbonate (siderite) are abundant. Loglike dark yellowish-brown limy concretions as much as 10 feet long and 1 to 3 feet in diameter occur in the friable sandstone. Thin beds of carbonaceous shale and lignite occur at some places in the upper few feet of the Hell Creek but are of little or no commercial importance. The rocks are poorly cemented and therefore easily eroded. Badlands and broad, flat interareas of grassland studded with low rounded knobs devoid of vegetation characterize outcrops of the formation.

The contact of the Hell Creek and the overlying Ludlow Member of the Fort Union Formation is, in general, transitional from dark, somber gray and greenish-gray rocks of the Hell Creek to lighter yellowish-brown rocks of the Fort Union. Early workers differentiated the two units on the basis of differences in color. Locally, this criterion is difficult to apply because the typical colors alternate through a stratigraphic interval of 100 feet or more. Following the usage of R. W. Brown (1952, p. 92) the contact has been placed at most places at the base of the lowest persistent bed of lignite.

The Hell Creek Formation is sparsely fossiliferous and has yielded species of turtles, dinosaurs (especially *Triceratops*), and poorly preserved plants of Late Cretaceous age at many localities in the region (Winchester and others, 1916, pl. 1, and p. 24; Hares, 1928, p. 23; Bauer, 1924, p. 240; and Curtiss, 1956).

### TERTIARY SYSTEM

#### LOWER TERTIARY COAL-BEARING ROCKS

##### FORT UNION FORMATION (PALEOCENE)

The Fort Union Formation of Paleocene age was named by Meek and Hayden (1862, p. 433) for rocks of continental origin typically exposed near the confluence of the Yellowstone and Missouri Rivers near the site of old Fort Union in northwestern McKenzie County, N. Dak. In the area of this report the Fort Union Formation consists of about 1,500 feet of lignite-bearing sandstone, shale, and claystone which conformably overlie the Hell Creek Formation of Late Cretaceous age. The upper part of the Fort Union has been removed by erosion except at a few localities near the center of the Williston basin where the Fort Union is conformably overlain by remnants of the Golden Valley Formation of Eocene age.

The lower 300 feet or so of these continental deposits is assigned to the Ludlow Member of the formation and intertongues to the east in northern Perkins and northeastern Harding Counties, S. Dak., and southern

Adams and southeastern Bowman Counties, N. Dak., with marine strata assigned to the Cannonball Member of the Fort Union Formation. Overlying the Ludlow and Cannonball Members with apparent conformity is the Tongue River Member which is in turn overlain by the Sentinel Butte Member.

The important lithologic characteristics and stratigraphic relationships of each of the four members have been described and discussed in detail by many geologists who have worked in the Williston basin. For these descriptions the reader is referred to reports by Winchester and others (1916, p. 14–31), Hares (1928, p. 13–42), Thom and Dobbin (1924, p. 484 and 495–497), Bauer (1924, p. 235–244), R. W. Brown (1948), Bergstrom (1956), Leonard (1908), and Lloyd (1914, p. 248). Table 1 of this report outlines briefly the general lithologic characteristics and thicknesses of each of the four members of the formation in eastern Montana and adjoining parts of North and South Dakota. Supplemental descriptions of these units are presented later in the report at appropriate places under "description of uraniferous areas."

#### GOLDEN VALLEY FORMATION (EOCENE)

The Golden Valley Formation of Eocene age was named by Benson and Laird (1947, p. 1166–1167) for exposures near the town of Golden Valley, Mercer County, which adjoins Dunn County, in western North Dakota. The formation is as much as 175 feet thick and consists of gray to yellow micaceous loosely cemented sandstone and siltstone and soft purplish-gray to white kaolinitic clay, which at some localities contain a few thin lenticular beds of lignite and carbonaceous shale.

The Golden Valley overlies the Fort Union Formation with apparent regional conformity and is unconformably overlain locally by the White River Group (Oligocene) or Arikaree Formation (Miocene). The formation occurs principally along the low divides and hills near the axis of the Williston basin in southwestern North Dakota (Benson, 1951) and has not been recognized in South Dakota.

#### LIGNITE RESERVES

Most of the uranium-bearing lignite deposits of North and South Dakota are in the Slim Buttes, Cave Hills, and Little Missouri River escarpment areas and are part of a larger area containing the largest lignite reserves in the United States. This area, centered in western North Dakota, extends westward into eastern Montana and southward into northwestern South Dakota (U.S. Bureau of Mines, 1948, p. 3). The part of the area in North and South Dakota contains an estimated reserve of 600,000 million tons which, in 1948, constituted 64 percent of the lignite resources and about 20 percent of the estimated coal resources of the United States (U.S. Bureau of Mines, 1948, p. 3–4). South Dakota is estimated to have a lignite reserve of 2,031 million tons (D. M. Brown, 1952, p. 1).

### MIDDLE AND UPPER TERTIARY TUFFACEOUS ROCKS

The middle and upper Tertiary tuffaceous rocks in the Williston basin comprise the White River Group of Oligocene age, the Arikaree Formation of Miocene age, and the Flaxville Formation of late Miocene and Pliocene age. The rocks in the White River Group and Arikaree Formation were studied because of their close relation to the occurrence of uranium in the rocks directly underlying them. Twenty-nine stratigraphic sections of these rocks were measured, and grab samples were collected for laboratory determinations during the course of the investigation of the uranium deposits in the basin. The correlation and lithology of the rock units measured, the stratigraphic positions from which most of the samples were collected, and other field and laboratory data are shown on plates 3 and 4.

#### OLIGOCENE SERIES

##### White River Group

The White River Group of Oligocene age was named by Meek and Hayden (1858, p. 119, 133) for exposures along White River in southwestern South Dakota. Later, Darton (1899, p. 736, 755–759) subdivided the White River Group into the Chadron and overlying Brule Formations. In the Williston basin the Chadron and Brule have a combined average thickness of about 250 feet. The White River Group, where present, rests with angular discordance on the older formations, and at most places is unconformably overlain by the Arikaree Formation of Miocene age. Exact correlation of various zones within the White River in the region studied is at many places difficult or impossible because of abrupt lateral variations in lithologic character and thickness. Vertebrate fossils collected from these rocks (pls. 3 and 4) indicate that rocks of early, middle, and late Oligocene age are present. The White River Group probably correlates, in part, with the Cypress Hills Formation of Saskatchewan and Alberta, Canada (Furnival, 1950, p. 119, 134).

The lower part of the Chadron is composed of a basal conglomerate and arkose, 5 to 100 feet thick. Pebbles and cobbles of chert, petrified wood, crystalline rocks, and other resistant debris are common constituents. Among the crystalline rocks are welded tuff, quartz latite porphyry, granite, and rhyolite (figs. 4, 5, and 6).

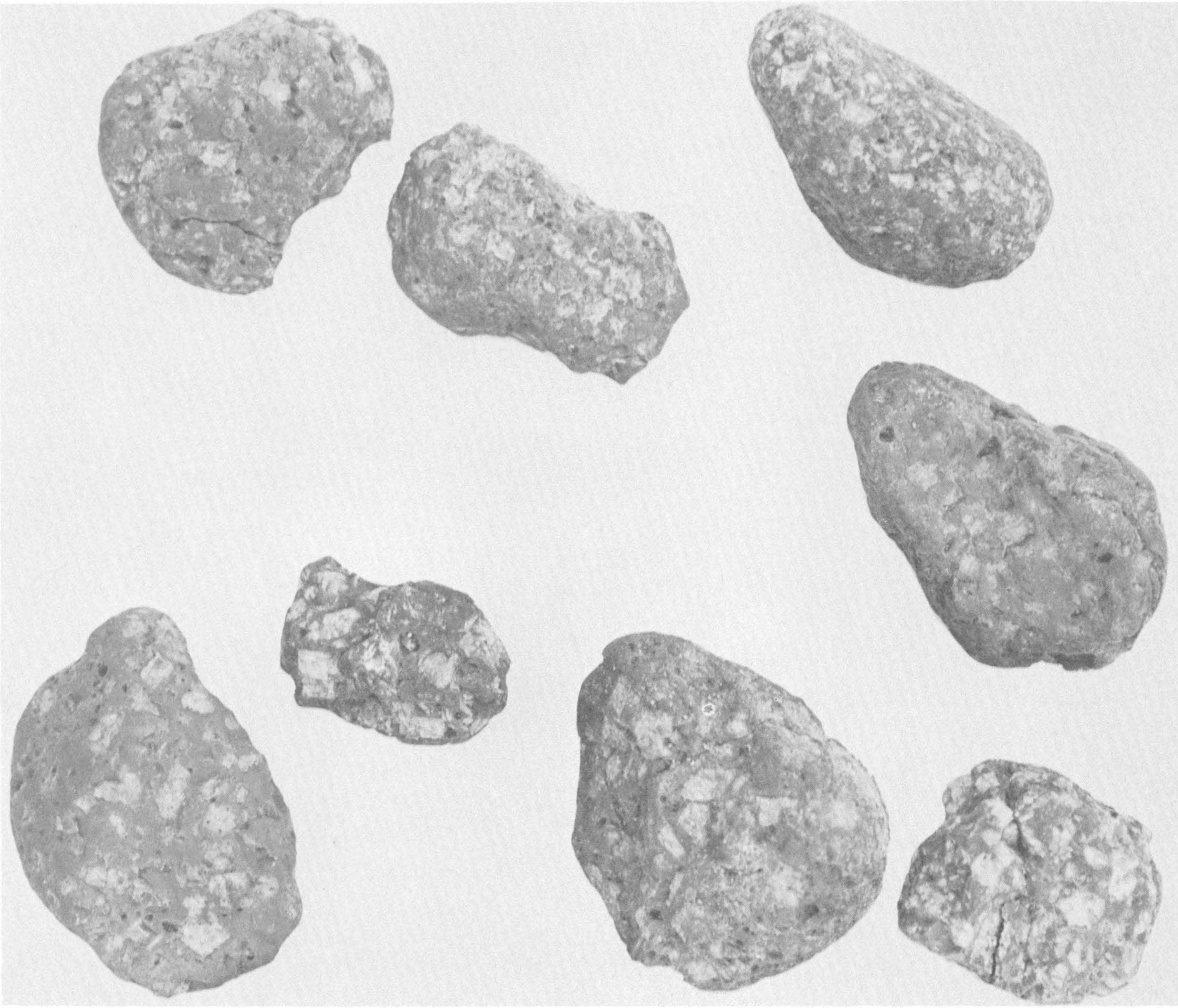

FIGURE 4.—Pebbles of reddish-brown quartz latite porphyry from base of Chadron Formation in the NW¼SW¼ sec. 2, T. 131 N., R. 90 W., Coffin Butte, Grant County, N. Dak. These pebbles are common detrital constituents associated with pebbles of welded tuff, rhyolite, and granite and beds of arkose at the base of the Oligocene in southwestern North Dakota. × 1.

The basal clastic unit is relatively thin except in areas where pre-Oligocene erosion formed topographic lows, as in parts of the Slim Buttes and Chalky Buttes areas. In these areas relatively thick beds of conglomerate and arkose fill the ancient depressions.

Fine-grained tuffaceous sandstone, siltstone, shale, claystone and beds of dark-weathering bentonite overlie the basal clastic unit of the Chadron. The finer grained sequence is locally 90 feet or more in thickness and contains at many places thin lenticular beds of light-gray fresh-water limestone that at some places contain small pellets of tan claystone.

At Signal Butte in Meade County, S. Dak. (see pl. 4, loc. 28), several beds of limestone and calcareous claystone in the lower part of the Chadron have yielded fresh-water gastropods and charophytes. R. E. Peck (written commun., Dec. 23, 1955) of the University of Missouri identified the charophytes and reports as follows:

> Material consists of numerous gyrogonites of charophytes that belong to the genus *Brachychara* and many vegetative parts, consisting of nodes and internodes, that presumably belong to the same genus. I do not know of any descriptions of Oligocene Charaphyta from North America and this species differs markedly from those described from older beds. In gross features it closely resembles *B. meriani helvetica* Madler, but I hesitate to refer it to that species without direct comparison.
>
> In so far as I know, this is the first record of charophytes from the Chadron.

FIGURE 5.—Quartz latite porphyry (specimen CB–1) from base of Chadron Formation in the NW¼SW¼ sec. 2, T. 131 N., R. 90 W., Coffin Butte, Grant County, N. Dak. Euhedral phenocrysts of albite (P) in a fine-grained groundmass of potassium feldspar, quartz, and plagioclase. Accessory minerals include magnetite, apatite, and chlorite. × 15. Crossed nicols. Identification by Mortimer Staatz.

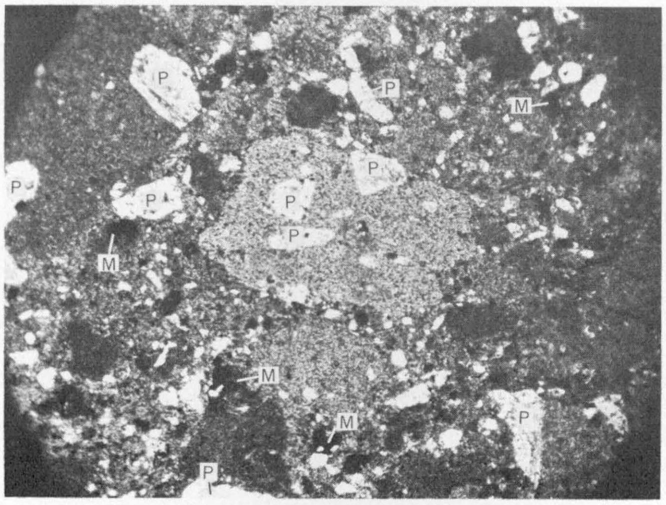

FIGURE 6.—Welded tuff (specimen MND–211b) from base of Chadron Formation in the SW¼SE¼ sec. 31, T. 134 N., R. 101 W., Chalky Buttes, Slope County, N. Dak. Tuff is composed of numerous rock fragments of rhyodacite in a matrix of rhyodacite; fragments and matrix contain phenocrysts of plagioclase (P), and magnetite (M). Accessory minerals include apatite, epidote, and chlorite. × 15. Crossed nicols. Identification by Mortimer Staatz.

Chemical analyses showing calcium and magnesium carbonate content of 14 limestone samples from the Chadron Formation in the Williston basin are shown on plates 3 and 4. These analyses and the five spectrographic analyses listed in table 2 indicate that carbonate rocks from the Chadron are limestones containing little magnesium, potassium, sodium, or strontium. Hansen (1953) describes the limestone deposits in the White River Group of Stark and Hettinger Counties, N. Dak., as potentially valuable for the manufacture of cement. Chemical analyses in Hansen's report are similar to those described in this report for samples from the Chadron Formation.

The Brule Formation conformably overlies the Chadron Formation and is composed principally of massive fine-grained pinkish-gray nodular claystone interbedded with thin lenticular beds of channel sandstone and conglomerate. The formation ranges from 0 to 250 feet in thickness and is thickest in the Little Badlands of Stark County, N. Dak. At Slim Buttes and at places in the West Short Pine Hills, S. Dak., the Brule is preserved in pre-Arikaree landslide blocks. Here the formation, ranging from 150 to 200 feet in thickness, is overlain with angular discordance by nearly horizontal beds of the Arikaree Formation of Miocene age (fig. 7). The maximum original thickness of the formation in the Williston basin is unknown. The Brule Formation is thin or absent in southeastern Montana and was removed by erosion throughout most of western North Dakota prior to deposition of Miocene rocks.

The Brule in the Williston basin contains many well-preserved vertebrate fossils of middle and late Oligocene age. (See pls. 3 and 4 for fossil identifications.)

### ANCIENT LANDSLIDE DEPOSITS

In the Slim Buttes and East and West Short Pine Hills, S. Dak., and in the Long Pine Hills and Finger Buttes, Mont. (fig. 1), strata ranging in age from Late Cretaceous to Oligocene are tilted and downdropped along surfaces that superficially appear to be orogenic faults. In the areas studied the tilted blocks are as much as 3,800 feet long and 500 feet wide and contain a thickness of as much as 400 feet of relatively unbroken strata which have been displaced downward as much as 350 feet. Most of the rock in the tilted blocks consists of bentonitic clay, porous tuff, and fine-grained sandstone of the Chadron and Brule Formations of Oligocene age. Locally, minor amounts of the underlying strata of Paleocene and Late Cretaceous age are also tilted. The strike of most of the blocks is about N. 45°–65° W. and the dip, which at most places is to the southwest, ranges from nearly vertical to 5°. The displaced rocks are unconformably overlain by nearly horizontal beds of tuffaceous sandstone that contain vertebrate fossils of early(?) Miocene age. These inclined rocks have been interpreted by Winchester (1913, p. 550) as giant crossbedding, by Todd (1895) and Petsch (1954) as fault blocks resulting from major tectonic movements, and by Toepelman (1923, p. 9) as fossil landslide blocks. Because the blocks generally occur in parallel series with similar strikes and dips and are parallel to a pronounced widely spaced system of major joints, most of which trend N. 45°–65° W., they


FIGURE 7.—Fossil landslide block showing tilted strata of Chadron and Brule Formations (Oligocene) unconformably overlain by nearly horizontal beds of Arikaree Formation in sec. 32, T. 18 N., R. 8 E., Slim Buttes, S. Dak.

are interpreted to be joint-controlled fossil landslide blocks similar to the modern Toreva-block landslide described by Reiche (1937, p. 538). These landslide blocks are described in detail in a separate report by Gill (1962, p. 725–736).

MIOCENE SERIES

**Arikaree Formation**

The Arikaree Formation of Miocene age was named by Darton (1899, p. 732) for extensive exposures along the Niobrara River in northwestern Nebraska and southwestern South Dakota. This formation at one time extended across most of the Williston basin but today is present only on the tops of the higher buttes and mesas because erosion during Pliocene and Pleistocene time stripped most of it away.

In normal succession the Arikaree rests unconformably on the Brule of middle and late Oligocene age. In many areas in the Williston basin, however, the Brule was removed by erosion prior to deposition of Miocene rocks, and at these localities the Arikaree either overlies the Chadron of early Oligocene age or rests on older rocks ranging from Eocene to Late Cretaceous in age. In southeastern Montana the Arikaree Formation rests in turn on the Pierre Shale, the Fox Hills Sandstone, and the Hell Creek, Fort Union, and Chadron Formations within a distance of 15 miles, from A-Bar-B Buttes northeastward to the Long Pine Hills. Pre-Miocene erosion truncates at least 800 feet of rocks in this area.

The maximum original thickness of the formation in the Williston basin is not known. Thicknesses ranging from 200 to 360 feet, however, were measured at widely separated localities in the Killdeer Mountains in Dunn County, N. Dak., in the Long Pine Hills, Chalk Buttes, and Ekalaka Hills in Carter County, Mont., and in the Short Pine Hills and Slim Buttes in Harding County, S. Dak. (pls. 3 and 4).

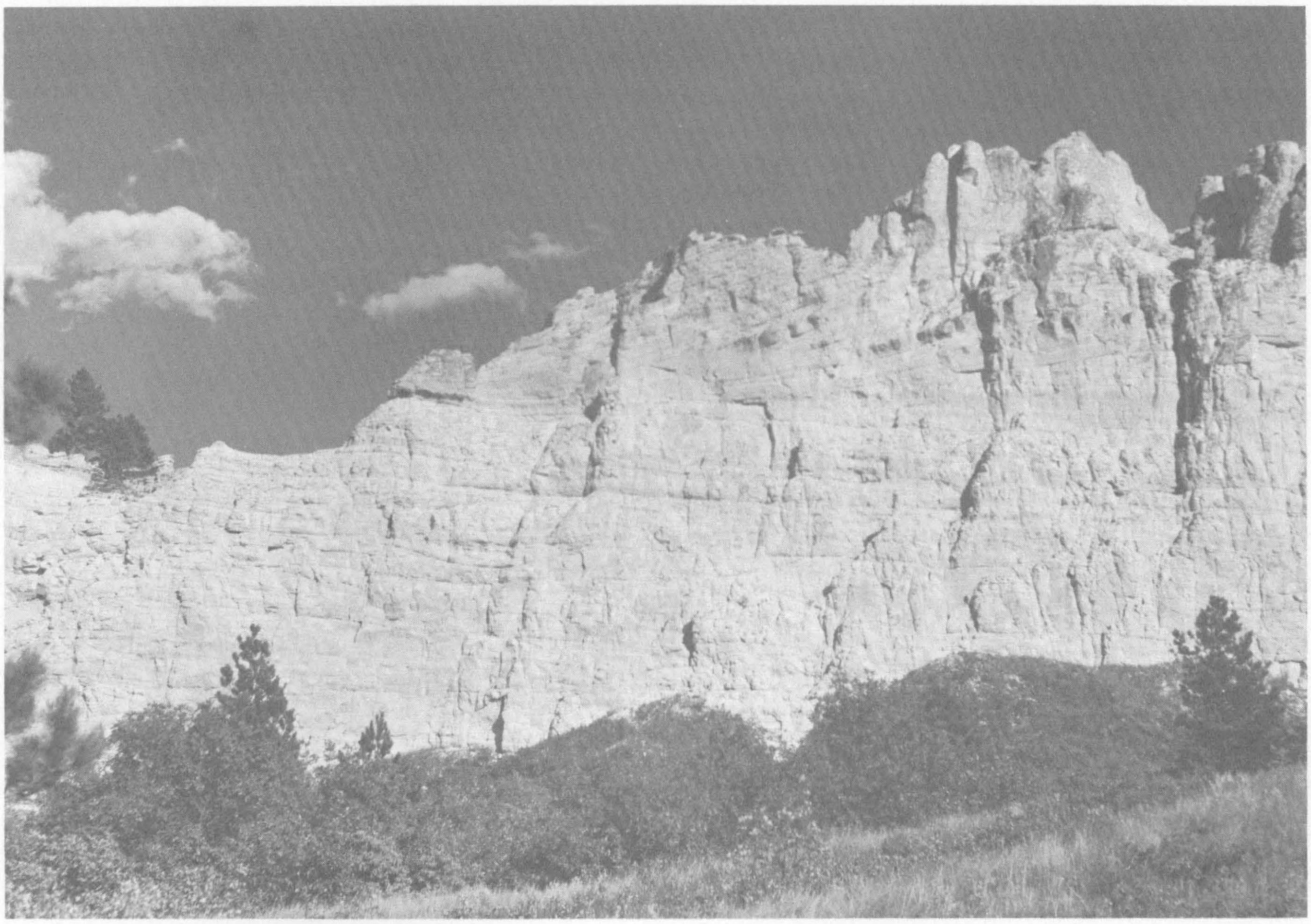

FIGURE 8.—Massive crossbedded sandstone in the lower part of the Arikaree Formation (Miocene) in the NE¼ sec. 18, T. 18 N., R. 8 E., Harding County, S. Dak.

The rocks assigned to the Arikaree are mostly calcareous, are commonly crossbedded sandstone, and contian subordinate amounts of dolomite, dolomitic limestone, shale, and conglomerate. Some of these rock types are shown on figures 8, 9, and 10. The formation includes large amounts of disseminated volcanic ash, as well as relatively pure ash, in laminated beds of small lateral extent and thickness (fig. 11). The rocks in the formation are porous and permeable, and ground water circulates easily. As a result the ash is generally altered to silica that occurs in nodules and laminae (fig. 11), and concretions of diverse types are present throughout the unit (fig. 12).

The age assigned to the Arikaree Formation in the Williston basin is based largely on two fossil collections, one near the base of the formation in the Ekalaka Hills area, and the other approximately 270 feet above the base of the formation on Fighting Butte in the southwestern part of the same area, Carter County, Mont. (locs. 17 and 18, pl. 4). G. E. Lewis of the U.S. Geological Survey examined the fossils from the Ekalaka Hills and concluded that their age "probably falls somewhere between late Oligocene and early medial Miocene and is definitely pre-late Miocene." The fossil reported from Fighting Butte is considered by Mylan Stout (written commun., May 2, 1957) of the University of Nebraska to be middle Miocene. Throughout most of northwestern South Dakota and southwestern North Dakota the assignment of rocks to the Arikaree is based largely on their unconformable relations to the underlying Brule and on their lithologic similarity to the rocks in the Big Badlands in west-central South Dakota from which Miocene fossils have been collected. Recent collections have been made by Jean Hough

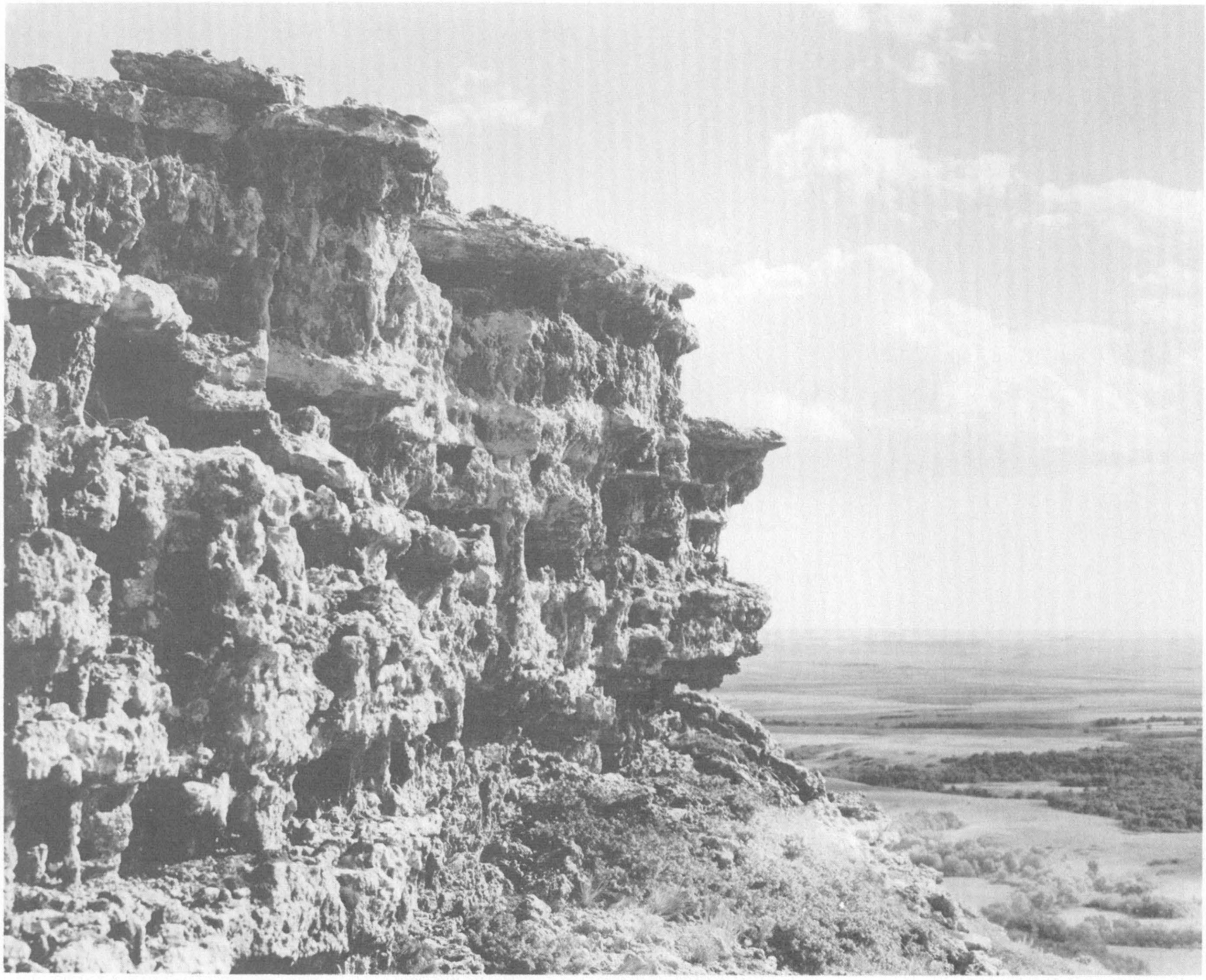

FIGURE 9.—A distinctive and widespread unit of calcareous sandstone and dolomitic limestone about 75 feet above the base of the Arikaree Formation in the Killdeer Mountains, Dunn County, N. Dak. (See pl. 3, loc. 1.)

(written commun., Sept. 28, 1957, and July 31, 1959) of the University of Chicago from the Arikaree in the Little Badlands and at Chalky Buttes in Stark and Slope Counties, N. Dak., but the fossils have not yet been identified.

The composition of carbonate rocks in the Arikaree is markedly different from those in the underlying White River Group of Oligocene age. Calcium and magnesium carbonate determinations of six samples from the Arikaree Formation are shown on plates 3 and 4. These analyses and the spectrographic analyses given in table 2 indicate that in contrast to the carbonate rocks from the Chadron, which are limestones with little or no magnesium, potassium, sodium, or strontium, the carbonate rocks from the Arikaree are dolomites or dolomitic limestones rich in iron, magnesium, potassium, sodium, and strontium but relatively low in calcium and manganese. Whether a similar relationship holds for samples from correlative units in other areas is not known, but, if so, analyses of carbonate rocks from isolated outcrops of unfossiliferous strata might be useful in correlation. For example, a thin sequence of tuffaceous rocks on Sentinel Butte (loc. 2, pl. 3) has been assigned by previous workers to the Chadron Formation (Leonard, 1908, p. 65; Bergstrom, 1956; Moore and others, 1959, p. 154). A 2-foot-thick carbonate bed from the sequence is very similar in composition to the carbonate rocks from the

FIGURE 10.—Conglomerate commonly present at the base of the Arikaree Formation in areas adjacent to pre-Arikaree landslide blocks. Pebbles consist of limy claystone and siltstone derived from the Brule Formation and are tightly cemented by tuffaceous sandstone of the Arikaree Formation. J. B. Pass, Slim Buttes, S. Dak.

Arikaree Formation. The rocks capping Sentinel Butte, therefore, may be correlative with the Miocene rocks in the Killdeer Mountains, Ekalaka Hills, and Chalk Buttes where the White River Group is absent and the Arikaree Formation rests directly on older rocks.

Spectrographic and chemical analyses of samples of volcanic ash and tuffaceous sandstone from the Arikaree show relatively high amounts of barium, boron, scandium, strontium, uranium, and ytterbium (p. 56). Analyses of 10 core samples of tuff from the lower 185 feet of the formation at Slim Buttes (NW¼NW¼ sec. 31, T. 18 N., R. 8 E., Harding County, S. Dak.) have been averaged, as follows:

| *Constituents* | *Percent* | *Constituents* | *Percent* |
|---|---|---|---|
| $SiO_2$ | 62. 0 | $TiO_2$ | . 39 |
| $Al_2O_3$ | 12. 4 | $P_2O_5$ | . 10 |
| $Fe_2O_3$ | 2. 7 | MnO | . 06 |
| FeO | . 15 | $H_2O$ | 7. 7 |
| MgO | 1. 7 | $CO_2$ | 2. 9 |
| CaO | 4. 7 | | |
| $Na_2O$ | 2. 0 | Total | 100 |
| $K_2O$ | 3. 2 | | |

This average chemical analysis approximates the composition of quartz latite or rhyodacite (Nockolds, 1954, p. 1014, col. 4). The fact that sodium and potassium are relatively low indicates possible leaching during or after deposition. Spectrographic analyses of 12 samples (table 9) showed relatively high amounts of sodium (70,000–300,000 ppb in 11 samples) and potassium (7,000–30,000 ppb) in ground water draining Miocene rocks in the Williston basin. Pebbles of quartz latite porphyry described earlier are abundant in the base of the Chadron Formation of early Oligocene age in southwestern North Dakota. The fact that the Miocene rocks in the Williston basin have an average chemical composition similar to quartz latite suggests that both have been derived from the same or similar petrographic provinces.

### MIOCENE OR PLIOCENE SERIES

#### Flaxville Formation

The Flaxville Formation was named and described by Collier and Thom (1918, p. 179–182) for exposures near the town of Flaxville about 15 miles south of the Canadian boundary and 50 miles west of the Montana-

TABLE 2.—*Analyses, in percent, of carbonate rocks from Oligocene and Miocene formations in Williston basin*

[M, major constituent (more than 10 percent). Tr., trace amount detected. Comparison of semiquantitative spectrographic analyses with quantitative analyses shows 60 percent or more of the results to be in the correct bracket. Analysts: Chemical, J. A. Thomas; spectrographic, R. G. Havens]

| No. | Formation | Rock type | Laboratory No. | Chemical analyses | | | | Semiquantitative spectrographic analyses [2] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | $CaCO_3$ [1] | $MgCO_3$ [1] | Total carbonate | Insoluble residue | Si | Al | Fe | Mg | Ca | Na | K | Ti | Mn |
| | | | | **Miocene** | | | | | | | | | | | | |
| 1 | Arikaree | Dolomite | 271369 | 51 | 39 | 90 | 10 | 0.7 | 0.3 | 0.15 | 7 | M | 0.3 | <0.5 | 0.007 | 0.015 |
| 2 | do | do | 368 | 49 | 34 | 83 | 17 | .7 | .7 | .7 | 7 | M | .3 | .7 | .03 | .07 |
| 3 | do | do | 372 | 47 | 33 | 80 | 20 | .7 | .7 | .7 | 7 | M | .3 | .7 | .03 | .15 |
| 4 | Arikaree(?) | do | 370 | 46 | 32 | 78 | 22 | 1.5 | .7 | .7 | 7 | M | .7 | 1.5 | .03 | .15 |
| 5 | Arikaree | Dolomitic limestone. | 373 | 69 | 4 | 73 | 27 | 7 | 1.5 | .7 | 1.5 | M | .7 | 1.5 | .03 | .03 |
| | | | | **Oligocene** | | | | | | | | | | | | |
| 6 | Chadron | Limestone | 271375 | 95 | 0 | 95 | 5 | 0.7 | 0.07 | 0.03 | 0.15 | M | 0.07 | 0 | 0.003 | 0.3 |
| 7 | do | do | 381 | 93 | 0 | 93 | 7 | .7 | .07 | .07 | .7 | M | .15 | 0 | .003 | .15 |
| 8 | do | do | 377 | 87 | 0 | 87 | 13 | 1.5 | .3 | .15 | .3 | M | .15 | 0 | .015 | .15 |
| 9 | do | do | 378 | 86 | 0 | 86 | 14 | 1.5 | .7 | .3 | .3 | M | .15 | 0 | .03 | .3 |
| 10 | do | do | 379 | 66 | 0 | 66 | 34 | 7.0 | 1.5 | .7 | .5 | M | .3 | 0 | .07 | .3 |

| No. | Formation | Rock type | Laboratory No. | Semiquantitative spectrographic analyses [2] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Ba | Cr | Cu | Ga | Ms | Ni | Sc | Sr | V | Y | Yb | Zn | Pb |
| | | | | **Miocene** | | | | | | | | | | | | |
| 1 | Arikaree | Dolomite | 271369 | 0.007 | 0.0007 | 0.0003 | 0 | 0 | Tr. | 0 | 0.3 | Tr. | 0 | 0 | 0.0007 | 0 |
| 2 | do | do | 368 | .007 | .0015 | .0007 | 0 | 0 | 0.0003 | 0 | .3 | 0.0015 | 0.0007 | 0.00015 | .0015 | 0 |
| 3 | do | do | 372 | .007 | .0007 | .0007 | 0 | 0.0007 | .0007 | 0 | .15 | .015 | 0 | 0 | .0015 | 0 |
| 4 | Arikaree(?) | do | 370 | .007 | .0015 | .0007 | 0 | 0 | Tr. | 0.0007 | .15 | .007 | .0015 | .00015 | .0015 | 0 |
| 5 | Arikaree | Dolomitic limestone | 373 | .015 | .0015 | .0007 | 0.00015 | 0 | Tr. | 0 | .07 | .003 | 0 | 0 | .007 | 0 |
| | | | | **Oligocene** | | | | | | | | | | | | |
| 6 | Chadron | Limestone | 271375 | 0.0015 | 0 | 0.0007 | 0 | 0 | Tr. | 0 | 0.015 | 0.0015 | 0 | 0 | 0 | 0 |
| 7 | do | do | 381 | .007 | 0 | .00015 | 0 | 0 | Tr. | 0 | .03 | .0015 | 0 | 0 | 0 | 0 |
| 8 | do | do | 377 | .003 | 0.0007 | .0003 | 0 | 0 | Tr. | 0 | .03 | .003 | 0.0015 | Tr. | 0.0015 | 0 |
| 9 | do | do | 378 | .007 | .0007 | .0007 | 0 | 0 | Tr. | 0 | .015 | .003 | .0007 | 0 | .0015 | 0 |
| 10 | do | do | 379 | .007 | .0015 | .007 | Tr. | 0 | 0.0003 | 0 | .015 | .003 | .0015 | 0.00015 | .003 | 0.003 |

[1] Computed from rapid analyses for Ca and Mg, insoluble residue by difference.
[2] Looked for but not detected: Ag, As, Au, B, Be, Bi, Cd, Ce, Co, Dy, Er, Eu, Gd, Ge, Hf, Hg, Ho, In, Ir, La, Li, Lu, Nb, Nd, Os, P, Pr, Pt, Re, Rh, Ru, Sb, Sn, Sm, Ta, Tb, Te, Th, Tl, Tm, U, W, and Zn. Not looked for: Cs, F, and Rb.

1, 2. Chalk Buttes, Carter County, Mont. (pl. 4, loc. 17).
3. West Short Pine Hills, Harding County, S. Dak. (pl. 4, loc. 20).
4. Sentinel Butte, Golden Valley County, N. Dak. (pl. 3, loc. 2).
5. Killdeer Mountains, Dunn County, N. Dak. (pl. 3, loc. 1).
6. Signal Butte-Fox Ridge, Meade County, S. Dak. (pl. 4, loc. 28).
7. White Butte, Hettinger County, N. Dak. (pl. 3, loc. 12).
8. Rainy Butte Outlier, Slope County, N. Dak. (pl. 3, loc. 8).
9. Young Mans Butte, Stark County, N. Dak. (pl. 3, loc. 14).
10. Coffin Butte, Grant County, N. Dak. (pl. 3, loc. 16).

North Dakota State line in the east-central part of Daniels County, Mont. The formation lies unconformably on the truncated edges of the Bearpaw Shale, Fox Hills Sandstone, and Hell Creek Formation of Late Cretaceous age and on the Fort Union Formation of Paleocene age. It caps the topographically highest points in the area. These points range in altitude from about 3,600 feet on Sheep Mountain in western Prairie County, Mont., to about 2,500 feet along the Montana-North Dakota State line (pl. 1).

The formation consists principally of poorly cemented sand and gravel 20 to 100 feet thick overlain by finer grained calcareous buff to dark-gray tuffaceous sandstone, white marlstone, and volcanic ash about 100 feet thick. At most places the upper calcareous finer grained unit has been removed by erosion leaving porous gravels and weakly cemented conglomerates as a resistant covering on softer shale and sandstone of Late Cretaceous and Paleocene age. The basal gravels and conglomerates consists of rocks of Precambrian and Paleozoic age derived from the Rocky Mountains and are composed principally of reddish quartzite and gray argillite pebbles, cobbles, and boulders, ranging generally from an inch to a foot in diameter. They are at many places strongly crossbedded and well cemented, forming hard, resistant ledges near the tops of the plateau upland.

Poorly preserved vertebrate fossils of late Miocene and Pliocene age have been reported from widely separated areas in the region (Collier and Thom, 1918, p. 180). Fossils collected by the writers from the Flaxville in northeastern Montana and from its partial correla-

FIGURE 11.—Part of a bed of volcanic ash 12 feet thick in the lower part of the Arikaree Formation in the SW¼ sec. 6, T. 2 S., R. 61 E., Carter County, Mont. Note secondary silica resulting from weathering and devitrification, upper left corner.

tive, the Wood Mountain Formation in southern Saskatchewan, were identified by G. E. Lewis as follows:

*Daniels County, Mont.*

Loc. DF6-3, NW¼ sec. 17, T. 35 N., R. 44 E.: indeterminate equine, tooth fragments. The age is either late Miocene or Pliocene.

Loc. GF6-2, SW¼ sec. 7, T. 36 N., R. 44 E., and loc. GF6-1, NE¼ sec. 31, T. 36 N., R. 45 E.: ?*Merychippus* sp., fragments of teeth and astragalus. A late Miocene age is indicated.

*Prairie County, Mont.*

Loc. SM-1, S½ sec. 24, T. 15 N., R. 47 E. (Sheep Mountain): ?*Paracamelus* sp., fragments of atlas and axis. The age is probably Pliocene.

*Valley County, Mont.*

Loc. DF6-1a, SE¼NE¼ sec. 35, T. 33 N., R. 43 E.: ?*Pliohippus* sp., tooth fragment; ?*Nannippus* sp., tooth fragments; Camelid, tooth fragment; Antilocaprid, phalanx; Mastodon, tooth fragment. The age probably is early to middle Pliocene.

Loc. DF6-2a, NW¼SW¼ sec. 36, T. 35 N., R. 42 E.; indeterminate mastodont, tooth fragments. The age is either late Miocene or Pliocene.

*Saskatchewan, Canada*

Loc. WM-1, NE¼NE¼ sec. 6, T. 4 N., R. 3 W., near the village Wood Mountain; *Merychippus* sp., teeth and tooth fragments; *Merycodus* sp., fragments of teeth and foot bones; Indeterminate large perissodactyl, tooth fragment; Indeterminate mastodont, tooth fragments. A late Miocene age is indicated.

Loc. WM-2, sec. 31, T. 2 N., R. 30 W., near the village Rockglen; *Merychippus* sp., tooth and fragment of tibia. A late Miocene age is indicated.

Analyses of samples of volcanic ash and marlstone from the Flaxville show relatively high amounts of cerium, lanthanum, molybdenum, tin, uranium, and

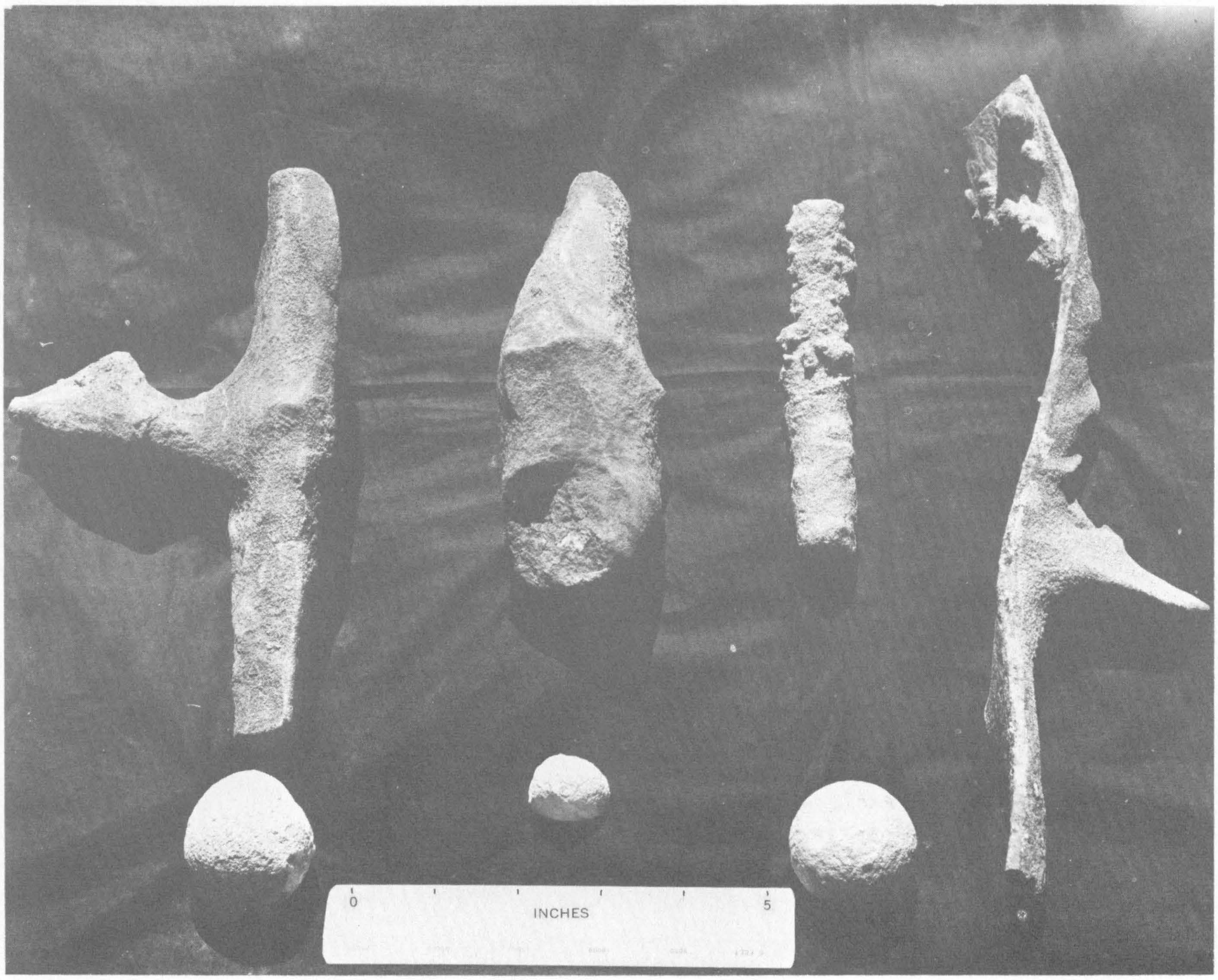


FIGURE 12.—Concretions commonly found in sandstone beds of the Arikaree Formation.

ytterbium. For field and laboratory data on individual samples and for comparisons with analyses of samples from other Tertiary formations, see plate 18 and page 56 of this report, and tables 22 and 23 of a paper by Denson and Gill (1965c, 1965e).

#### SOURCE OF VOLCANIC MATERIALS AND IGNEOUS ROCK FRAGMENTS

Most of the rock constituents composing the formations of middle and late Tertiary age in eastern Montana and adjacent parts of North and South Dakota are of volcanic origin. Beds of volcanic ash, bentonite, and tuffaceous claystone, siltsone, and sandstone are abundantly represented throughout the stratigraphic sequence. These rocks are remarkably uniform in lithology from area to area and are known to have extended across the truncated edges of the older formations throughout most of the Williston basin. Remnants of fossiliferous strata of Oligocene and Miocene age cap most of the higher mountain ranges in Wyoming and occur at progressively lower elevations from the Beartooth Mountains northeastward toward the Williston basin. The base of these rocks occurs at about 10,000 feet in the vicinity of the Beartooth Mountains, 9,000 feet in the Owl Creek Mountains, 8,000± feet near the top of the Bighorn Mountains, 6,000 feet on Pumpkin Buttes in the Powder River basin, 4,000 feet in the vicinity of Finger Buttes at the north end of the Black Hills uplift, and 2,600 feet near the south-central part of the Williston basin. These relations indicate that most of the sediments composing this sequence were deposited on a broad northeasterly sloping surface that extended across the present major mountain ranges in western Wyoming and western Montana onto the present plains areas of eastern Montana, western North Dakota, and northwestern South Dakota. The direction of slope of the reconstructed surface at the base of the Oligocene rocks suggests that the source of the volcanic materials in the White River Group and Arikaree Formation in the area of this report is in the general region of the Absaroka volcanic field in western Wyoming. Figure 13 shows the present generalized configuration of this surface in parts of the northern Rocky Mountain and Great Plains provinces as reconstructed from its remnants. Although modified by post-Miocene tilting, folding, and faulting, the present configuration is, in general, probably similar to the configuration of the surface upon which the White River Group was deposited. The slope of the surface at the base of the White River also suggests a probable southwesterly source and northeasterly direction of transport for the rocks in the basal part of the White River Group in southwestern North Dakota and southeastern Montana. The base of the White River Group in these areas contains pebbles and cobbles of igneous rocks including quartz latite porphyry and welded tuff (figs. 4, 5, and 6) which have no counterparts in the Black Hills uplift (C. S. Robinson, V. R. Wilmarth, and J. A. Redden, written communication, June 3, 1958). Igneous and metamorphic rock fragments derived from the Black Hills uplift are present in the base of the Chadron east of the Black Hills in west-central South Dakota (Wanless, 1923, p. 194; Bump, 1951, p. 38), but are absent in the base of the Chadron in southwestern North Dakota and southeastern Montana. This evidence suggests that the clastic materials in the base of the Chadron north of the Black Hills were probably derived from igneous and metamorphic land masses to the southwest. Inasmuch as quartz latite porphyry, welded tuff, and other rock types in the base of the Chadron in southwestern North Dakota have not been specifically identified in possible source areas to the west, their exact source is not known. However, some of the reddish-brown porphyry pebbles in the base of the Chadron in southwestern North Dakota were probably derived from the large porphyry intrusives of early Tertiary and Late Cretaceous age described by Rouse and others (1937) along the northern and eastern flanks of the Beartooth Mountains in southwestern Montana.

### QUATERNARY SYSTEM

Pleistocene and Recent deposits of silt, sand, and gravel in dunes, terraces, and alluvial fans occur along many of the main stream channels south of the Missouri River. These deposits are derived mostly from Oligocene and Miocene rocks but in many areas are mixed with large fragments of silicified wood and wind-polished fine-grained quartzite derived from the Fort Union Formation of Paleocene age. In general these deposits have yielded few fossils, but at some localities fragments of either mastodon or elephant bones and teeth have been reported (Baker, 1952, p. 30).

Recent landslides and small pediment deposits of probable Pleistocene or Pliocene age occur along the flanks of some of the large buttes in the area. The pediment deposits are composed of poorly consolidated clay, silt, sand, and gravel derived and reworked from the Arikaree and older formations. At some localities these deposits have been deeply dissected by Recent erosion, leaving the deposits in relatively low, sloping isolated tables (fig. 14). Local areas of slump and recent landslides (fig. 15) occur in the southern part of the area and obscure the contacts between the older rocks for long distances along the flanks of some of the higher buttes. The material in the landslides is generally composed of jumbled blocks and masses of rock from the Arikaree with some rocks from the White River and older formations, and the slides extend at some places more than a mile from the cliff faces. In some areas coherent blocks, as much as half a mile long, have moved as a single unit.

Glacial and glaciofluviatile deposits as much as 250 feet thick cover a large part of the region north of the Missouri River. These deposits include alluvium, eskers, kames, and glacial outwash sand and gravel. No study was made of these deposits and no attempt was made to map them.

## ROCKS NOT EXPOSED

Sedimentary rocks as much as 12,000 feet thick are present but, for the most part, are not exposed in the region of this report. The general character of these rocks is well known from electric and gamma-ray logs, well cuttings, and core tests, and have been studied and described by many geologists. A generalized stratigraphic column (table 3) lists the formations commonly recognized in the subsurface of the basin.

A study of the subsurface data indicates that the older rocks away from the major uplifts have slightly steeper dips than do the surface and near-surface rocks as a result of more or less continuous subsidence since Cambrian time. Thus, sedimentary rocks in the deepest part of the basin in the vicinity of the Killdeer Mountains in northern Dunn and northeastern McKenzie Counties, N. Dak., have a thickness of about 16,000

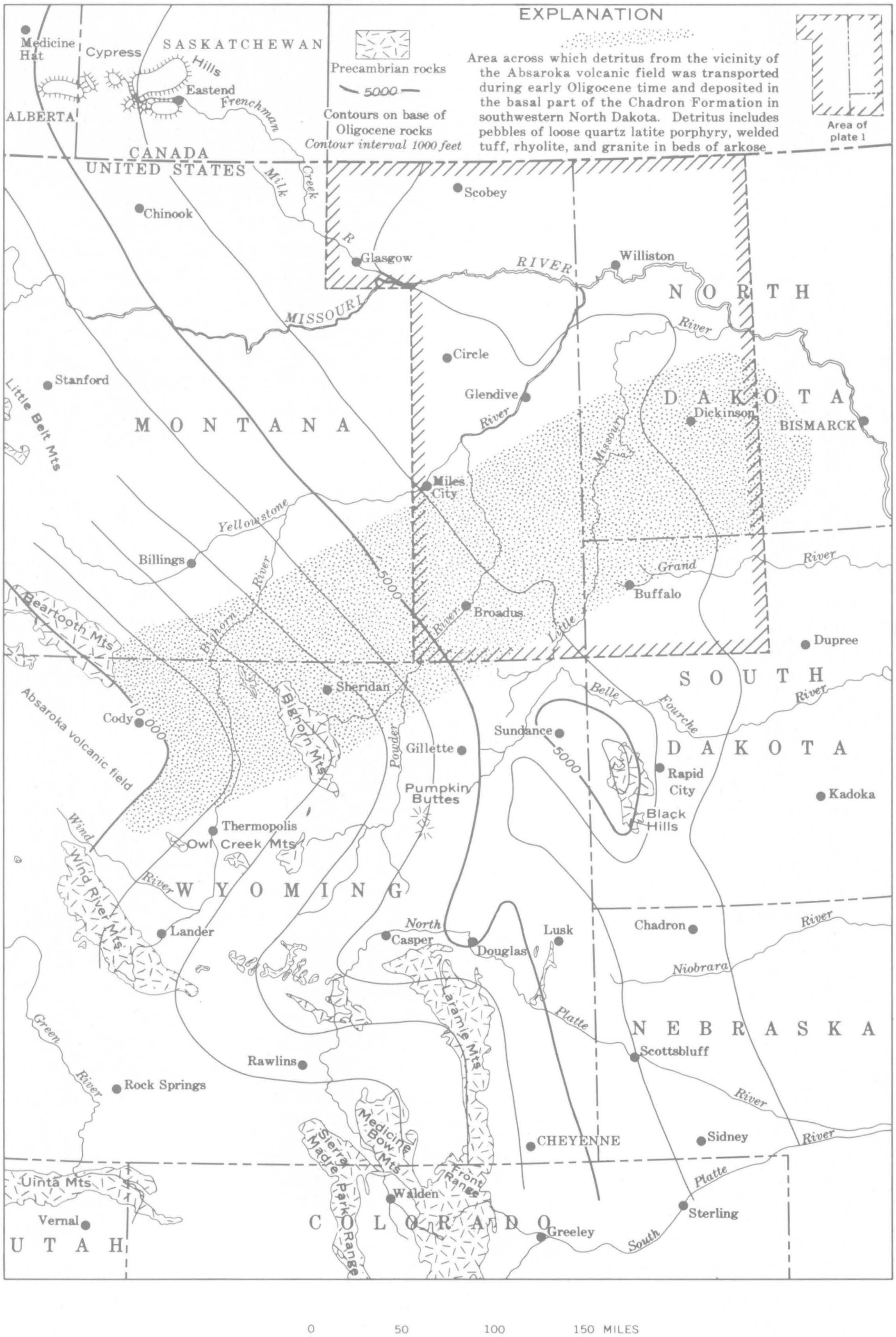


FIGURE 13.—Generalized configuration of surface at base of Oligocene rocks in parts of the Northern Rocky Mountain and Great Plains provinces. Compiled in part from data supplied by G. B. Gott, D. M. Kinney, J. D. Love, W. J. Mapel, Harold Masursky, L. W. McGrew, J. D. Redden, E. I. Rich, C. S. Robinson, W. N. Sharp, and H. D. Zeller and from W. O. Kupsch (1956).

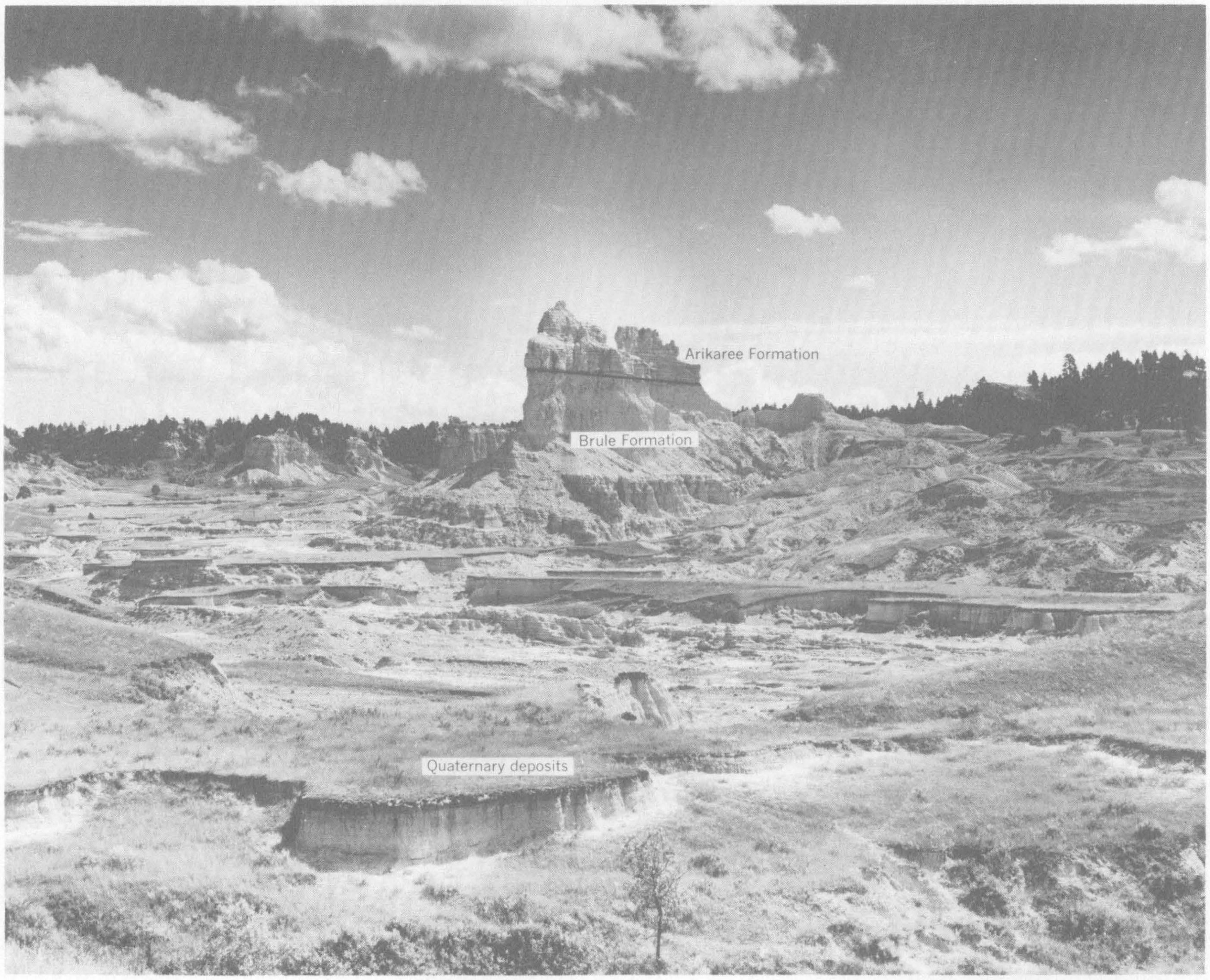


FIGURE 14.—Quaternary deposits of poorly consolidated clay, silt, and sand undergoing dissection along margins of Slim Buttes in the vicinity of Reva Gap.

feet. Outward from the center of the basin, the sedimentary column from the top of the Pierre Shale to the top of the Precambrian thins markedly and is only 7,000 feet thick along the southern margin of the basin in the vicinity of Fox Ridge and about 9,000 feet thick along the western margin near Sheep Mountain (pl. 2).

## HEAVY MINERALS IN CRETACEOUS AND TERTIARY ROCKS ASSOCIATED WITH URANIUM OCCURRENCES

By W. A. CHISHOLM

### GENERAL DISCUSSION

Grab samples from about 30 measured sections of Cretaceous and Tertiary rocks in the region were collected for microscopic examination of the nonopaque heavy-mineral grains. This study was undertaken to determine whether heavy minerals in the clastic sediments composing the lignite-bearing sequence differed markedly from those in the overlying tuffaceous rocks, and, if so, whether stratigraphic zoning of diagnostic heavy minerals showed any relation to the various ore-bearing strata within the region. Results from a microscopic study of 135 grab samples from the Hell Creek, Fort Union, Chadron, Brule, and Arikaree Formations are presented in this report. Heavy-mineral studies of rocks from the same or correlative units in other areas have been made by Lindberg (1944), Stow (1938, 1946), and Van Houten (1954).

The samples studied were disaggregated, and the heavy minerals from the very fine grained sand fraction (0.062 to 0.125 mm) were concentrated in bromoform. This grain size was chosen for comparisons between samples because it generally contains a relatively large amount and variety of nonopaque heavy minerals.

FIGURE 15.—Recent landslides and rock falls along the north face of Slim Buttes. Arikaree Formation forms vertical cliff. Fort Union and Chadron Formations form the bedrock beneath the slope-forming landslide debris.

Quantitative determinations were made from approximately equal amounts of samples, and mineral ratios were determined on a percentage basis by counts of 100 or more grains per sample. Authigenic minerals such as barite were not counted. Muscovite was not counted as in many samples it occurs in both the light and heavy separates. In some samples heavy minerals were coated with hematite or limonite. These samples were warmed in dilute (3:1) hydrochloric acid or dilute (10:1) nitric acid from 5 to 45 minutes to remove the coatings and facilitate mineral identification.

## MINERALOGY

*Opaque minerals.*—A detailed study was not made of the opaque heavy mineral grains, although the percentage of opaques in each sample was determined. The opaque minerals in most of the samples consist largely of magnetite, ferruginous and clay aggregates, leucoxene, and pyrite. As much as 50 percent of the concentrates in some samples was magnetite.

*Light minerals.*—Quartz, plagioclase, orthoclase, microcline, muscovite, and glass shards were present but were not specifically studied. Quartz is the predominant mineral in most of the samples examined.

*Nonopaque heavy minerals.*—Garnet, zircon, augite, hornblende, biotite, staurolite, kyanite, and epidote were found to be useful for stratigraphic correlation. A summary of the average percentages of these and other nonopaque heavy-mineral grains for each of the seven stratigraphic units studied is graphically shown on figure 16 and tabulated in table 4. (Percentages of heavy minerals identified in the nonopaque fraction for each sample studied are listed in tables 1–7 in Denson and Gill (1965a).) The locations of the measured sec-

TABLE 3.—*Williston basin stratigraphic column of rocks present but not exposed in region of this report*

[Adapted from North Dakota Geol. Soc., 1954, p. 2]

| Age | Group | Formation |
|---|---|---|
| Cretaceous | Colorado | Niobrara [1]<br>Carlile [1]<br>Greenhorn [1]<br>Belle Fourche [1] |
| | | Mowry [1]<br>Newcastle<br>Skull Creek<br>Dakota<br>Lakota |
| Jurassic | | Morrison<br>Swift<br>Rierdon<br>Piper |
| Triassic | | Spearfish |
| Permian | | Minnekahta<br>Opeche |
| Pennsylvanian | | Minnelusa |
| Mississippian | | Amsden |
| | Big Snowy | Heath<br>Otter<br>Kibbey |
| | Madison | Charles<br>Mission Canyon<br>Lodgepole<br>Bakken |
| Devonian | | Three Forks |
| | Saskatchewan | Nisku<br>Duperow |
| | Beaverhill Lake | Souris River<br>Dawson Bay |
| | | Prairie<br>Winnipegosis |
| | | Ashern |
| Silurian | Interlake | Interlake |
| Ordovician | | Stony Mountain<br>Red River<br>Winnipeg |
| Cambrian | | Deadwood |

[1] Exposed in small area in southern Carter County, Mont.

tions and the stratigraphic positions from which most of the samples were collected are shown on the correlation charts (pls. 3 and 4).

## CONCLUSIONS

Microscopic studies of grab samples from the continental basin-fill sediments composing the Hell Creek, Fort Union, Chadron, Brule, and Arikaree Formations reveal a characteristic heavy-mineral assemblage for each formation that differs sufficiently from the assemblage in the adjacent formation to help in correlation. Comparisons were made between the heavy minerals of samples collected adjacent to uraniferous lignite and the heavy minerals of samples from the same stratigraphic units remote from uranium deposits, but no relation was found to exist between any of the heavy-mineral assemblages and the occurrence of uranium.

The heavy-mineral suites from each stratigraphic unit studied are summarized below:

The heavy mineral suite from the Arikaree Formation (Miocene) is characterized by the abundance of augite and a paucity of opaque minerals. Most of the nonopaque heavy minerals were derived from extrusive igneous rocks. A large amount of this material is pyroclastic but was considerably reworked by water and perhaps by eolian processes. Hornblende and augite make up about 80 percent of the nonopaque fraction. Blue-green, green, brown, green-brown, and red-brown varieties of hornblende are present. In most of the concentrates, green-brown hornblende is most abundant. The grains of these minerals are better rounded and about 20 percent more abundant than those in the underlying Brule Formation. These characteristics and the compositional differences in the carbonate rocks from the Oligocene and Miocene shown in table 2 are largely the basis for assigning a Miocene age to 260 feet of tuffaceous rocks capping the Killdeer Mountains in Dunn County, N. Dak. (See pl. 3, loc. 1 (this report) and table 1 (Denson and Gill, 1965a).) These rocks previously had been assigned to the White River Formation (Group) of Oligocene age (Quirke, 1918, p. 265).

The Brule Formation (middle and upper Oligocene) is like the Arikaree Formation in that it contains mostly heavy minerals derived from extrusive igneous rocks largely of pyroclastic origin. The chief difference in the nonopaque heavy-mineral suite between the Arikaree and Brule is the large amount of biotite in many of the Brule samples. The heavy minerals in the Brule, although somewhat rounded, are noticeably less rounded than those in the Arikaree. There are several samples from the Brule, however, that are indistinguishable from the Arikaree on the basis of heavy minerals. Furthermore, hornblende, which is the most abundant heavy mineral in both the Arikaree and Brule, cannot be differentiated on the basis of color.

The lower 50 feet of the Chadron Formation (lower Oligocene) contains, in general, a suite of heavy minerals similar to those in some sandstones in the upper part of the Sentinel Butte Member of the Fort Union Formation. This suite is characterized by staurolite, kyanite, tourmaline, and an abundance of opaque minerals, largely magnetite. Above this lower part, tuffaceous rocks in the Chadron contain heavy minerals of

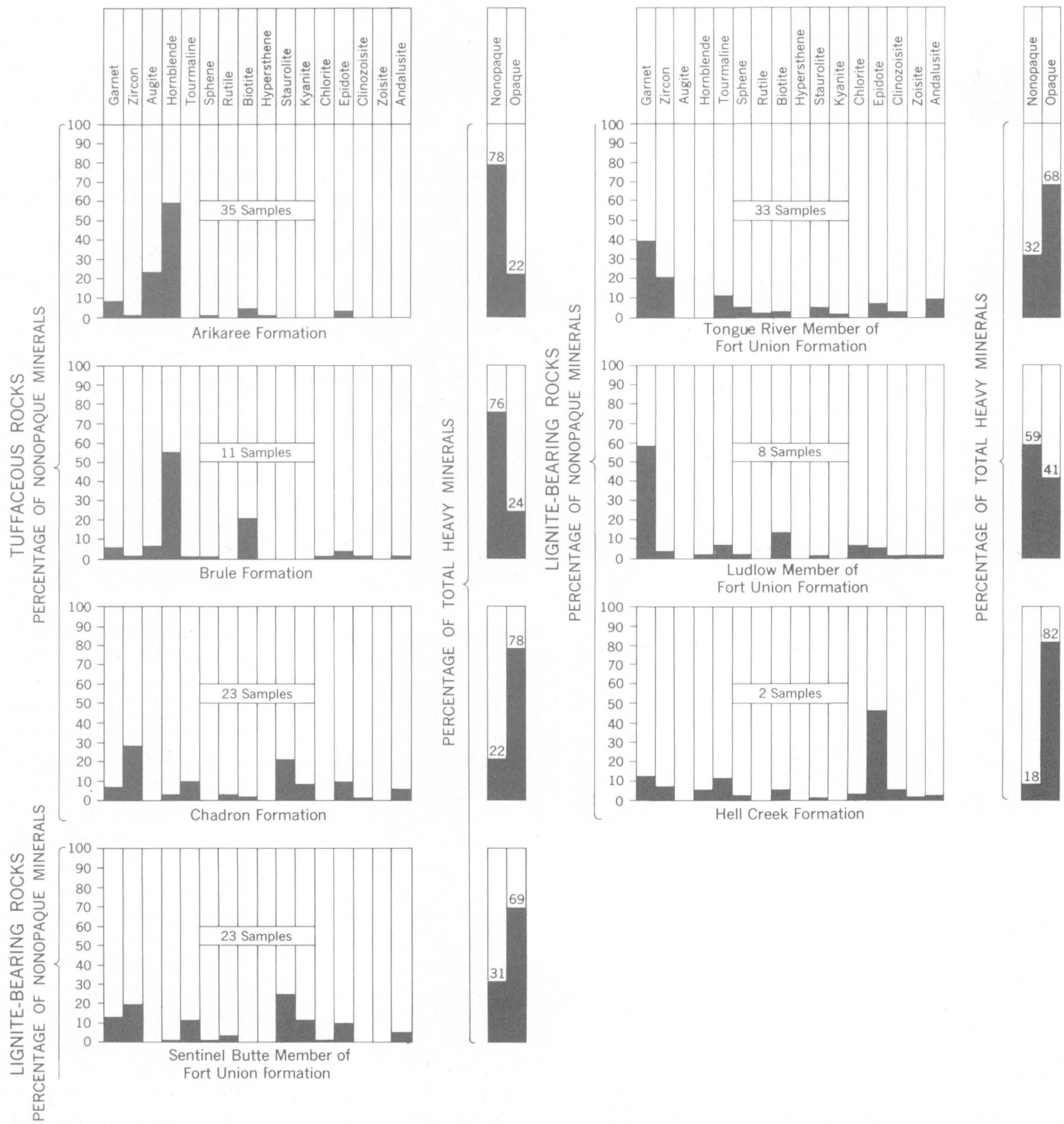


FIGURE 16.—Heavy-mineral content of grab samples of Upper Cretaceous and Tertiary rocks in the southwestern part of the Williston basin.

pyroclastic origin. Important ones are hornblende and augite. The heavy minerals in the upper parts of the Chadron are very similar to those in the Arikaree Formation and were probably derived from the same volcanic source.

The nonopaque heavy minerals from the Sentinel Butte Member of the Fort Union Formation (Paleocene) are characterized by garnet, zircon, tourmaline, epidote, and andalusite. Some widespread sandstones in the upper part of the Sentinel Butte also contain abundant staurolite and kyanite and were probably derived from a source area underlain by mesozonal schists.

The heavy minerals studied from the Tongue River Member of the Fort Union Formation are mainly from the lower 200 feet of the member. The assemblage is

TABLE 4.—*Average percentages of heavy minerals in 135 grab samples from Cretaceous and Tertiary rocks associated with uranium-bearing lignite deposits in Williston basin*

[Total nonopaque minerals=100 percent]

| Age | | Group, formation, member | | Average thickness (feet) | Lithologic description | Number of samples | Nonopaque minerals | | | | | | | | | | | | | | | | Opaque minerals [1] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Garnet | Zircon | Augite | Hornblende | Tourmaline | Sphene | Rutile | Biotite | Hypersthene | Staurolite | Kyanite | Chlorite | Epidote | Clinozoisite | Zoisite | Andalusite | |
| Tertiary | Miocene | | Arikaree Formation | 260 | Volcanic rocks—largely tuffaceous sandstone, siltstone, and claystone. | 35 | 8 | 1 | 23 | 59 | 0 | 1 | 0 | 4 | 1 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 22 |
| | | Unconformity | | | | | | | | | | | | | | | | | | | | | |
| | Oligocene | White River Group | Brule Formation | 200 | | 11 | 6 | 2 | 7 | 55 | 1 | 1 | 0 | 21 | 0 | 0 | 0 | 1 | 4 | 1 | 0 | 1 | 24 |
| | | | Chadron Formation | 100 | | 23 | 7 | 28 | 0 | 3 | 10 | 1 | 3 | 2 | 0 | 22 | 8 | 0 | 9 | 1 | 0 | 6 | 78 |
| | | Unconformity | | | | | | | | | | | | | | | | | | | | | |
| | Paleocene | Fort Union Formation | Sentinel Butte Member | 700 | Fluviatile deposits of lignite-bearing sandstone and shale. | 23 | 13 | 19 | 0 | 1 | 12 | 1 | 3 | 0 | 0 | 24 | 12 | 1 | 9 | 0 | 0 | 5 | 69 |
| | | | Tongue River Member | 600 | | 33 | 39 | 20 | 0 | 0 | 11 | 4 | 1 | 2 | 0 | 4 | 1 | 0 | 7 | 2 | 0 | 9 | 68 |
| | | | Ludlow Member | 350 | | 8 | 58 | 3 | 0 | 1 | 7 | 2 | 0 | 13 | 0 | 1 | 0 | 7 | 5 | 1 | 1 | 1 | 41 |
| Cretaceous | Late Cretaceous | Hell Creek Formation | | 500 | Fluviatile shale and sandstone. | 2 | 13 | 7 | 0 | 4 | 11 | 2 | 0 | 5 | 0 | 1 | 0 | 3 | 45 | 5 | 1 | 2 | 82 |

[1] Percent of total heavy fraction.

characterized by an abundance of garnet, zircon, and tourmaline. In the lower 50 feet epidote, clinozoisite, zoisite, and trace amounts of glaucophane are present. Andalusite and staurolite are conspicuous constituents in the upper 100 feet. Opaque minerals are abundant and constitute about 70 percent of the total heavy-mineral fraction.

The Ludlow Member of the Fort Union Formation is characterized by very abundant garnet in its heavy-mineral suites. Other nonopaque minerals commonly present are biotite, sphene, chlorite, tourmaline, and epidote. The percentage of opaque minerals is very low, generally less than 40 percent of the heavy-mineral fraction. The percentage of opaques in this member is markedly lower than that in other members of the Fort Union Formation, in which the opaques generally compose 65 to 70 percent of the total heavy minerals.

The chief differences in the heavy minerals from the Hell Creek Formation (Upper Cretaceous) and the overlying Ludlow Member are the preponderance of opaque minerals, which constitute about 80 percent of the total heavy minerals, and the abundance of epidote, which generally constitutes 35 to 55 percent of the nonopaque fraction. Cursory examination of samples from a test well drilled for oil and gas in the North Cave Hills also reveals that hornblende is an important constituent in sandstone in the Hell Creek. Hornblende is either absent or sparse in the overlying Ludlow, Tongue River, and Sentinel Butte Members of the Fort Union Formation.

The relative abundance of garnet, zircon, tourmaline, and—locally—biotite, staurolite, epidote, and andalusite suggests that the sedimentary materials composing the Fort Union Formation were probably derived mainly from a source area of igneous and low-grade metamorphic rocks. Of the samples studied, only those from the upper half of a 100-foot-thick sandstone bed at the base of the Tongue River Member of the Fort Union Formation in the Cave Hills area contain relatively large amounts of well-rounded grains which are characteristic of minerals derived from preexisting sedimentary rocks. Most of the other samples studied from the lignite-bearing rocks are predominantly first-cycle sediments as indicated by several fairly unstable minerals and by many angular grains.

A striking similarity among the heavy-mineral assemblages, especially the preponderance of staurolite, kyanite, and zircon in the Sentinel Butte Member and in the overlying basal arkose of the Chadron Formation of early Oligocene age, indicates either that the source area is the same or similar or that the basal Chadron contains much material reworked from the Sentinel Butte Member. Where the Chadron Formation directly overlies the Hell Creek and the lower part of the Fort Union Formation, the heavy-mineral suite in samples from the Chadron differs from the suite in the underlying rocks. This evidence indicates that the Chadron was not derived to any appreciable degree from local reworking of those rocks.

### REGIONAL STRUCTURE

The region described in this report lies in the southwestern part of the Williston basin, a large structural depression about 550 miles long and 300 miles wide in northwestern South Dakota, northeastern Montana, western North Dakota, and south-central Saskatchewan (Porter and Fuller, 1959, fig. 1). At the deepest part of the basin in northeastern McKenzie County, N. Dak., the top of the Precambrian is about 13,700 feet below sea level, whereas along the southwestern margin of the basin at the southwest corner of Harding County, S. Dak., Precambrian rocks are about 3,700 feet below sea level, giving a maximum structural relief of about 10,000 feet. The configuration of the basin and its main structural features are shown on plate 5*G* and *H*.

Four prominent north-northwest-trending anticlinal uplifts occur along the northern and western margins of the basin. These are the Nesson anticline, the Poplar dome, the Cedar Creek anticline, and the north end of the Black Hills uplift. Oil is produced from the first three uplifts (pl. 1), and large volumes of gas have been produced from shallow depths on the Cedar Creek anticline. Subsurface information indicates that these uplifts had their inception in Paleozoic time, were periodically reactivated from time to time during the geologic past, and were brought into prominence most recently by Laramide folding during Late Cretaceous and early Eocene time. The region underwent folding during a later period as shown by shallow folds in middle and upper Tertiary rocks in the Little Badlands and Chalky Buttes, Stark and Slope Counties, N. Dak., and at Slim Buttes, Harding County, S. Dak. In the Little Badlands these shallow folds trend northeastward in contrast to the Laramide and earlier structural features that trend northwestward. The later folding may have produced small anticlinal noses and gentle northeast-trending folds in the lignite-bearing Paleocene rocks reported by Hanson (1955) and Caldwell (1954) in Billings and Stark Counties, N. Dak.

At most places in the basin the surface rocks adjacent to and between the major upwarps have gentle, relatively uniform dips of less than 25 feet per mile. Along the axis of the basin from the southwest corner of Perkins County northwest to Watford City in northeastern McKenzie County, N. Dak., the top of the Precambrian has a regional dip of about 40 feet per mile.

Faults having more than a few tens of feet of stratigraphic displacement have been recognized at only a few places in the region. The largest faults are along the southeast flank of the Nesson anticline (Bateman, 1957), the southeast flank of the Poplar dome (Colton and Bateman, 1956), and the west flank of the Cedar Creek anticline (McCabe, 1954, p. 2003). The surface trace of these faults and their displacements are shown on plate 5*G* and *H*.

## URANIUM DEPOSITS

### OCCURRENCE AND DISTRIBUTION

Uranium-bearing lignite and carbonaceous shale in the Williston basin occur throughout about 2,500 feet of basin-fill continental deposits ranging from Late Cretaceous to Eocene in age. Uranium in small amounts in carbonaceous rocks occurs sporadically over an area about 150 miles long and 50 miles wide along the south-central part of the basin; however, important reserves of carbonaceous rocks containing greater than 0.1 percent uranium are known only in the Slim Buttes and North Cave Hills areas in Harding County, S. Dak., and in the Little Missouri River escarpment area (Rocky Ridge and Saddle Butte localities) in eastern Billings and northwestern Stark Counties, N. Dak. (fig. 1). In these areas the relatively high-grade deposits occur in the Fort Union Formation of Paleocene age about 750, 1,050, and 2,050 feet stratigraphically above the top of the Pierre Shale. The principal host rocks are nearly flat lying, and in general the stratigraphically and topographically higher carbonaceous beds in the mineralized sequence contain the most uranium. The carbonaceous host rocks range from 6 inches to more than 2 feet in thickness and are characterized by their lenticularity, relatively high ash contents (35 to 40 percent), and low heating values. At many places they are overlain by relatively thin overburden which makes them easily mined by stripping methods.

### REGIONAL GEOLOGIC RELATIONS

Regional structure and thickness maps of rocks in the Williston basin were compiled from a study of about 500 electric, 200 gamma-ray, and 90 sample logs released by commercial companies for wells drilled for oil and gas prior to about March 1958.[1] This study was undertaken to determine whether uranium occurrences are related to major regional structure, to stratigraphic position, or to areas of abnormally high radioactivity in pre-Tertiary rocks as indicated on gamma-ray well logs.

Plate 5*A–F* shows the thicknesses of six selected stratigraphic intervals between the present-day erosion surface and the base of the Deadwood Formation (Cambrian). Plate 5*A* and *F* shows the distribution of known uranium deposits, their relative stratigraphic position above the base of the coal-bearing rocks, and their relation to the thickness of rock between the top of Pierre Shale and the top of the basement rocks. Plate 5*B–E* provides data which were useful in interpreting the geologic history of the basin and which were used in extrapolating rock thicknesses and subsurface elevations in areas where test wells failed to reach the top of the Precambrian.

The distribution of uranium in relation to the structure of the top of Precambrian rocks and the top of the Pierre Shale is shown on plate 5*G* and *H*, respectively. The structure of the lignite-bearing Fort Union Formation presumably conforms with the structure of the top of the Pierre Shale.

Locations of wells from which data were used in compiling these maps are shown on plate 1. Pertinent field and drilling information for each well, listed by county, is shown in table 8 (Denson and Gill, 1965b).

As shown on plate 5*A* and *F*, the vertical distances between the uranium deposits and the Precambrian surface varies widely; along the southern margin of the basin the deposits occur about 9,000 feet above Precambrian rocks, whereas near the center the deposits are about 16,000 feet above the Precambrian basement. Furthermore, the deposits appear to coincide with the axis of the basin as determined by contours on the Precambrian (pl. 5*G*). The axis of maximum subsidence of the pre-Tertiary basin, as shown by maximum thickness of sedimentary rocks between the top of the Pierre Shale and the top of the Precambrian basement (pl. 5*F*), trends northward 150 miles or more through the more important uranium deposits in the region. The original thicknesses of the lignite-bearing rocks could not be determined because of post-Eocene erosion; however, the lignite-bearing rocks that still remain are thickest along the axis of maximum pre-Tertiary subsidence (pl. 5*A*). The northward alinement of the uranium deposits may have resulted from the flow of mineralizing solutions down the flanks to the axis of the basin. Field and analytical data indicate that, given favorable host rocks, the most intense mineralization occurs along the axis and flanks of local shallow synclines superimposed on the broad regional structure. Differences in permeability of the rocks over and underlying the lignite beds are also considered to have influenced the flow of uranium-bearing ground

[1] For supplemental data on the regional structure and thickness of rocks in and adjacent to the Williston basin, the reader is referred to Porter and Fuller (1959), Dobbin and Erdmann (1955), Kunkel (1954), Laird and Towse (1953), Petsch (1953a and 1953b), and Sandberg (1959). R. W. Brown (1949) shows the extent of Paleocene deposits in the Rocky Mountains and Plains regions.

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water and the deposition of the higher grade uranium deposits.

Variations and intensity of radioactivity of the rocks in the subsurface, as indicated by gamma-ray logs and analyses of core samples, were carefully studied because some workers believe that the uranium in the lignite-bearing rocks originally was contained in juvenile hydrothermal solutions (Everhart, 1956, p. 93, 94, and 97; and King and Young, 1956, p. 427). They postulate that the uranium rose to the site of deposition through faults that cut the Precambrian or that entered the ground-water system from Tertiary intrusive masses [2] and migrated laterally along permeable beds at shallow depths. Evidence to corroborate either of these hypotheses was not found by studying gamma-ray logs or by analyzing core samples from wells drilled in the basin. Two lines of sections of well logs near the principal uranium-bearing lignite deposits show the general level of radioactivity of the subsurface rocks (pls. 6 and 7). These sections indicate that there are five to eight appreciably radioactive zones in the Paleozoic and Mesozoic strata between the base of the lignite-bearing rocks and the top of the Precambrian. The zones are from 10 to 50 feet thick. They can be identified and correlated by means of gamma-ray logs and are known to extend over large areas within the region. Six of the more important radioactive zones are identified on the charts as follows: Base of Claggett Shale or the equivalent of the Sharon Springs Member of Pierre Shale (Upper Cretaceous); top of Niobrara Formation (Upper Cretaceous); top of Greenhorn Limestone (Upper Cretaceous); base of Madison Group (Mississippian); top of Red River Formation (Upper Ordovician); and top of Winnipeg Formation (Middle Ordovician). Other equally important radioactive zones are found in the Minnelusa Formation of Pennsylvanian age and the Mowry Shale of Early Cretaceous age but are not identified on the illustrations. The radioactivity in these zones is apparently not more intense near the faults, which probably cut the Precambrian along the Cedar Creek and Nesson anticlines, than near the known occurrences of uranium-bearing lignite. The youngest of these zones is near the base of the Claggett Shale or the equivalent of the Sharon Springs Member of the Pierre Shale of Late Cretaceous age about 1,500 feet below the base of the uranium-bearing lignite sequence. The stratigraphically lowest radioactive zone in the region occurs in the Winnipeg Formation of Middle Ordovician age about 900 feet above the top of the Precambrian basement.

The radioactive materials in these zones were probably deposited at about the same time as the enclosing rocks, most of which were deposited in a marine environment. Many of these zones occur at the boundaries between formations and may represent regional unconformities or sites of relatively little accumulation during long periods of geologic time. Kepferle (1959, p. 602), who studied one of the radioactive zones in the Pierre Shale in the southern and western part of the Williston basin, concluded that the uniform distribution of the uranium (averaging 0.0015 percent in the radioactive zone) was due to an increase in the uranium content of the sea water after the deposition of volcanic ash, which has since altered to bentonite. It seems reasonable to attribute the widespread distribution and uniform deposition of radioactive material in most of these zones to relatively uniform marine conditions of deposition rather than to the subsequent introduction of radioactive elements from outside sources. The possibility that the uranium in the lignite was introduced from hydrothermal solutions entering along faults cutting the Precambrian is diminished by the presence of a body of impervious shale of Late Cretaceous age 3,000 to 4,200 feet thick that directly underlies the lignite-bearing rocks of the region (pl. 2). Had hydrothermal activity been prevalent this unit would have probably served as an effective seal or barrier to either ascending or descending solutions.

Analyses of core samples from two of the radioactive zones found in the subsurface in the Williston basin are shown in table 9 (Denson and Gill, 1965c). These analyses indicate the uranium content of the radioactive zones shown on gamma-ray logs. Radioactivity data and analyses of samples from other radioactivity zones in the Williston basin region of Montana, North Dakota, and adjacent parts of Canada are given by Mapel (1956, p. 472 and 474).

### CONTROLS OF MINERALIZATION

Controls of mineralization of the carbonaceous beds in the Williston basin and theories of origin and accumulation have been described and discussed previously in reports by Denson and Gill (1956, p. 416–418), Bergstrom (1956), and Denson, Bachman, and Zeller (1959, p. 28–40). Important new data bearing on the subject have since been obtained from regional and local study of the deposits. The principal controls of uranium mineralization in lignite and carbonaceous

[2] The locations of several intrusive masses, not exposed at the surface but indicated by gravimetric surveys, are shown in reports covering parts of eastern Montana and the Dakotas by Osterwald and Dean (1957a, 1957b, and 1958). Deep-seated plugs in the northern Great Plains province in adjacent parts of Canada are noted by Gallup (1956, p. 65).

shale in the Williston basin are briefly summarized as follows:

1. Stratigraphic proximity of carbonaceous host rocks to the unconformity at the base of Oligocene and Miocene rocks. Many beds of lignite and carbonaceous shale are exposed along the low plains and stream valleys throughout the Dakotas and eastern Montana, but about 90 percent of the known radioactive coals occurs on the flanks of the highest buttes capped with tuffaceous rocks of middle and late Tertiary age.
2. Permeability and thickness of beds directly overlying the host rocks. With few exceptions, the important ore-grade deposits occur in the basin where massive, thick porous sandstones overlie the uranium-bearing carbonaceous beds. These sandstones are probably the conduits through which the mineralizing solutions moved downward and laterally, in some places perhaps for considerable distances.
3. Shallow troughs superimposed on the broad regional structure. These features occur in the Slim Buttes and Cave Hills areas in Harding County, S. Dak. The highest grade deposits in these areas occur principally along the flanks and in the troughs of shallow folds. The folds were probably of primary importance in locally concentrating the flow of the mineralizing solutions. The effect of structure and permeability on uranium mineralization in the carbonaceous beds of the basin is schematically shown on figure 17.
4. Absence of thick impervious beds at the base of the tuffaceous Miocene rocks. The highest grade material occurs in areas where rocks of the Chadron and Brule Formations are absent beneath the Arikaree. In these areas, as for example at Slim

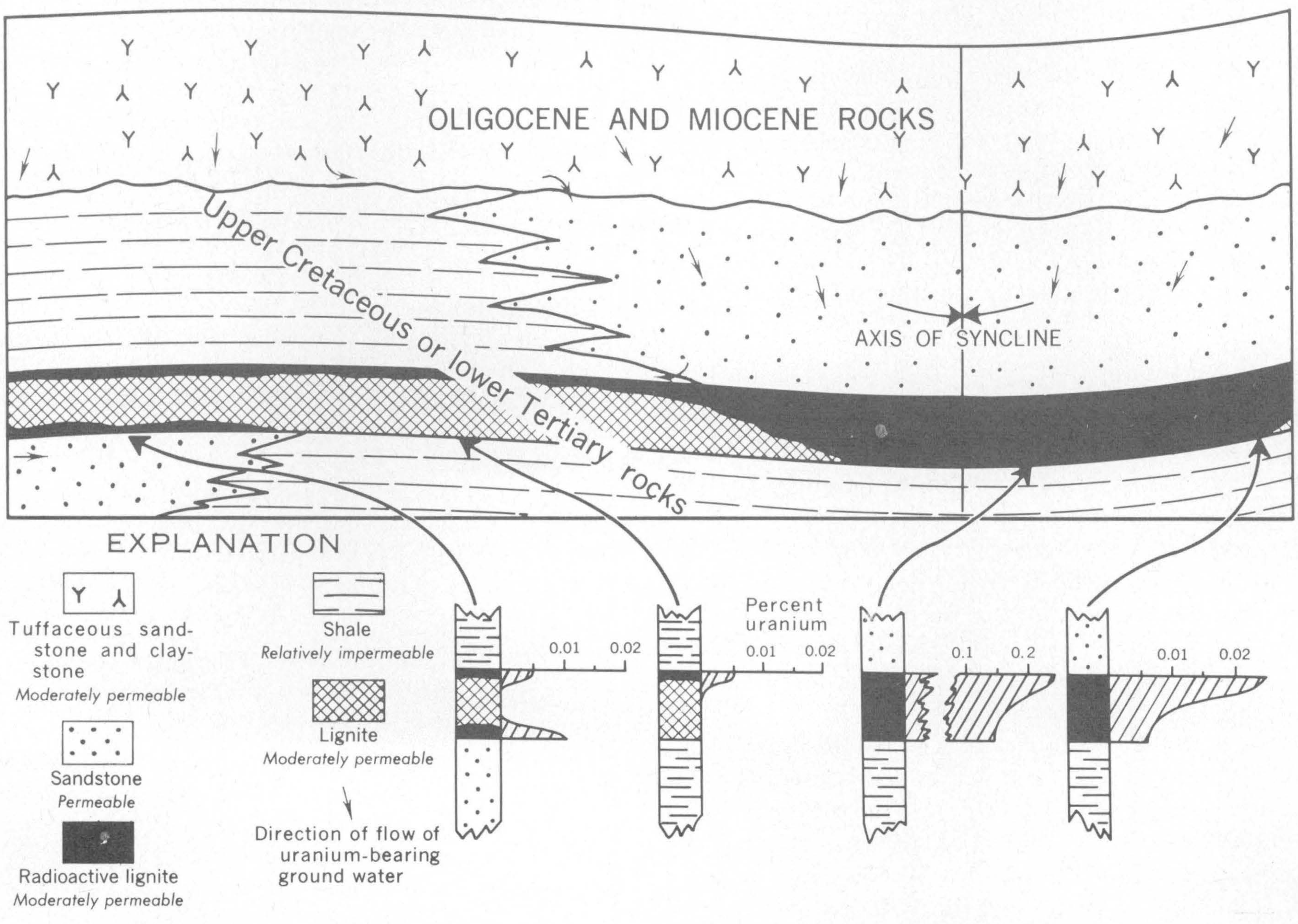


FIGURE 17.—Schematic diagram showing effect of structure and permeability on uranium mineralization.

Buttes in the east-central part of T. 16 N., R. 8 E., and the southeastern part of T. 18 N., R. 7 E., thick permeable tuffaceous beds of the Arikaree Formation rest directly on the older lignite-bearing sequence. The absence of thick impervious bentonite in the lower and middle parts of the Chadron Formation in these areas may have facilitated the relatively rapid and easy downward migration of the mineralizing solutions from the Arikaree into the underlying lignites to produce ore-grade material. The relative abundance of analcite in uraniferous beds is a rough indication of the extent of ground-water circulation and degree of mineralization. Analcite is absent or sparse in the weakly radioactive lignite deposits where overlain by the relatively impervious clay and bentonite of the White River Group and is most abundant along topographic highs where the ore-grade deposits are directly overlain by the porous sandstone of the Arikaree Formation. (See p. 43.)

5. Porosity of the host materials. The principal host rocks that contain the important reserves of uranium in the basin are relatively thin lenticular carbonaceous beds that contain about 35 to 40 percent ash. The thicker and more persistent carbonaceous beds at most places contain less ash, but because they are generally less pervious, they do not admit so easily the mineralizing solutions.

## MINERALOGY

Uranium in carbonaceous rocks in the Williston basin occurs mostly as a disseminated amorphous organouranium complex or compound closely associated with the organic fraction of the lignite or carbonaceous shale (Breger and others, 1955, p. 226). Yellow fluorescent and nonfluorescent secondary uranium minerals, however, occur at many widely scattered localities within the basin, in both the carbonaceous rocks of the Fort Union Formation (Gruner and others, 1956, p. 15–17) and in lesser amounts in rocks of the White River Group and the Arikaree Formation. In areas where the carbonaceous rocks contain appreciable amounts of uranium, uranium minerals generally coat bedding planes and joints that cut the deposit. Fresh samples from low-grade deposits lack visible mineral impurities except for pyrite. Weathering results in the oxidation of pyrite and in the formation of abundant gypsum ($CaSO_4 \cdot 2H_2O$) and jarosite [$(KFe_3(SO_4)_2(OH)_6$] or melanterite ($FeSO_4 \cdot 7H_2O$); the last two minerals superficially resemble some uranium minerals.

The following uranium minerals have been identified in the Fort Union Formation principally in the carbonaceous rocks:

| | |
|---|---|
| | *Arsenates* |
| Abernathyite | $K_2(UO_2)_2(AsO_4)_2 \cdot 8H_2O$ |
| Metanovacekite | $Mg(UO_2)_2(AsO_4)_2 \cdot 8\text{–}10H_2O$ |
| Metazeunerite | $Cu(UO_2)_2(AsO_4)_2 \cdot 8H_2O$ |
| | *Oxides* |
| Becquerelite | $7UO_3 \cdot 11H_2O$ |
| Uraninite | $UO_2$ |
| | *Phosphates* |
| Bassettite | $Fe(UO_2)_2(PO_4)_2 \cdot 8H_2O$ |
| Meta-autunite | $Ca(UO_2)_2(PO_4)_2 \cdot 2\frac{1}{2}\text{–}6\frac{1}{2}H_2O$ |
| Metatorbernite | $Cu(UO_2)_2(PO_4)_2 \cdot 8H_2O$ |
| Saléeite | $Mg(UO_2)_2(PO_4)_2 \cdot 8H_2O$ |
| Meta-uranocircite | $Ba(UO_2)_2(PO_4)_2 \cdot 8H_2O$ |
| | *Silicate* |
| Uranophane | $Ca(UO_2)_2Si_2O_7 \cdot 6H_2O$ |
| | *Vanadates* |
| Carnotite | $K_2(UO_2)_2(VO_4)1\text{–}3H_2O$ |
| Metatyuyamunite | $Ca(UO_2)_2(VO_4)_2 \cdot 3\text{–}5H_2O$ |

Of these, meta-autunite, a calcium uranyl phospate; metatyuyamunite, a calcium uranyl vanadate; and abernathyite, a potassium uranyl arsenate, occur at the most localities.

The White River Group and Arikaree Formation are known to contain traces of uranium, but at most places the uranium apparently is held as a finely disseminated constituent of volcanic ash rather than as visible discrete uranium minerals. Carnotite in minor amounts occurs in silicified sandstone in the upper part of the Chadron Formation at Slim Buttes (Gill and Moore, 1955), in claystone in the upper part of the Chadron Formation in NE¼NW¼ sec. 31, T. 139 N., R. 97 W., in the Little Badlands of North Dakota (pl. 10), and in silty dolomite in the upper part of the Arikaree Formation in the SE¼ sec. 24, T. 17 N., R. 1 E., in West Short Pine Hills, S. Dak. (pl. 14). Specimens of metatyuyamunite have been identified from the basal arkosic sandstone of the Chadron Formation in the NE¼SW¼ sec. 26, T. 17 N., R. 3 E., in the East Short Pine Hills, S. Dak. (pl. 14).

## DESCRIPTION OF URANIFEROUS AREAS

### LITTLE MISSOURI RIVER ESCARPMENT AREA

#### LOCATION AND ACCESSIBILITY

The Little Missouri River escarpment area in southwestern North Dakota lies in west-central Billings County and the northwestern part of Stark County (pl. 8), principally in Tps. 137–142 N., Rs. 99–100 W., and covers about 300 square miles of gently rolling upland and about 100 square miles of rugged badland terrain. The upland area is easily accessible by county roads and U.S. Highways 85 and 10 which intersect at Belfield (population 900). The badland areas are accessible by trail or horseback. The Northern Pacific

Railway crosses the area and provides shipping facilities at Belfield. Medora, the county seat of Billings County and gateway to the South Unit, Roosevelt National Park, is on U.S. Highway 10, 15 miles west of the area. The area is about 140 miles west of Bismarck, 150 miles north of the Black Hills, and 50 miles northeast of the Cedar Creek anticline.

The area derives its name from a prominent north-northeast-trending escarpment about 35 miles long on the east side of the Missouri River. This divide, along which most of the uranium-bearing lignites crop out, separates intermittent streams draining westward in youthful steep-sided valleys to the Little Missouri River from streams draining eastward across relatively flat, undissected uplands toward the southeastward-flowing Heart and Cannonball Rivers.

### EARLIER INVESTIGATIONS

Uranium was discovered in the Little Missouri River escarpment area in 1948 by Wyant and Beroni (1950, p. 15). The first reported occurrences in the southwestern part of the area at Bullion Butte, however, were of low grade, and it was not until 1954 that local prospectors discovered material of possible economic interest [3] 15 miles east of Bullion Butte in the vicinity of Rocky Ridge. Since then, relatively high-grade deposits of uranium in lignite and carbonaceous shale have been discovered on the escarpment. This general region is now known to contain some of the most important reserves of uranium in the Williston basin. The geology of the area has been described by many geologists, principally Leonard (1908), Hares (1928), and R. W. Brown (1948). Descriptions of some of the higher grade uranium deposits are given by Bergstrom (1956), Towse (1957), and Curtiss (1957).

### STRATIGRAPHY

All the rocks exposed in the Little Missouri River escarpment area are of continental origin and are of Paleocene age. They consist of 850 to 950 feet of fine-grained sandstone, siltstone, carbonaceous shale, and lignite which are excellently exposed along the Little Missouri River and the adjacent badlands in the western and central parts of Billings County. Rock exposures are generally poor on the surrounding uplands, which are largely under cultivation. The outcropping rocks are assigned to the Tongue River and overlying Sentinel Butte Members of the Fort Union Formation. The lower members of the formation, the Cannonball of marine origin and the underlying Ludlow of continental origin, are not exposed. Drill holes indicate that the Fort Union Formation in the vicinity of the uranium deposits has a minimum thickness of about 1,500 feet.

The Golden Valley Formation of Eocene age is not present in the area shown on plate 8, but overlies the Sentinel Butte Member of the Fort Union in a group of low hills outside the area in the northeastern part of Billings County (Benson, 1951). Rocks of Oligocene age have not been identified, but boulders and cobbles of chert and chalcedony, similar to those present at the base of Oligocene strata in other areas, are strewn over some of the higher hills at elevations of about 3,060 feet in sec. 14, T. 137 N., R. 101 W.

#### TERTIARY ROCKS

**Fort Union Formation (Paleocene)**

*Tongue River Member.*—In the Little Missouri River escarpment area the oldest rocks exposed are the upper 400 feet of the Tongue River Member of the Fort Union Formation. The member consists principally of poorly indurated light-yellow to buff calcareous sandstone, interbedded gray and chocolate-brown carbonaceous shale, and thick persistent beds of lignite. The best exposures of these rocks are in the vicinity of Bullion Butte, where the H T lignite bed, 25 feet thick, has been mapped and described by Hares (1928, p. 50, pl. 14) as marking a conformable boundary with the overlying Sentinel Butte Member.

Lignite beds and other carbonaceous rocks in the Tongue River Member are not radioactive in the Little Missouri River escarpment area, and, therefore, were not studied in detail.

*Sentinel Butte Member.*—In the Little Missouri River escarpment area only the lower part of the Sentinel Butte Member is present, the upper part having been removed by erosion. The unit consists of about 550 feet of dark shale and massive dark-gray lenticular sandstone as much as 200 feet thick. Carbonized and silicified logs, limonite-replaced stumps in place, and iron-cemented sandstone concretions 6 inches to 3 feet in diameter are abundant. Lenticular beds of lignite and carbonaceous shale that generally range from 6 inches to 2½ feet in thickness occur in the upper 200 feet of the unit; the lower 350 feet contains 2 or more persistent lignite beds 3 to 6 feet thick.

### STRUCTURE

The Little Missouri River escarpment area is on the northeast flank of the Cedar Creek anticline, a long narrow asymmetrical fold trending northwest through the southwest corner of North Dakota. On the east flank of the fold the surface rocks dip northeast at an average rate of about 20 to 25 feet per mile toward the center of the Williston basin. Superimposed upon this large

[3] Because of buying policies of the Atomic Energy Comm. in the period 1952–62, material of economic interest is arbitrarily defined as material containing greater than 0.1 percent uranium.

fold is the Fryburg anticline, a northwest-trending fold about 2½ miles long and 1½ miles wide that does not greatly affect the neary horizontal attitude of the surface rocks.

Small anticlinal noses and gentle folds trending to the northeast have been noted at a few places in the area by Caldwell (1954) and Hanson (1955).

#### URANIUM OCCURRENCES

Along the Little Missouri River escarpment important deposits of uraniferous lignite and carbonaceous shale are present only in the upper 200 feet of the Sentinel Butte Member of the Fort Union Formation. Older lignite beds are weakly uraniferous or are not radioactive. The important mineralized beds are about 350 to 400 feet above the base of the Sentinel Butte Member and 2,000 to 2,100 feet above the top of the Pierre Shale. The deposits occur principally in the vicinity of Rocky Ridge, T. 137 N., R. 100 W., and near Saddle Butte, T. 141 N., R. 99 W. Correlation of the lignites between Saddle Butte and Rocky Ridge is uncertain, but the available subsurface data indicate that the occurences at Saddle Butte may be 100 feet or more stratigraphically higher than those farther south at Rocky Ridge.

The mineralized beds of lignite and other carbonaceous materials in the Little Missouri River escarpment area range mostly from 6 inches to 2½ feet in thickness, and at many localities contain 0.1 percent or more uranium (pls. 8 and 9). These beds, which are characterized by their high moisture content and low heating values, have an average ash content of about 35 percent. Limonite, jarosite, and gypsum are common impurities.

As indicated on plate 9, localities 4, 5, 6A, and 6B, the uranium content of the mineralized beds differs markedly from place to place, and, as in other areas in the Williston basin, appears to be influenced by the permeability and thickness of the beds that directly overlie the host rocks. Where thick beds of permeable sandstone directly overlie the carbonaceous host rocks, the uranium content is much greater than where the same bed of lignite or carbonaceous shale is overlain by clay or shale beds of relatively low permeability.

Blanket-type deposits containing in excess of 150,000 tons of uraniferous lignite and carbonaceous shale in the area have been discussed by Towse (1957, p. 908), who described one such deposit as follows: thickness, 1.78 feet; average assay, 0.15 percent $U_3O_8$; and overburden, 5 to 22 feet. According to Towse (1957, p. 909), lenticular deposits are more common and may be of any size containing from only a few hundred pounds of ore to as much as 1,500 tons. He reported this type of deposit as containing higher grade material than found in blanket deposits. Uranium Magazine (1958, p. 13 and 26) reported that in the western Dakotas about 900,000 tons of proved reserves have been established, about half of which are in the Little Missouri River escarpment area.

Plate 8 (this report) and table 10 (Denson and Gill, 1965d) show the thickness and uranium and ash contents of carbonaceous beds at selected localities from which samples were analyzed. Localities at which nineteen 150- to 700-pound samples were collected by the Atomic Energy Commission for chemical analyses and metallurgical studies are shown on plate 9. Analyses of 10 of these large samples (see pl. 9) indicate an average content of 0.18 percent uranium, 0.3 percent molybdenum, 0.09 percent phosphorus, and 0.01 percent vanadium. Table 5 shows the average content of some other elements in the ash of these samples.

## LITTLE BADLANDS

### LOCATION AND ACCESSIBILITY

The Little Badlands in southwestern North Dakota lie in the southwestern part of Stark County (pl. 10), principally in Tps. 137 and 138 N., Rs. 97 and 98 W.,

TABLE 5—*Chemical analyses, in percent, showing average amounts of selected elements in the ash samples of uranium-bearing lignite and carbonaceous shale from Williston basin*

[Analyses of samples from the Sentinel Butte Member of Fort Union Formation by National Lead Co., Inc., Raw Materials Development Laboratory, Winchester, Mass., for the Atomic Energy Commission; analyses of samples from the Ludlow Member of Fort Union Formation by A. M. Sherwood, U.S. Geol. Survey]

| Stratigraphic unit from which samples were collected | Area sampled (see fig. 1) | Samples analyzed | Ash | Uranium in unashed samples | Uranium in ashed samples | Elements [1] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Silicon | Aluminum | Iron | Calcium | Sodium | Potassium | Magnesium | Titanium | Molybdenum | Vanadium | Phosphorus | Manganese |
| Sentinel Butte Member; beds 1,500 ft above base of Fort Union Formation. | Little Missouri River escarpment, North Dakota. | 10 | 46 | 0.18 | 0.38 | 19 | 8 | 12 | [2] 5 | 1.5 | (3) | 2 | (3) | 0.69 | 0.025 | 0.19 | (3) |
| Ludlow Member; beds 200-500 ft above base of Fort Union Formation. | Cave Hills and Slim Buttes, S. Dak. | 6 | 26 | .02 | .07 | 9 | 10 | 17 | 9 | 5 | 0.9 | .8 | 0.16 | (3) | (3) | (3) | 0.28 |

[1] Converted from reported oxides. (See pl. 9 and Deul and Annell, 1956, table 3.)
[2] Includes potassium.
[3] Not determined.

and cover about 150 square miles of rolling farmland and badlands of low relief on the drainage divide between the southeastward-flowing Heart River on the north and the North Fork of the Cannonball River on the south. U.S. Highway 10 and the Northern Pacific Railway pass about 3 miles north of the area, and State Highway 22 crosses the eastern margin of the area. Many dirt and graveled roads provide easy access to most places in the area.

### EARLIER INVESTIGATIONS

Investigations for uranium in the Little Badlands area had not been systematically undertaken prior to 1955. Consequently, earlier published references concern largely the stratigraphy and structure of the region and some detailed descriptions of the lignite and clay deposits (Caldwell, 1954; Leonard and others, 1925, p. 140–146; Babcock and Clapp, 1906).

### STRATIGRAPHY

The rocks exposed in the Little Badlands comprise about 350 feet of coal-bearing rocks of Paleocene and Eocene age unconformably overlain by 250 feet or more of tuffaceous rocks of Oligocene and Miocene age. Caldwell (1954) assigned the upper 190 feet of the coal-bearing rocks exposed in the area to the Golden Valley Formation (Eocene) (fig. 18) and included the lower part of the sequence in the Fort Union Formation (Paleocene). A study of surface and subsurface data indicates that these units have a combined average thickness of about 1,600 feet in the vicinity of the Little Badlands. These stratigraphic units were not differentiated by the writers because they are not readily recognizable as separate mappable units. The middle and upper Tertiary tuffaceous rocks are assigned on the basis of lithologic similarities and fossil evidence to the Chadron and Brule Formations of the White River


FIGURE 18.—Golden Valley Formation (Eocene) unconformably overlain by bentonite and arkose in the lower part of the Chadron Formation (Oligocene) in the NE¼ sec. 22, T. 138 N., R. 98 W., Little Badlands, Stark County, N. Dak.

Group (Oligocene) and to the unconformably overlying Arikaree Formation (Miocene).

A general description of the lignite-bearing rocks and their relation to the unconformably overlying tuffaceous sequence can be found in Caldwell (1954) and Skinner (1951). The areal distribution of the middle and upper Tertiary rocks in the Little Badlands and their correlation with equivalent rocks in southwestern North Dakota are shown on plates 3 and 10. (Rock samples collected from the various stratigraphic units and the results of laboratory determinations are shown in tables 2 and 22 of Denson and Gill (1965a, 1965c).)

#### STRUCTURE

Data from oil and gas test wells drilled in the western parts of North and South Dakota and eastern Montana indicate that the Little Badlands occupy one of the structurally lowest points in the south-central part of the Williston basin (pls. 5*H* and 10). The lignite-bearing rocks in the Little Badlands have a regional northeastward dip of about 20 to 30 feet per mile toward the center of the basin. The axis of the basin, as determined by elevations on top of the Pierre Shale, trends north-northwest and passes near Dickinson about 5 miles northeast of the area.

Superimposed upon this regional dip is a series of shallow folds which trend at nearly right angles to the regional strike (pls. 5*H* and 10). These folds, inasmuch as they affect middle and upper Tertiary rocks, are younger than the Black Hills uplift and the Cedar Creek anticline, which are considered by most workers to have been folded during Late Cretaceous and early Eocene time. The Chadron and Brule Formations are of relatively uniform thickness throughout the area; therefore, the low northeast-trending folds in the Little Badlands are probably tectonic in origin rather than the result of compaction over topographic highs. These folds were produced by forces unlike those active in the basin during most of geologic time. They trend northeastward in marked contrast to most of the Laramide and earlier structural features that trend northwestward. (See pls. 5*G* and *H*.)

Faults of major displacement were not observed in the area, although faults having stratigraphic displacements of 30 to 40 feet were mapped in secs. 28 and 29, T. 138 N., R. 97 W. These faults displace rocks of Oligocene and Miocene age and may represent recurrent movements along older faults, which in the subsurface may have much greater stratigraphic displacements.

#### URANIUM OCCURRENCES

The Little Badlands area is difficult to appraise because of poor exposures. Uranium occurs in relatively large amounts in ground water from the Chadron and Brule Formations, and shallow synclines are present similar to ones that in the Slim Buttes and Cave Hills areas seem to have been important in channeling the flow of uraniferous ground water to sites of uranium deposition. Although these and some other geologic relations appear favorable for the occurrence of uranium, deposits of commercial interest were not discovered. A general absence of carbonaceous material in the rocks directly underlying the Chadron and Brule Formations is perhaps an important factor in the absence of deposits.

Uranium occurs in small amounts at two localities in the Little Badlands: (1) in the NW¼NW¼ sec. 31, T. 139 N., R. 97 W., where a channel sample of a 0.5-foot-thick bed of lignite contains 6 percent ash and 0.09 percent uranium, and (2) NE¼NW¼ sec. 28, T. 138 N., R. 98 W., where carnotite identified by X-ray methods coats joint planes in massive beds of tuffaceous claystone in the upper part of the Chadron Formation.

#### ANALYSES OF WATER SAMPLES

Eleven samples of ground water from the Little Badlands were analyzed for uranium, and one large sample was analyzed for selected trace elements. (See table 9, this report, and table 11 (Denson and Gill, 1965d).) The most uranium was found in water draining the Chadron and Brule Formations. Six samples from these units showed a uranium content from 13 to 19 ppb (parts per billion), whereas four samples from the underlying Fort Union and Golden Valley Formations, undifferentiated, showed an average uranium content of 2 ppb. All the samples showed high alkalinity, those from the tuff having an average pH of about 8.6 and those from underlying rocks about 8.1.

A summary of the analyses of the water samples collected in the Little Badlands, as well as from other areas, is shown on p. 57.

### CHALKY BUTTES AREA

#### LOCATION AND ACCESSIBILITY

The Chalky Buttes area is in T. 134 N., R. 101 W., near the south-central part of Slope County, N. Dak. (pl. 11). Chalky Buttes, which has an altitude of about 3,530 feet is the highest point in North Dakota. The buttes and nearby H T and Slide Buttes comprise an area of about 15 square miles, the northern end of which is about 4 miles south of Amidon. U.S. Highway 85 parallels the area about half a mile to the west. The nearest railroad is the Chicago, Milwaukee, St. Paul and Pacific, which serves Bowman, 12 miles south of the area.

### EARLIER INVESTIGATIONS

Uranium occurrences at Chalky Buttes and at Slide and H T Buttes adjacent on the west were discovered by Wyant and Beroni (1950, p. 15). They were mapped and described by Moore, Melin, and Kepferle (1959). The present report summarizes the results of their work and provides supplemental data on the stratigraphic relationships of the middle and upper Tertiary units and on the configuration of pre-Oligocene erosion surface. Water analyses and structural data provide leads for prospecting for deposits of possible commercial interest.

### STRATIGRAPHY

The rocks exposed at Chalky, H T, and Slide Buttes are of continental origin. They have an average combined thickness of about 850 feet and are subdivided into two major groups—a lignite-bearing sequence 500 feet or more thick consisting of the Tongue River and Sentinel Butte Members of the Fort Union Formation of Paleocene age, and an overlying tuffaceous sequence about 350 feet thick assigned to the Chadron (lower Oligocene), Brule (middle and upper Oligocene), and Arikaree (Miocene) Formations. Plate 3 shows stratigraphic sections of the tuffaceous rocks which unconformably overlie the Sentinel Butte Member on Slide and Chalky Buttes.

#### TERTIARY ROCKS

##### Fort Union Formation (Paleocene)

*Tongue River Member.*—The Tongue River Member of the Fort Union Formation, the oldest unit exposed in the area, is about 650 feet thick but only the upper part of the member is exposed at Chalky Buttes. The unit is composed primarily of light-colored sandy shale, limy sandstone, and thick persistent beds of lignite. Thin lenticular beds of quartzite (Hares, 1928, p. 34) and fresh-water limestone occur locally. The contact between the Tongue River Member and the overlying Sentinel Butte Member is placed arbitrarily at the top of the H T lignite bed. This bed has wide areal extent and has been mapped as the contact between the Tongue River and Sentinel Butte Members in other areas in southwestern North Dakota (Leonard and Smith, 1909; Hares, 1928; Kepferle and Culbertson, 1955; Moore and others, 1959). The beds of lignite and associated carbonaceous rocks in the Tongue River Member in the Chalky Buttes area are nonradioactive and were not studied in detail.

*Sentinel Butte Member.*—The Sentinel Butte Member of the Fort Union Formation is the youngest lignite-bearing unit in the area and consists of 170 to 340 feet of dark-colored sandy shale, claystone, siltstone, and fine-grained sandstone. These beds are truncated by the unconformity at the base of the overlying Chadron Formation and represent only the lower part of the Sentinel Butte Member of other areas. Two beds of lignite and carbonaceous shale referred to as the Chalky Buttes lignite bed and Slide Butte lignite bed (Moore and others, 1959, p. 154) occur about 90 and 160 feet, respectively, above the base of the Sentinel Butte Member. The Chalky Buttes bed ranges in thickness from 0.5 to 4 feet and averages 2 feet. The Slide Butte bed has a maximum thickness of 7 feet and averages about 2 feet. These beds contain the only known occurrences of uranium in the area.

##### Chadron Formation (lower Oligocene)

At Chalky Buttes the Chadron Formation of early Oligocene age has a maximum thickness of about 185 feet and is composed of a basal conglomeratic arkose containing rounded pebbles, 2 to 3 inches in diameter, of igneous rocks and of an upper fine-grained unit of bentonite, claystone, and sandstone interbedded with thin lenticular beds of fresh-water limestone. A persistent bed of hard white silicified sandy bentonite, 2 to 5 feet thick, marks the contact between the basal coarse-grained unit and the overlying fine-grained unit. The contact with the overlying Brule Formation is placed at the top of the stratigraphically highest limestone.

The basal coarse-grained unit ranges in thickness from a few feet on Slide Butte to about 100 feet at Chalky Buttes. An area including H T Butte appears to have been topographically high during Oligocene time for there the basal clastic unit is absent and the white sandy silicified bentonite of the Chadron rests directly on the thick massive Fort Union Sandstone near the top of the butte. The basal clastic unit appears to be thickest where it fills depressions that may represent pre-Oligocene stream channels.

Fossils were not found in the Chadron Formation in the Chalky Buttes area, but lithologic similarity to rocks containing early Oligocene fossils in other areas makes correlation with the Chadron Formation reasonably certain.

##### Brule Formation (middle and upper Oligocene)

The Brule Formation of middle and late Oligocene age is thin and only locally present at Chalky Buttes. Uplift and erosion of the Brule prior to deposition of the Arikaree Formation of Miocene age removed most of the upper Oligocene rocks from the area. The Brule Formation is 12 to 65 feet thick and composed of massive nodular pinkish-gray calcareous claystone, siltstone, and sandstone. A fauna of late Oligocene age was collected in 1953 by J. R. Gill and R. C. Kepferle from the formation in the NE¼SW¼ sec. 31, T. 134 N., R. 100 W. (Kepferle and Culbertson, 1955, p. 136).

#### Arikaree Formation (Miocene)

The Arikaree Formation of Miocene age unconformably overlies the Brule Formation at Chalky Buttes. Erosion remnants capping the buttes indicate that the formation had a minimum thickness of about 135 feet and probably was much thicker prior to dissection and removal during the present cycle of erosion. The Arikaree is principally yellowish-green to gray fine- to coarse-grained tuffaceous sandstone, and contains several 2- to 4-foot thick beds of conglomerate at or near the base. Some of the conglomerate beds contain pebbles, 1 to 2 inches in diameter, of tan calcareous siltstone and claystone and waterworn bone fragments from the underlying Brule Formation, and thus are similar to conglomerate beds at the base of the Arikaree Formation at the Slim Buttes, Harding County, S. Dak. (See fig. 10.) Other conglomerate beds contain rounded pebbles, 2 to 3 inches in diameter, of igneous rocks derived from the basal conglomeratic unit of the Chadron, as well as waterworn red fragments of clinker that resulted from the burning of lignite beds in the Fort Union Formation. Rock materials in these conglomerate beds indicate that uplift and erosion prior to deposition of Miocene rocks were of sufficient magnitude to remove from nearby areas several hundred feet of Oligocene strata and an unknown thickness of beds of the Fort Union Formation. Presence of fragile clinker fragments in rocks at the base of the Miocene indicates that the present-day phenomenon of burning coal beds also took place in the geologic past. Hard, dense residual blocks of cherty dolomitic limestone and sandstone from preexisting beds higher in the formation cover most of the higher areas on the butte. The cherty fragments are similar to cherty rocks in the Arikaree in the Killdeer Mountains in Dunn County, N. Dak.

The authors did not find identifiable fossils in the Arikaree Formation at Chalky Buttes. Assignment of these rocks to the Miocene is based on the unconformable relation to the underlying Brule and to their lithologic similarity to the Arikaree Formation at Slim Buttes and the Killdeer Mountains. Vertebrate fossils recently have been collected from this unit by Jean Hough at Chalky Buttes (written commun., July 31, 1959) but have not been identified.

### STRUCTURE

The Fort Union Formation at Chalky Buttes dips northeastward into the Williston basin at about 20 to 25 feet per mile. (See pls. 5*H* and 11.) The Oligocene and older rocks in the southwestern part of Chalky Buttes are slightly folded into a gentle southeastward-plunging syncline about 3 miles long and a mile wide; in the rest of the area the Oligocene and Miocene rocks are virtually horizontal.

### URANIUM-BEARING LIGNITE

Outcrops of uranium-bearing lignite beds in the Chalky Buttes area are shown on the geologic map (pl. 11). Representative sections adapted from Moore, Melin, and Kepferle (1959) showing variation in thicknesses of these beds and their uranium contents are given on figure 19 (this report) and in table 12 of Denson and Gill (1965d). The carbonaceous beds average 2 feet in thickness and have an average ash content of about 30 percent. Their average uranium content is about 0.017 percent in the mineralized area; apparently the uranium content is highest where permeable rocks directly overlie the deposits. Approximately 7 square miles at Chalky Buttes are estimated to be underlain by 15,400,000 tons of uranium-bearing lignite (Moore and others, 1959, p. 161). This estimate is based on 35 measured sections from which 82 samples were analyzed for uranium. About 80 percent of the mineralized rock is overlain by less than 300 feet of overburden.

Uranium reserves in the Chalky Buttes area were not of commercial interest in 1960. Higher grade deposits might occur in the southeastern part of the area along the axis of a shallow syncline, where the circulation of uraniferous ground water may have been greater.

### ANALYSES OF WATER SAMPLES

Fifteen samples of ground water from wells and springs from the Chalky Buttes area were analyzed for uranium as shown in table 13 (Denson and Gill, 1965d). (See also pl. 11.) Ten samples from wells and springs in the Fort Union Formation 100 feet or more in elevation below the base of the Chadron Formation contain from 1 to 10 ppb uranium; five samples contain 27 to 55 ppb uranium. At these localities ground water may be draining areas where further prospecting for higher grade uranium occurences might be profitable.

One water sample collected from the Chadron Formation at Chalky Buttes contains 29 ppb uranium. Analyses of ground water from the Chadron and overlying Arikaree Formations in other areas show similarly high uranium contents. (See also p. 57.)

## SLIM BUTTES

### LOCATION AND ACCESSIBILITY

Slim Buttes is in Tps. 16 to 19 N., Rs. 7 to 9 E., in the southeastern part of Harding County, northwestern South Dakota (pl. 12). State Highway 8 crosses the

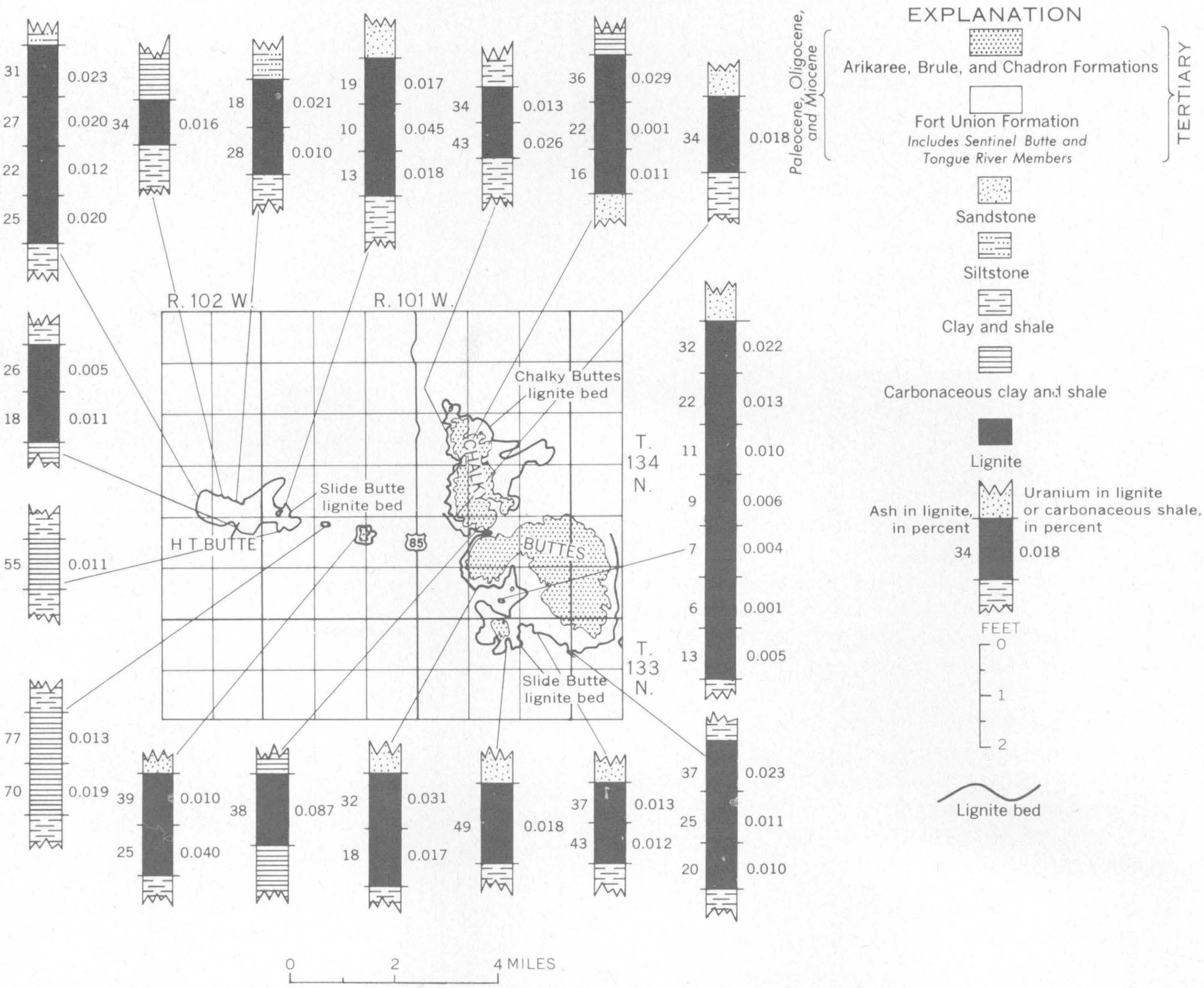


**FIGURE 19.**—Uranium occurrences in the Chalky Buttes area, Slope County, N. Dak. Stratigraphic and analytical data from Moore, Melin, and Kepferle (1959).

north end of the buttes in Reva Gap 21 miles east of Buffalo and 36 miles west of Bison, the county seats of Harding and Perkins Counties, respectively. Newell, about 60 miles south of the buttes, is the nearest railroad shipping point. A graded county road connecting U.S. Highway 212 at Newell with State Highway 8 about 5 miles east of Reva Gap crosses the south end of the buttes at Cedar Pass. Most of the buttes lie within the Custer National Forest and are accessible by dirt roads or trails maintained by local ranchers or by the U.S. Forest Service.

### EARLIER INVESTIGATIONS

Reports by N. H. Winchell (1875) of lignite in northwestern South Dakota provided stimulus for a brief examination by Todd in 1894 of the lignite deposits of the area (Todd, 1896). A detailed appraisal of the lignite resources of northwestern South Dakota, including the Slim Buttes area, was made by Winchester and others (1916). The discovery that some of the lignite beds at Slim Buttes contain appreciable quantities of uranium was made in October 1949, in sec. 8, T. 18 N., R. 8 E., by E. P. Beroni and H. L. Bauer, Jr., during a reconnaissance investigation of the lignite deposits of Paleocene age in eastern Montana, northern Wyoming, and northwestern South Dakota (Beroni and Bauer, 1952, p. 6, 9, and 75).

Since the initial discovery of uranium in this area, examination for radioactive materials, coal-resource appraisals, and appraisal of the oil and gas possibilities has been carried on by many investigators. Private organizations and individuals, under contract to the Atomic Energy Commission, have investigated the following: Mineralogy, petrography, and paleobotany of the uranium-bearing lignite deposits of this area; beneficiation of uranium; and recovery methods for the deposits. The results of some of these investigations are described in published reports by Baker (1952), Gill and Moore (1955), Curtiss (1955), Petsch (1954, 1955a and 1955b), Schopf and Gray (1954), King and Young (1956), Burton (1955), Gill and Denson in U.S. Geological Survey (1955a, p. 233–240; 1956a, p. 235–243; 1957b, p. 160–171; 1958, p. 188–201), Denson, Bachman, and Zeller (1955, 1959), Zeller and Schopf (1959), Gill, Zeller, and Schopf (1959), and White (1958).

### STRATIGRAPHY

Rocks exposed in the Slim Buttes range in age from Late Cretaceous to Recent. All the rocks are continental in origin. Two periods of uplift and erosion are indicated by unconformities at the base of Oligocene rocks and at the base of Miocene rocks. The unconformity at the base of the Oligocene rocks possibly represents the longer and more intense period of uplift and erosion during which time about 1,300 feet of rocks was removed from the area. At Slim Buttes this surface has a relief of about 100 feet locally and is characterized by an average slope of about 15 feet per mile to the northeast. The second period of uplift and erosion resulted in a mature surface of low relief on the Oligocene rocks prior to the deposition of Miocene strata. During the formation of this surface as much as 300 feet of strata of the Chadron and Brule Formations was removed from the area.

#### CRETACEOUS ROCKS

##### Hell Creek Formation

The Hell Creek Formation of Late Cretaceous age conformably overlies the marine Fox Hills Sandstone and underlies the lignite-bearing Ludlow Member of the Fort Union Formation (Paleocene). At Slim Buttes it is the oldest formation exposed and has an average thickness of about 550 feet. The formation crops out extensively along the southern and western margins of the buttes but is below the ground surface in the eastern and northeastern parts of the area because of the gentle regional northeastward dip.

The formation is composed predominantly of drab somber bentonitic silty shale and claystone and lenticular beds of medium-grained sandstone of fluviatile and possibly brackish-water origin.

Along the north fork of the Moreau River, 3 miles south of the mapped area, the Hell Creek Formation rests conformably on the Fox Hills Sandstone at an elevation of about 2,750 feet (Baker, 1952, p. 37). The contact of the Hell Creek and overlying Ludlow Member of the Fort Union Formation is well exposed near the center of T. 16 N., R. 8 E., in the vicinity of Cedar Pass, but at most places in the area it is obscured by extensive landslides and slumping. At Cedar Pass the boundary between the Hell Creek and Fort Union Formations is drawn at the base of a persistent bed of lignite (elev 3,250 ft).

#### TERTIARY ROCKS

##### Fort Union Formation (Paleocene)

The Ludlow Member of the Fort Union Formation ranges in thickness from less than 100 feet in the southern part of Slim Buttes to more than 350 feet in the vicinity of Reva Gap (sec. 1, T. 18 N. R. 7 E.). It is the oldest member of the Fort Union Formation and is the only recognizable unit of Paleocene age in the area. At Slim Buttes the Ludlow Member conformably overlies the Hell Creek Formation and is unconformably overlain by the Chadron Formation of Oligocene age except in isolated areas where pre-Miocene erosion has removed all Oligocene rocks, and the Arikaree Formation of Miocene age unconformably overlies the Ludlow Member.

Rocks of the Ludlow Member include poorly indurated yellowish-brown fine-grained sandstone and siltstone, gray clay shale, and lignite. These rocks are covered at most places along the margins of the buttes, but core-hole data (Gill and others, 1959) indicate that they are persistent for at least several miles.

Directly below the pre-Oligocene erosion surface the rocks of the Ludlow Member and Hell Creek Formation are varicolored and contrast sharply in color with both underlying and overlying beds. The altered rocks generally range from a few to about 50 feet in thickness and are most highly altered adjacent to topographic highs on the pre-Oligocene erosion surface. They consist principally of bright-yellow, orange, and pink claystones and siltstones. The fact that the varicolored beds grade downward into beds of normal color suggests the coloration resulted from extensive weathering during Eocene time. Dr. John Clark (written commun., Feb. 16, 1959) of the South Dakota School of Mines and Technology collected vertebrate fossils that he tentatively identifies as Eocene in age from this weathered zone in the southern part of Slim Buttes. Whether these fossils are from a stratigraphic unit heretofore not recognized that rests unconformably between the Ludlow Member and the Chadron, or whether they are from lag constituents that were deposited on the pre-Oligocene erosion surface from a preexisting Eocene unit is not known.

##### Quality of the lignite

Lignite from the Slim Buttes is dark brown to black and is dull on a fresh surface. On exposure to air the lignite loses moisture and slacks within a short time. Weathering also results in a change in luster from dull to vitreous. These coals are similar to the lignites mined in North Dakota for fuel and are petrologically classified as banded lignite. They contain an abundance of thick woody bands (anthraxylon), which have been chiefly derived from gymnospermous wood of a moderately resinous type (J. M. Schopf and R. J. Gray, written commun., 1956). The following data, adapted from Schopf and Gray (1954, p. 3), show that samples from Slim Buttes and from several mines in North Dakota are very similar in composition, though a comparison of Standard Coal Analyses shows that the North Dakota coals have a slightly lower ash content and higher heating value (Btu) and volatile-matter and fixed-carbon contents. The higher heating value is apparently due to an increase in rank and not to differences in physical composition.

*Composition, in percent, of Slim Buttes lignite beds and some lignite mined in North Dakota*[1]

| Source | Anthraxylon | Translucent attritus | Opaque attritus | Fusain |
|---|---|---|---|---|
| **Uraniferous lignite of Slim Buttes** | | | | |
| Core hole GS-16, SE¼NW¼ sec. 31, T. 18 N., R. 8 E.: Mendenhall "rider" | 53 | 17 | 24 | 3 |
| Core hole SD-10, NE¼SE¼ sec. 12, T. 17 N., R. 7 E.: Top split of Olesrud bed, upper bench | 50 | 32 | 7 | 11 |
| Core hole SD-10, NE¼SE¼ sec. 12, T. 17 N., R7 E.: Bottom split of Olesrud bed, upper bench | 75 | 23 | 1 | 1 |
| Core hole SD-10, NE¼SE¼ sec. 12, T. 17 N., 7 E.: Olesrud bed, lower bench | 56 | 31 | 6 | 7 |
| Average | 59.0 | 26.0 | 9.5 | 5.5 |
| **Lignite mined in North Dakota** | | | | |
| Burleigh lignite | 63 | 31 | 5 | 1 |
| Lehigh lignite | 59 | 36 | 3 | 2 |
| Beulah lignite | 53 | 25 | 15 | 6 |
| Baukel-Noonan lignite | 56 | 33 | 4 | 7 |
| Average | 58.0 | 31.0 | 7.0 | 4.0 |

[1] Modified from Schopf and Gray (1954, p. 3).

*Standard coal analyses,*[1] *in percent, of lignite in the Slim Buttes and some lignite mined in North Dakota*[2]

| | Moisture | Volatile matter | Fixed carbon | Ash | Btu |
|---|---|---|---|---|---|
| Slim Buttes lignites: 127 samples from core holes | 35.9 | 23.8 | 25.8 | 14.5 | 5,800 |
| North Dakota lignites: 39 samples | 37.7 | 27.3 | 28.0 | 7.0 | 6,590 |

[1] As-received basis, proximate analysis.
[2] From Brant (1953, p. 5, table 3).

**White River Group (Oligocene)**

The White River Group of Oligocene age is divided into the Chadron and overlying Brule Formations. The Chadron Formation is present throughout most of the Slim Buttes, but the Brule Formation is preserved only in fossil landslides.

*Chadron Formation.*—The Chadron consists of a basal clastic unit, 5 feet to at least 100 feet thick, which is composed principally of poorly cemented white coarse-grained arkose and conglomerate overlain by an upper unit, 10 to 75 feet thick, of bentonite, fine-grained tuffaceous sandstone, and siltstone. The base of the Chadron is difficult to identify exactly at a few places because it contains reworked materials derived from the underlying rocks. The bentonite in the upper finer grained unit of the Chadron is in beds locally more than 20 feet thick. On fresh surfaces the bentonite is light olive gray but weathers dark gray or grayish black and in outcrops has a loosely compacted granular texture like cornmeal. The bentonite contains bluish-gray barite nodules, gray translucent chalcedony pseudomorphs after barite, and concretions of fibrous aragonite 2 to 3 inches in diameter. Lenticular beds of silicified tuffaceous sandstone and opalized clay are present locally.

A perched water table formed by the impervious beds of bentonite in the upper part of the Chadron is present at Slim Buttes. The base of the water-saturated rocks is marked by springs and seeps along the margins of the buttes at the top of these impervious beds. In the southern part of the Slim Buttes at Cedar Pass, carnotite-bearing sandstone occurs at the approximate stratigraphic position of the springs and seeps (Gill and Moore, 1955).

Fossils are not abundant in rocks of the Chadron Formation at the Slim Buttes, and only a few fossil vertebrate fragments were found. Rocks of similar lithology capping the South Cave Hills in north-central Harding County yielded a few fossil fragments of early Oligocene age.

*Brule Formation.*—The Brule Formation is composed of flesh-colored thin-bedded to massive nodular claystone, tuffaceous siltstone, and sandstone that are well indurated and contrast sharply with the poorly cemented arkose, and bentonite in the underlying Chadron Formation. The Brule Formation ranges in thickness from 0 to more than 150 feet; an unknown additional amount has been removed by pre-Arikaree erosion. At Slim Buttes the Brule is preserved only in fossil landslide blocks and is unconformably overlain by nearly horizontal beds of the Arikaree Formation (Miocene) (fig. 7).

The Brule Formation is abundantly fossiliferous. Numerous skulls, jawbones, and teeth collected from the unit in pre-Arikaree landslide blocks have been identified by Jean Hough (written commun., 1952 and 1953) as follows:

*Paleolagus haydeni* Leidy
*Eumys elegans* Leidy
*Ischyromys typus* Leidy

*Leptomeryx evansi* Leidy
L. sp.
*Pseudocynodictis* sp.
*Merycoidodon culbertsoni* Leidy
M. *gracilis* (Leidy)
*Mesohippus bairdi* (Leidy)
*Titanotheriomys* sp.
*Hyracodon nebraskensis* Leidy
Rhinoceros jaw fragments
Turtle

J. B. Reeside, Jr. (written commun., July 27, 1953), identified gastropods from the landslide blocks as *Helix leidyi*. Other collections were made from Brule rocks in the Slim Buttes and were identified by G. E. Lewis (written commun., 1957) as follows:

*Stibarus* cf. S. *obtusilobus* Cope
?*Megalagus* sp.
*Ischyromys* cf. *I. typus* Leidy

Jean Hough and G. E. Lewis assigned the fauna to the middle Oligocene and noted similarities to faunas of the Orella Member (Schultz and Stout, 1938; see also Schultz and Stout, 1955, p. 41–44) in the Brule Formation of Nebraska and of the lower part of the Brule in the Big Badlands of southern South Dakota.

#### Arikaree Formation (Miocene)

The Arikaree Formation of Miocene age is composed of fluviatile and eolian deposits of yellowish-gray very fine grained tuffaceous sandstone and siltstone containing abundant volcanic material. Several thin beds of crossbedded coarse-grained sandstone occur about 120 feet above the base of the formation. Earlier workers have placed the contact between the Arikaree and Brule at the base of these sandstone beds (Petsch, 1955a). In contrast with the more massive upper part, the basal 30 feet of the formation contains some material reworked from the underlying Brule and Chadron formations and is thin bedded.

The Arikaree locally contains lenses of pebble-and-cobble conglomerate consisting of limy claystone, siltstone, and abundant reworked fragments of vertebrate fossils. (See fig. 10.) The fragments average 2 inches in diameter. The conglomerate, including the fossils, was derived from the Brule and Chadron Formations. The conglomerate lenses are most abundant, thickest, and most extensive in areas adjacent to the pre-Arikaree landslide blocks and are seldom found overlying them.

Tuffaceous sandstone of the Arikaree forms the cap rock and the steep upper cliffs of the Slim Buttes. The formation ranges in thickness from 200 feet at the extreme southeast corner of the buttes to 320 feet near Cedar Pass and 290 feet in the Bar H area north of Reva Gap. The average thickness is about 225 feet. The upper surface has a slight slope to the east of 30 feet per mile. This nearly flat surface is independent of variation in thickness and structure, and represents an erosion surface possibly Pliocene in age.

The Arikaree Formation forms bare, almost vertical cliffs along the west and south sides of the buttes and vegetated moderate to steep slopes on the east side. Erosion by slumping and rockfall causes the west face of the buttes to retreat so rapidly that breaching of the cliff face and formation of major westward-draining canyons are prevented.

Fossils were not found in the Arikaree Formation in the Slim Buttes. The formation closely resembles fossiliferous beds of the Arikaree in the Ekalaka Hills, Carter County, Mont.

### QUATERNARY ROCKS

Deposits of probable Pliocene or Pleistocene age occur as alluvial fans and pediments at the bases of cliffs and as terraces along many of the stream valleys. The terraces are composed of silt, sand, and gravel derived dominantly from Oligocene and Miocene rocks. The pediments at places have been deeply dissected by recent erosion (fig. 14).

Landsliding was extensive around the northern (fig. 15), western, and southern margins of the Slim Buttes during Pleistocene and early Recent time. Blocks and masses of the Arikaree and some White River and older rocks are displaced at some places more than a mile from cliff faces. Material from landslides and rockfalls disintegrates rapidly into small fragments and is quickly removed by streams. On the north, south, and west sides of Slim Buttes, landslide material obscures the bedrock for long distances. Slower erosion, primarily headward action by streams unaided by slumping and rockfall, caused the formation of long, shallow eastward-draining canyons on the east side of the buttes. Intersection of landslides and rockfalls on the west with headward erosion by streams on the east has formed three access routes across the Slim Buttes; they are Reva Gap, J. B. Pass, and Cedar Pass.

### STRUCTURE

The Slim Buttes are on the southwestern flank of the Williston basin 150 miles northeast of the center of the Black Hills uplift. The beds in general strike about N. 50° W. and dip northeastward at about 25 feet per mile into the basin. Superimposed on the gentle northeasterly dip is a series of gentle anticlines and synclines that strike about N. 60° W. and plunge at the rate of 25 feet per mile to the southeast.

Several faults have been described by earlier workers in the Slim Buttes area (Todd, 1895; Winchester and others, 1916, p. 36–38; Baker, 1952, p. 31–32; and Petsch, 1954, 1955b), but in this report the features are interpreted to be the soles of fossil landslide blocks and not as being related to tectonic activity.

### URANIUM OCCURRENCES

#### URANIUM-BEARING LIGNITE AND CARBONACEOUS SHALE

Uranium-bearing lignite occurs at Slim Buttes in the Ludlow Member of the Fort Union Formation of Paleocene age. In the southern part of the buttes in the vicinity of Cedar Canyon the mineralized beds crop out near the base of the Ludlow Member; in the northern part of the buttes in the vicinity of the Bar H mine the mineralized beds crop out near the top of the member. Low-grade deposits containing 0.005 to 0.02 percent uranium, with concentrations of 0.05 to 0.1 percent in the ash, are extensive in the Slim Buttes and generally underlie the entire buttes. In the northern part of the buttes at least 8 beds of lignite 1 foot to more than 14 feet thick occur; however, the Fort Union Formation is truncated beneath Oligocene rocks with the result that at the southern end of the buttes three thin beds of lignite ranging in thickness from 0.5 to 2.4 feet are present. These beds crop out sporadically along the base of Slim Buttes. The continuity, however, of individual beds from one exposure to the next is difficult to establish because of a heavy mantle of talus and landslide debris along the precipitous cliffs at the sides of the buttes. Adding to the difficulty of correlation is the lenticularity of the beds, which vary considerably in thickness and may diverge or converge within short distances. The central and northern parts of Slim Buttes were core drilled for data on uranium-bearing lignite by the U.S. Bureau of Mines and the U.S. Geological Survey during the summers of 1951 and 1952 and during the period October 1952 to July 1953.

Results of core drilling in the Mendenhall area (9 sq mi), located in the central part of the Slim Buttes, indicate a coal reserve of 127 million tons in beds 3 to 12 feet thick. Core and auger hole data supplemented by several hundred surface measurements along the flanks of the buttes indicate a possible lignite reserve of about 425 million tons in beds 2½ feet or more thick. Included in these totals are large reserves of low-grade uranium-bearing lignite. The Mendenhall area has been estimated to contain 49 million tons of lignite containing about 0.005 percent uranium in beds averaging 5.4 feet in thickness. The buttes, exclusive of the Mendenhall area, have been estimated to have 340 million tons of lignite containing 0.007 percent uranium (Gill and others, 1959, p. 97).

The geologic map (pl. 12) accompanying this report shows the thickness and uranium content of the mineralized beds around the margins of the buttes. Table 14 of Denson and Gill (1965d) lists the laboratory and field data for 245 lignite and carbonaceous shale surface samples analyzed for uranium. Semiquantitative spectrographic data for selected samples are given in tables 25 and 26 of Denson and Gill (1965e).

High-grade deposits of uranium in lignite and carbonaceous shale are present at nine localities in Slim Buttes (locs. 21, 45, 48, 49, 53, 54, and 58–60, pl. 12 (this report) and table 14 (Denson and Gill, 1965d)). Seven of the nine high-grade deposits occur in the southern part of the buttes mainly in T. 16 N., Rs. 8 and 9 E. Most of these deposits occur along the axis of a shallow syncline that trends about N. 70° W. and plunges about 25 feet per mile to the southeast. At six of the nine localities the Chadron and Brule Formations are absent and the Arikaree Formation rests directly on the truncated edges of the Ludlow Member. (See pl. 12 and fig. 20.) The radioactive beds in T. 16 N., Rs. 8 and 9 E., exhibit marked variations in thickness and uranium content as shown on figure 20. They are 0.3 to 2.0 feet thick and contain from about 0.33 to less than 0.05 percent uranium. The permeability of the rocks adjacent to the lignite beds apparently has a marked influence on the pattern of uranium distribution. In general, the uranium content is higher where a lignite bed is overlain by sandstone than where the same bed is overlain by less permeable siltstone. (See fig. 20, locs. 48, 53, and 54, vs. 46, 49, and 51.) Similarly where the lignite is overlain by a siltstone it contains more uranium than where overlain by clay or shale. See fig. 20, locs. 46, 49, and 51, vs. 45, 50, and 56.) The less permeable strata tend to insulate the lignite from the mineralizing solutions.

The lignite beds range from soft and earthy to hard, dense, and woody. Fine-textured (attrital) coal layers at some places contain more uranium than woody layers, but numerous exceptions show that plant composition is less important than stratigraphic position of lignite beds relative to the overlying tuffaceous deposits that are the potential source of the uranium (J. M. Schopf, R. J. Gray, and C. J. Felix, written commun., 1955). The generalization that the stratigraphically highest lignite bed will contain the most uranium has been questioned by some workers (King and Young, 1956, p. 427) who cite occurrences similar to those shown on figure 20, locality 53. Here the stratigraphically highest bed is not the most radioactive containing only 0.006 to 0.012 percent uranium, whereas a bed 15 feet lower in the section contains as much as 0.26 percent uranium. The uppermost bed though not containing especially large quantities of uranium shows clearly that it has undergone mineralization. The difference in uranium content may be explained by noting that the

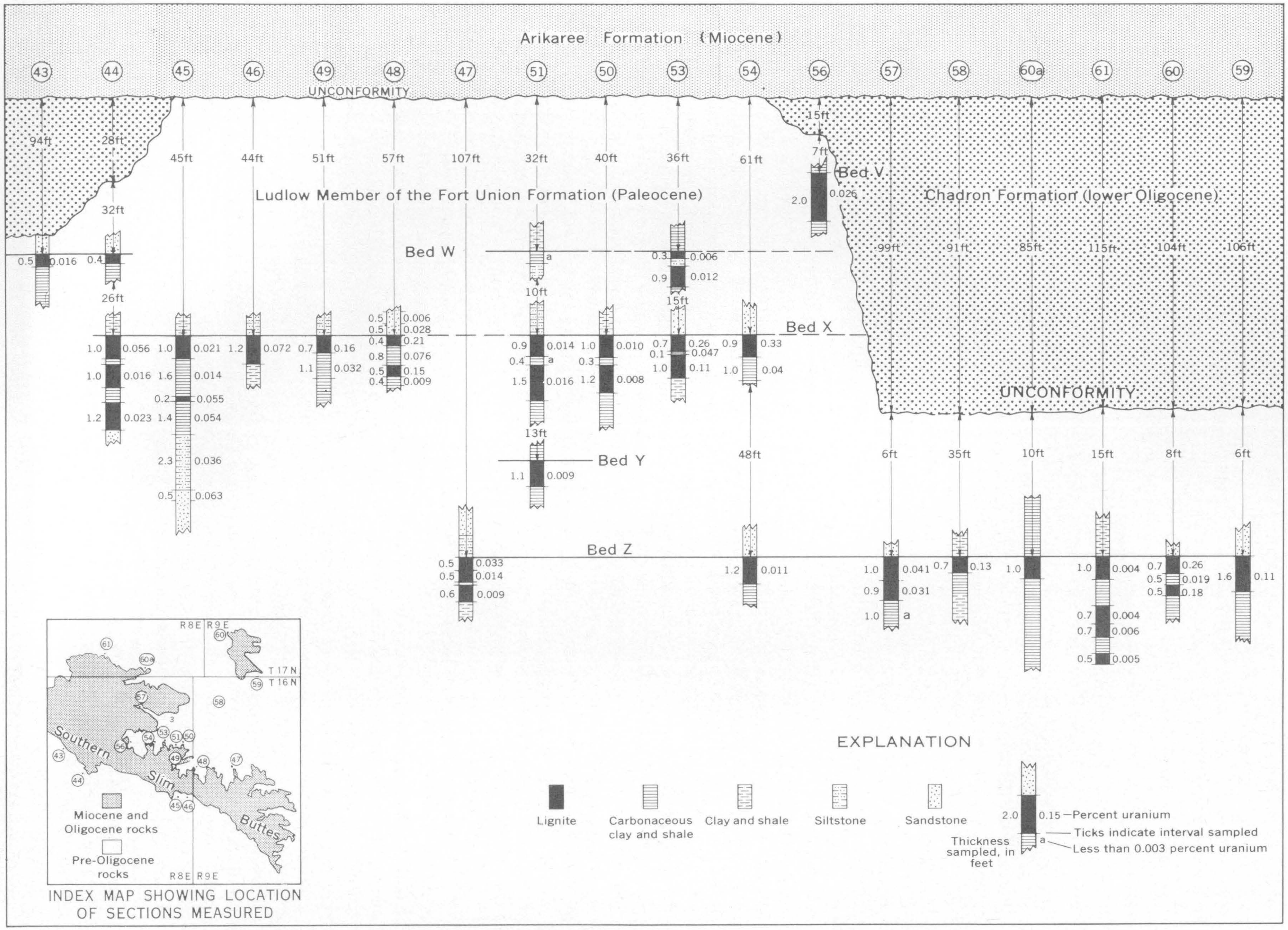


**Figure 20.**—Uranium content and correlation of lignite beds in the southern part of the Slim Buttes area, Harding County, S. Dak.

stratigraphically highest bed is interbedded with impermeable clay and shale and the lower bed is overlain by permeable sandstone.

The higher grade uranium deposits in the Slim Buttes at some localities contain uranium minerals that are commonly present along joints and bedding planes in the carbonaceous rocks. The following uranium minerals have been identified.

*Arsenates*

Abernathyite, $K_2(UO_2)_2(ASO_4)_2{\cdot}8H_2O$ (White, 1958, p. 36; and Gruner and others 1956, p. 16).
Metanovacekite, $Mg(UO_2)_2(ASO_4)_2{\cdot}8\text{–}10H_2O$

*Phosphates*

Meta-autunite, $Ca(UO_2)_2(PO_4)_2{\cdot}2\tfrac{1}{2}\text{–}6\tfrac{1}{2}H_2O$
Metatorbernite, $Cu(UO_2)_2(PO_4)_2{\cdot}8H_2O$
Metauranocircite, $Ba(UO_2)_2(PO_4)_2{\cdot}8H_2O$ (White, 1958, p. 30)

*Vanadate*

Metatyuyamunite, $Ca(UO_2)_2(VO_4)_2{\cdot}3\text{–}5H_2O$

The size and shape of the higher grade deposits could not be determined by surface mapping because of poor exposures and extensive thick cover. Available surface data indicate several lens-shaped bodies each containing 1,500 tons or more of material having a grade of 0.1 percent uranium. Because of thick overburden, development of these deposits by stripping methods can be done only locally.

Three hundred tons of impure lignite containing 0.33 percent uranium has been mined from bed X at locality 54. (See pl. 12.) In addition to uranium, the lignite contained 0.04 percent vanadium oxide and 3.4 percent calcium carbonate (King and Young, 1956, p. 428–429).

A column sample of unweathered lignite from bed Z collected by the authors at locality 57 (fig. 20) was examined petrographically by Schopf and Gray (1954). This sample had an average uranium content of about 0.04 percent and visibly contained pyrite, analcite (analcime), and detrital clay material. According to Schopf and Gray (1954, p. 27–28), the pyrite apparently formed early during coal diagenesis, but the analcite was formed from ionic solutions after the organic material had reached its present state of compaction. They conclude that "groundwater could readily serve to transfer sodium, aluminum, and silicon ions into the coal from overlying tuffaceous deposits and permit the forms of secondary analcite, just described, to form. Accordingly, the presence of analcite spherulites is regarded as a rough indication of the extent of groundwater circulation." These conclusions are in general agreement with the field relations at Slim Buttes, for analcite is either absent or sparse in radioactive lignite overlain by the relatively impervious clay and bentonite of the White River Group and is most abundant where the radioactive lignite is overlain by the porous sandstone of the Arikaree Formation.

### URANIUM-BEARING SANDSTONE DEPOSITS

Two small deposits of uranium-bearing sandstone occur in the Slim Buttes. One is in the upper part of the Chadron Formation of Oligocene age, and the other is in the upper part of the Ludlow Member of the Fort Union Formation of Paleocene age. The age of the two deposits is unknown.

#### Cedar Canyon area

Carnotite-bearing silicified sandstone occurs in the upper part of the Chadron Formation at Cedar Pass (pl. 12) in the NE¼NE¼ sec. 8, T. 16 N., R. 8 E. The deposit is not of commercial importance but is of interest because of its bearing on the problem of the origin of uranium in the lignites in the underlying rocks. The deposit consists of efflorescent coatings of carnotite ($K_2(UO_2)_2(VO_4)_2{\cdot}1\text{–}3H_2O$) on the surface of silicified tuffaceous sandstone. Carnotite is sparsely disseminated throughout the sandstone and adjacent clays. Evaporation after rainstorms and the melting of snow cause an increase of uranium minerals on the surface of the sandstones.

Gill and Moore (1955, p. 260) concluded that uranium, vanadium, silicon, and some other elements in the carnotite and silicified sandstone were leached by moving ground water from the weakly radioactive volcanic material in the Arikaree Formation. Gill and Moore (1955, p. 263) sampled numerous springs and wells in the southern part of the Slim Buttes and suggested that the uranium content of ground water might be used as a guide in the prospecting for uranium deposits . Subsequent discoveries in the Slim Buttes have shown that many of the higher grade lignite deposits are generally located in the vicinity of springs that contain 30 ppb or more uranium. The Thybo uranium deposit described below was discovered by using the uranium content of ground water as a guide.

#### Thybo prospect

A small deposit of uranophane-bearing sandstone in the Ludlow Member of the Fort Union Formation occurs in the SE¼SW¼ sec. 10, T. 18 N., R. 8 E., in the Reva Gap area of the northern Slim Buttes. This deposit was discovered in July 1954 by the Geological Survey using car-mounted scintillation equipment after water samples from wells and springs in the area showed abnormally high amounts of uranium. Map and sections of the deposit are shown on plate 13.

The deposit is located on the south side of Gap Creek in an area of low relief (pl. 12). The rocks of the area are part of extensive pre-Arikaree landslides. Soil and slope wash, as much as 3 feet thick over the area of the deposit, necessitates digging numerous pits to determine the extent of the mineralized sandstone. The most intense radioactivity is at a shallow spoon-shaped soil-slump scar of Pleistocene or Recent age. An isorad map of the area (pl. 13) shows a marked downslope extension of radioactivity from the area of soil slippage.

The mineralized sandstone is preserved in a pre-Arikaree landslide block. The beds in the mineralized block dip 8° SW. into a slip plane at the edge of the landslide block. The mineralized block is displaced about 5 feet downhill which brings the uranium-bearing sandstone into contact with beds of shale in an adjacent landslide block. The fact that the second block is not mineralized indicates that deposition of uranium probably took place after landsliding.

Auger holes indicate that the mineralized sandstone has a maximum thickness of 5.3 feet and is underlain and overlain by shale. The sandstone is light gray tan, fine grained, and poorly consolidated. Pale greenish-yellow uranophane ($Ca(UO_2)_2Si_2O_7 \cdot 6H_2O$) that coats sand grains is disseminated throughout the bed. Organic material is sparsely present in the form of minute flecks of plant debris. At the east end of the discovery pit the shale underlying the sandstone is slightly carbonaceous, and the upper 0.7 foot of this bed contains about 0.15 percent uranium, with pale-yellow metatyuyamunite ($CA(UO_2)_2(VO_4)_2 \cdot 3\text{–}5H_2O$) forming yellow halos around small fragments of plant material. Two thin beds of carbonaceous shale overlie the sandstone. These beds also contain metatyuyamunite halos around organic material and contain as much as 0.18 percent uranium.

Samples from 14 auger holes (Denson and Gill, 1965d, table 15) and 4 prospect pits indicate that the deposit has about 27 tons of sandstone containing 0.35 percent uranium. The greatest concentration of uranium is in the area of soil slip, where the soil is the thinnest. Samples from the discovery pit and auger hole 10 show that the uranium content of the sandstone is greater than the equivalent uranium content. At other points along the outcrop where the bed is covered by a thick mantle of soil the equivalent uranium is greater than the uranium content. Possibly the uranium has been leached where the disequilibrium is in favor of equivalent uranium and redeposited where the disequilibrium is in favor of uranium.

### ANALYSES OF WATER SAMPLES

Samples of ground water from 115 wells and springs in the Slim Buttes area were analyzed for uranium as shown in table 16 (Denson and Gill, 1965d) and on plate 12 (this report). The analyses show that water from the Chadron, Brule, and Arikaree Formations (83 samples) has an average uranium content of 34 ppb and an average pH of 8.8. Of the 32 samples of ground water from the underlying Fort Union and Hell Creek Formations, only 6 samples contained more than 20 ppb uranium; the remainder had an average uranium content of about 3 ppb and an average pH of about 8.4. Those samples containing more than 20 ppb uranium are either from localities close to known occurrences of uranium or are stratigraphically near the base of the White River Group. Their abnormally high contents of uranium probably represent leaching from either of these sources.

Table 9 shows the trace metal content of three large samples of water from the tuffaceous rocks at Slim Buttes. The water samples from these rocks contain, in addition to uranium, relatively large amounts of vanadium, selenium, and arsenic.

## SHORT PINE HILLS

### LOCATION AND ACCESSIBILITY

The Short Pine Hills comprise about 23 square miles of high tableland which rises abruptly 400 feet or more above the gently rolling prairie in Tps. 16 and 17 N., Rs. 2 and 3 E., southwestern Harding County, about 20 miles southwest of Buffalo, S. Dak. (pl. 14). U.S. Highway 85, connecting Buffalo and Belle Fourche, passes 5 miles east of the area. State Highway 8, between Buffalo and Camp Crook, is about 8 miles north. Dirt roads maintained by the county, and access trails of the U.S. Forest Service make most places in the area fairly accessible.

### EARLIER INVESTIGATIONS

The rocks in the Short Pine Hills were first described by Winchell (1875, p. 1138–1139) and later mapped by Winchester and others (1916). Their descriptions of the rocks and geology of the area are brief. The area was restudied by Curtiss (1956) and Schulte (1956) in 1955 as part of the South Dakota Geological Survey's program of coal resource appraisal.

The authors sampled ground water from wells and springs for uranium determinations and determined elevations of middle and upper Tertiary rocks in order to evaluate the possible influence of structure on uranium mineralization.

### STRATIGRAPHY

The rocks exposed in the Short Pine Hills comprise the upper part of the Pierre Shale, the Fox Hills Sandstone, and the Hell Creek Formation of Late Cretaceous age and the unconformably overlying Chadron and Brule Formations of Oligocene age and the Arikaree Formation of Miocene age. These rocks have a combined thickness of about 1,300 feet and have been penetrated at several places in the western part of the area by wells drilled for oil and gas. (See pl. 14.) At least 2,000 feet of Paleocene and Eocene rocks present in other areas in the Williston basin was eroded away at the Short Pine Hills before deposition of the Chadron Formation.

Inasmuch as the present study concerns largely the lignite-bearing rocks of Late Cretaceous age and the tuffaceous rocks of Oligocene and Miocene age, only these rocks are discussed below.

### CRETACEOUS ROCKS

#### Hell Creek Formation (Upper Cretaceous)

The Hell Creek Formation of Late Cretaceous age conformably overlies the Fox Hills Sandstone and is unconformably overlain by the Chadron and Brule Formations of Oligocene age (fig. 2).

The Hell Creek Formation in the Short Pine Hills is about 500 feet thick. Thin lenticular beds of lignite and carbonaceous shale occur in the upper part of the formation in sec. 8, T. 16 N., R. 3 E., and sec. 13, T. 17 N., R. 3 E.

The Hell Creek Formation is excellently exposed in numerous deeply incised gullies along the lower flanks of the hills.

### TERTIARY ROCKS

#### White River Group (Oligocene)

The White River Group in the Short Pine Hills is thickest where it fills topographic lows in the pre- Oligocene erosion surface and, conversely, the group is thin or absent on the topographic highs. At the beginning of Chadron time the western part of the Short Pine Hills area was topographically higher than the eastern part. As a result, the Chadron Formation is as much as 80 feet thick in the eastern part of the Short Pine Hills and is thin or absent in the western part of the Short Pine Hills, where the group is represented largely by the Brule Formation. At one time 250 feet or more of the Brule Formation extended over most of the area, as indicated by the thickness of the formation in pre-Arikaree landslides in T. 17 N., R. 1 E., where tilted and downdropped blocks of the Brule are preserved. A stratigraphic section of the Brule measured in one of these fossil landslide blocks is shown on plate 4, locality 20. The Brule reaches a maximum thickness of about 150 feet where undisturbed by landslides.

The Chadron Formation consists principally of a basal arkose and conglomerate overlain by beds of dark-gray silty bentonite and tuffaceous siltstone. (See pl. 4, loc. 21.) A yellow mineral identified by X-ray as metatyuyamunite coats grains and fracture planes in the lower part of the formation in the NE¼SW¼ sec. 26, T. 17 N., R. 3 E. (pl. 14). The Chadron is conformably overlain by massive pinkish-gray calcareous claystone and lenticular beds of impure limestone as much as 8 feet thick containing clay nodules ¼ to ½ inch in diameter. On the basis of fossil and lithologic criteria these rocks are assigned to the Brule Formation. The contact between the two formations is arbitrarily placed at the base of the carbonate sequence.

#### Arikaree Formation (Miocene)

The Arikaree Formation, 275 feet or more thick, unconformably overlies the White River Group of Oligocene age and forms a prominent caprock on the Short Pine Hills. The rocks comprising the formation are principally massive chalky greenish-gray tuffaceous sandstone which is very coarse grained to conglomeratic near its base. Lenses, 2 to 5 feet thick, of quartzite, dolomite, volcanic ash, and bentonite are present locally, and fissile silty shale and claystone occur locally within 30 feet of the base of the Arikaree; persistent beds, however, are generally absent. The correlation of the rocks assigned here to the Arikaree is based largely on stratigraphic succession and lithologic similarity with rocks in adjacent areas. (See pl. 4.)

The Arikaree Formation rests on the upturned and truncated edges of ancient landslide blocks at several places. Many excellent examples of these downdropped blocks are found in T. 16 N., R. 3 E., and T. 17 N., R. 1 E. The blocks trend northwestward and are parallel to a major joint system in the underlying rocks formed prior to the deposition of the Arikaree. The movement of the landslides at most places is probably less than 250 feet. Only the upper part of the Hell Creek and the Chadron and Brule Formations are displaced by the slides.

### STRUCTURE

The Short Pine Hills occupy a position on the northeast flank of the Black Hills uplift and on the southwest flank of the Williston basin. (See pls. 1 and 5*H*.) The surface rocks in the Short Pine Hills and adjacent areas have a northeastward regional dip of 40 to 45 feet per mile toward the center of the basin. At several places, however, the Tertiary rocks are gently folded along axes trending nearly at right angles to the regional dip. Curtiss (1956) and Schulte (1956) described similar northwest-trending structures elsewhere in the area. Folds in the Tertiary rocks have closures of 50 feet or more, but the folds may be partly the result of differential compaction over topographic features on the pre-Oligocene erosion surface. The thickness map of the Red River Formation of Late

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Ordovician age (pl. 5*D*) shows thinning along an axis or trend line in southwestern Harding County which is subparallel to the northwest-trending structures in the Cretaceous and Tertiary rocks. Recurrent uplift or folding may have taken place during late Tertiary time along this older trend line to produce the gentle folds in the surface rocks. These low gentle folds are concordant with the northwest-trending Cedar Creek anticline and probably are genetically related to it.

#### URANIUM DEPOSITS

The stratigraphic setting for the occurrence of uranium in the Short Pine Hills appears unfavorable owing to the scarcity of carbonaceous material in the continental deposits underlying the White River Group and Arikaree Formation. Lenticular 1- and 2-foot thick beds of lignite and carbonaceous shale are locally present in the upper part of the Hell Creek Formation in sec. 8, T. 16 N., R. 3 E., and sec. 13, T. 17 N., R. 3 E. At these localities the carbonaceous beds are overlain within a few feet by siltstone and bentonitic claystone of the White River Group and are radioactive. Analyses show the carbonaceous material to contain as much as 0.1 percent uranium. The limited extent of the deposits along their outcrop and thick overburden, however, prohibit extensive development.

The only other known occurrence of uranium in the area is in the SE¼ sec. 24, T. 17 N., R. 1 E., where a 2- to 3-foot thick bed of silty dolomite about 200 feet stratigraphically above the base of the Arikaree Formation is radioactive. Carnotite coats the joints and fractures mostly in the upper part of the bed at several places along its outcrop in a small area. Analyses of selected grab samples indicate a content of about 0.1 percent uranium, 47 percent $CaCO_3$, and 33 percent $MgCO_3$.

#### ANALYSES OF WATER SAMPLES

Samples of ground water from 41 springs and wells in the Short Pine Hills were analyzed for uranium (pl. 14, this report; table 17 (Denson and Gill, 1965d)), and 4 large samples were analyzed for selected trace elements (tables 9–11). Thirty samples of water from the tuffaceous rocks of the Chadron, Brule, and Arikaree Formations have an average uranium content of about 8 ppb and an average pH of about 8.2. Most of the samples from the Hell Creek in the Short Pine Hills contain an average uranium content of about 4 ppb and have a pH of about 8.2; however, four samples show anomalously high uranium contents ranging from 20 to 598 ppb. Uranium in these samples may be from significant deposits, and the nearby areas are worthy of further prospecting.

### LONG PINE HILLS

#### LOCATION AND ACCESSIBILITY

The Long Pine Hills comprise about 25 square miles of relatively flat upland about 30 miles southeast of Ekalaka and 8 miles northeast of Camp Crook in the east-central part of Carter County, Mont. (pl. 15). About 10 square miles of high tableland and isolated buttes that lie 6 to 12 miles south and west of the Long Pine Hills comprise the Sheep Mountains and A-Bar-B Buttes. These areas were mapped and studied in conjunction with the work conducted in the Long Pine Hills.

The principal access road to the region is a gravel highway that connects Ekalaka, the county seat of Carter County, with Camp Crook, S. Dak., and passes a few miles south of the Long Pine Hills. From this highway relatively easy access to most points in the region is permitted by dirt roads and trails maintained by the U.S. Forest Service and by dirt roads maintained by the county.

#### EARLIER INVESTIGATIONS

The rocks in the Long Pine Hills were first mapped and described by Bauer (1924), whose studies were primarily for the purposes of land classification. His studies and mapping were mostly along the low-lying areas bordering the hills where important lignite deposits occur. In 1950, Denson, Bachman, and Zeller (1959, p. 47) conducted a brief reconnaissance of the area and reported the occurrence of weakly radioactive lignite in NE¼ sec. 21, T. 3 S., R. 62 E.

In 1955 the authors studied the occurrences of uranium in the area, mapped the middle and upper Tertiary tuffaceous rocks, and collected rock and water samples for uranium analyses. Elevations on selected geologic contacts throughout the area were established by single-base altimetry, and a map was compiled (pl. 15) to determine the relation of known uranium occurrences to the erosion surface at the base of the Tertiary tuffaceous rocks.

#### STRATIGRAPHY

Rocks exposed in the vicinity of the Long Pine Hills comprise about 800 feet of lignite-bearing strata of Late Cretaceous and Paleocene age unconformably overlain by about 500 feet of tuffaceous strata of Tertiary age. In the southwestern part of the area, in the vicinity of the A-Bar-B Buttes, the tuffaceous rocks overlie the marine Fox Hills Sandstone and the Pierre Shale of Late Cretaceous age. The unconformity at the base of the Tertiary sequence is an irregular surface which slopes gently eastward at about 15 to 20 feet per mile. (See pl. 15.) The rock units represented in the area are excellently exposed at many places along the sides of the mesas and on the low interstream divides.

#### CRETACEOUS AND TERTIARY ROCKS

##### Hell Creek and Fort Union Formations, undifferentiated (Upper Crataceous and Paleocene)

The Hell Creek and Fort Union Formations were not differentiated in mapping the Long Pine Hills. They are very similar lithologically to the same formations in the Slim Buttes and Ekalaka Hills areas of South Dakota and Montana. At the contact between the two formations, dark, somber clayey beds typical of the Hell Creek alternate for several hundred feet stratigraphically with yellow sandy beds typical of conformably overlying Fort Union Formation. Most of the important beds of lignite in the Long Pine Hills area occur in the Fort Union Formation; a few thin lenticular beds occur in the underlying Hell Creek at or near the transition between the two units. In the Sheep Mountains the upper part of the Hell Creek and all the Fort Union were removed by erosion, and the Arikaree Formation of Miocene age rests directly on the lower part of the Hell Creek. No beds of lignite or carbonaceous shale were observed in this part of the sequence, the lower part of the Hell Creek being composed principally of thick impervious beds of dark clay shale and lentils of calcareous ironstone.

##### White River Group (Oligocene)

Oligocene rocks of the White River group are present at only a few places in the Long Pine Hills and are absent in the A-Bar-B Buttes and at most places in the Sheep Mountains. These rocks, which reach a maximum thickness of about 250 feet near the south-central part of the Williston basin, at one time covered most of the Long Pine Hills area but were subsequently removed as a result of uplift and erosion prior to the deposition of the Arikaree Formation.

In the Long Pine Hills the rocks assigned to the White River Group have an average thickness of about 75 to 100 feet and consist principally of a basal conglomeratic sandstone overlain by 10- to 15-foot-thick beds of dark-gray bentonite and cream-colored tuffaceous siltstone. At Capitol Rock in the SE¼ sec. 17, T. 3 S., R. 62 E. (pl. 4, loc. 19), the upper 30 feet of the White River Group consists of a massive pinkish-gray calcareous clayey siltstone which may be a partial equivalent of the rocks assigned in other areas to the lower part of the Brule Formation. Fossils were collected from the White River Group in secs. 16 and 20, T. 3 S., R. 62 E., by Bauer (1924, p. 244) and identified by J. W. Gidley of the U.S. National Museum as parts of a lower jaw of *Titanothere*, an incisor tooth of *Mesohippus* sp., and fragments of turtle carapace. These fossils and the lithologic similarity of these rocks with fossiliferous strata of known Oligocene age in other areas provide a tentative basis for their correlation with the White River Group.

As indicated on the geologic map (pl. 15), much of the White River Group in the Long Pine Hills is preserved in slump blocks that slid from the sides of steep-walled valleys after deposition of the Brule Formation and prior to the deposition of the overlying Arikaree. Many of these jumbled and contorted slump blocks are exposed along the headwaters of Speelman Creek in the W½ T. 2 S., R. 61 E.

##### Arikaree Formation (Miocene)

The Arikaree Formation, which ranges from 50 feet to about 360 feet in thickness, forms the prominent caprock on the Long Pine Hills, the Sheep Mountains, and A-Bar-B Buttes. The formation is chalky-gray massive- to thin-bedded tuffaceous fine-grained sandstone interbedded with weakly radioactive volcanic ash in beds as much as 12 feet thick. (See fig. 11.) Lenticular beds of greenish-gray quartzite, dolomitic limestone, clayey siltstone, and calcareous shale 2 to 10 feet thick are commonly present throughout the sequence. Fresh-water ostracodes, gastropods, and pelecypods occur at various horizons in the clayey siltstone and limy shale, but identifiable vertebrate fossils are generally absent. Correlation of the rocks assigned to the Arikaree in the Long Pine Hills area is based largely on stratigraphic position and lithologic similarity with rocks forming the prominent caprock in Ekalaka Hills and Chalky Buttes, where vertebrate fossils of Miocene age have been identified.

#### STRUCTURE

The Long Pine Hills lie on the northeast flank of the Black Hills about midway between the northward-plunging axis of the north end of the Black Hills uplift and the Cedar Creek anticline. These two major uplifts are separated by a series of gentle folds which lie just to the north of the Long Pine Hills (Bauer, 1924, p. 247). The surface rocks in the Long Pine Hills area dip about 40 to 45 feet per mile to the northeast and have a regional strike of about 50°–60° NW. (See pl. 5*H*.)

Faults of tectonic origin and major stratigraphic displacement were not noted in the area.

#### URANIUM OCCURRENCES

The lignite and carbonaceous shale beds in the Long Pine Hills area are only weakly radioactive and at most localities contain only small amounts of uranium. Analyses of 21 samples from 13 localities where geiger counter and scintillation counter readings indicated higher than normal radioactivity show uranium contents ranging from about 0.003 to 0.061 percent. (See fig. 21 (this report) and table 18 (Denson and Gill (1965d).) Relatively high grade concentrations of uranium were found at only 2 of the 13 localities sampled. These are at the base of carbonaceous sandstones overlying thin lenticular beds of shale in the SW¼SE¼ sec. 35, T. 2 S., R. 60 E., and in the NW¼SE¼ sec. 29,

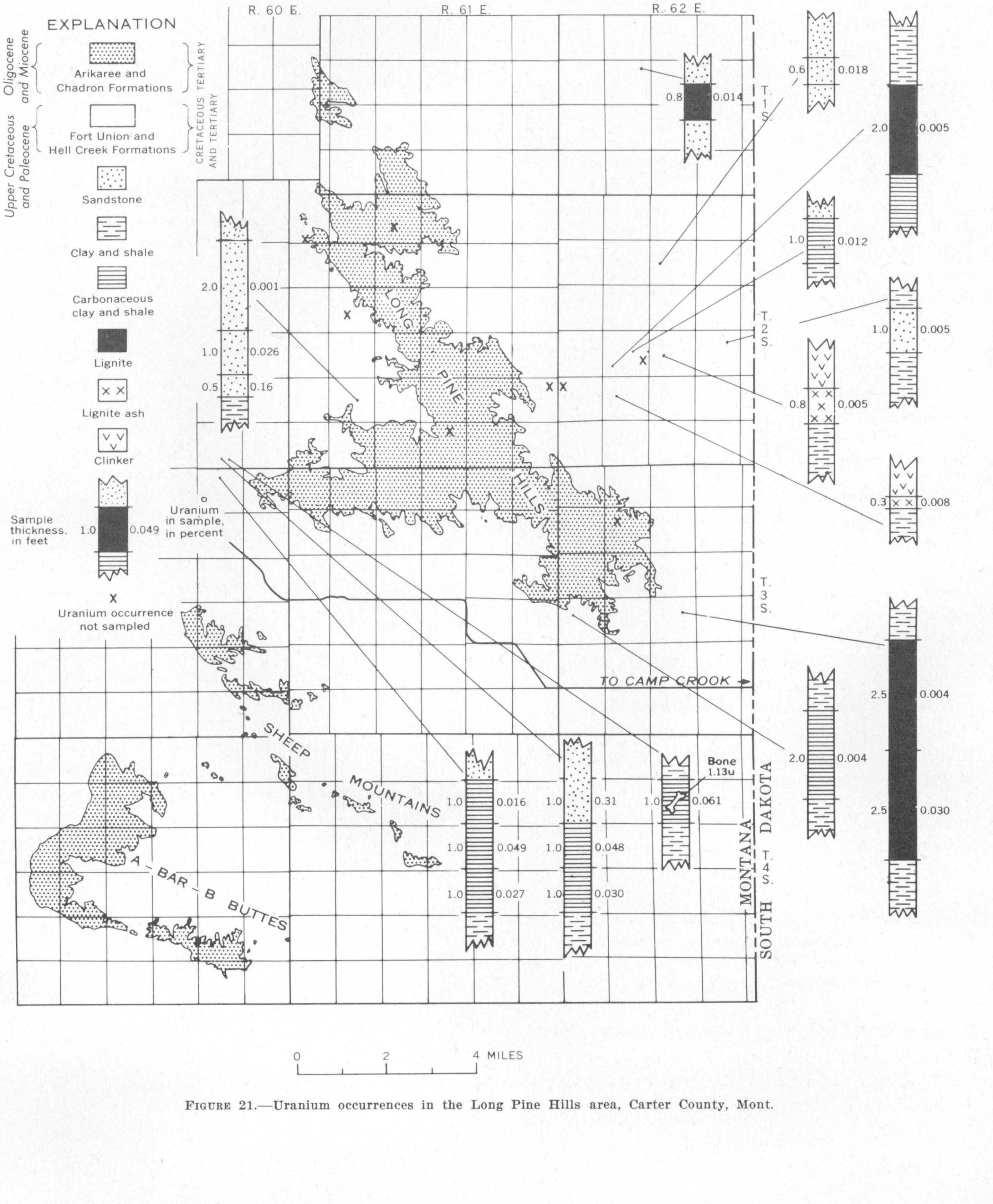



FIGURE 21.—Uranium occurrences in the Long Pine Hills area, Carter County, Mont.

T. 2 S., R. 61 E. Analyses of channel samples of sandstone representing thicknesses of 0.5 and 1.0 foot at these localities showed uranium contents of 0.16 and 0.31 percent, respectively. Analyses of channel samples taken at progressively higher intervals above the base of the sandstone show a marked upward decrease in uranium content. X-ray mineral identifications of the yellow coatings around sand grains and fracture planes near the base of the sandstone indicate the presence of carnotite and becquerelite.

#### ANALYSES OF WATER SAMPLES

Samples of ground water from 26 springs and wells in the Long Pine Hills and adjacent areas in the Sheep Mountains and A-Bar-B Buttes were analyzed for uranium, and 2 large samples were analyzed for selected trace elements. Results of the laboratory determinations are shown in tables 9 and 10 and are summarized on page 57. Supplemental data are given in table 19 (Denson and Gill, 1965d). As in samples analyzed from other areas, the uranium content of the water from the tuffaceous rocks averages about 15 ppb.

### FINGER BUTTES

The Finger Buttes are in Tps. 5 and 6 S., Rs. 59 and 60 E., about 17 miles southwest of the Long Pine Hills in the southeastern part of Carter County, Mont. (pl. 16). State Highway 323 crosses the southwest corner of the area and provides the main access road from Ekalaka 45 miles north and Albion 12 miles south. The area surrounding Finger Buttes is underlain by the marine Pierre Shale of Late Cretaceous age, which does not contain favorable uranium host beds. The buttes are composed of scattered remnants of middle and upper Tertiary rocks (fig. 22). The area contains the topographically highest remnants of Oligocene and Miocene rocks known in the basin. These remnants comprise about 200 feet of volcanic-rich siltstone, shale, and sandstone that were deposited upon a relatively even northeasterly sloping surface ranging from about 4,000 to 3,800 feet above sea level. Plate 16 shows the distribution of remnants of the Chadron, Brule, and Arikaree Formations and their unconformable relationship to the underlying Pierre Shale. The authors' interpretation of tilted blocks of the Chadron and Brule as pre-Arikaree landslides is described and discussed on pages 11–12. Along the boundaries of these fossil landslide blocks are thin translucent films, rosettes, and clear transparent euhedral crystals of analcite derived from the leaching of the overlying rocks. In many of the uraniferous lignite areas in the Williston basin analcite is a common constituent of the mineralized host rock.

Analyses of water from two springs in the area are shown on plate 16. The amounts of selected trace elements determined by chemical analysis of a large sample of ground water from the Arikaree Formation in the Finger Buttes area are listed in table 9.

### EKALAKA HILLS AND CHALK BUTTES

#### LOCATION AND ACCESSIBILITY

The Ekalaka Hills include about 30 square miles of relatively high timberland in Tps. 1 and 2 N., Rs. 57 to 59 E., in north-central Carter County, Mont. (pl. 17). Chalk Buttes lie about 4 miles southwest of the Ekalaka Hills. Most of the area is in the Custer National Forest and is accessible by State Highway 323, which crosses the hills about 6 miles south of Ekalaka (population 900).

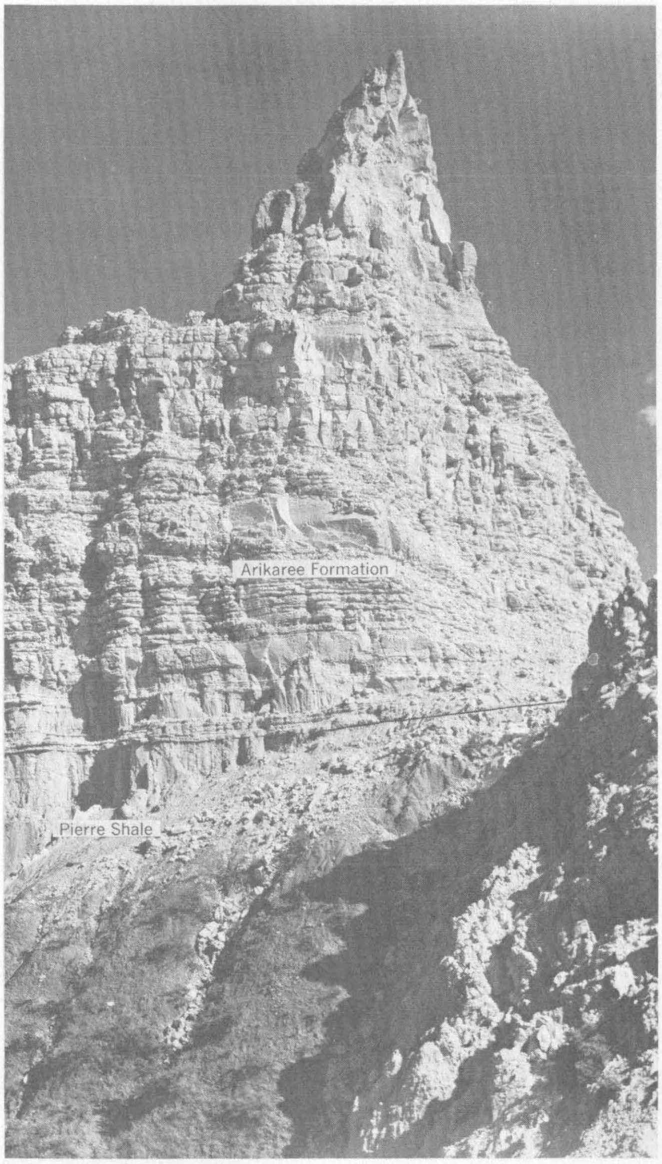



FIGURE 22.—Arikaree Formation (Miocene) unconformably overlying the Pierre Shale (Upper Cretaceous) in the NW¼NW¼ sec. 32, T. 5 S., R. 60 E., Finger Buttes, Carter County, Mont.

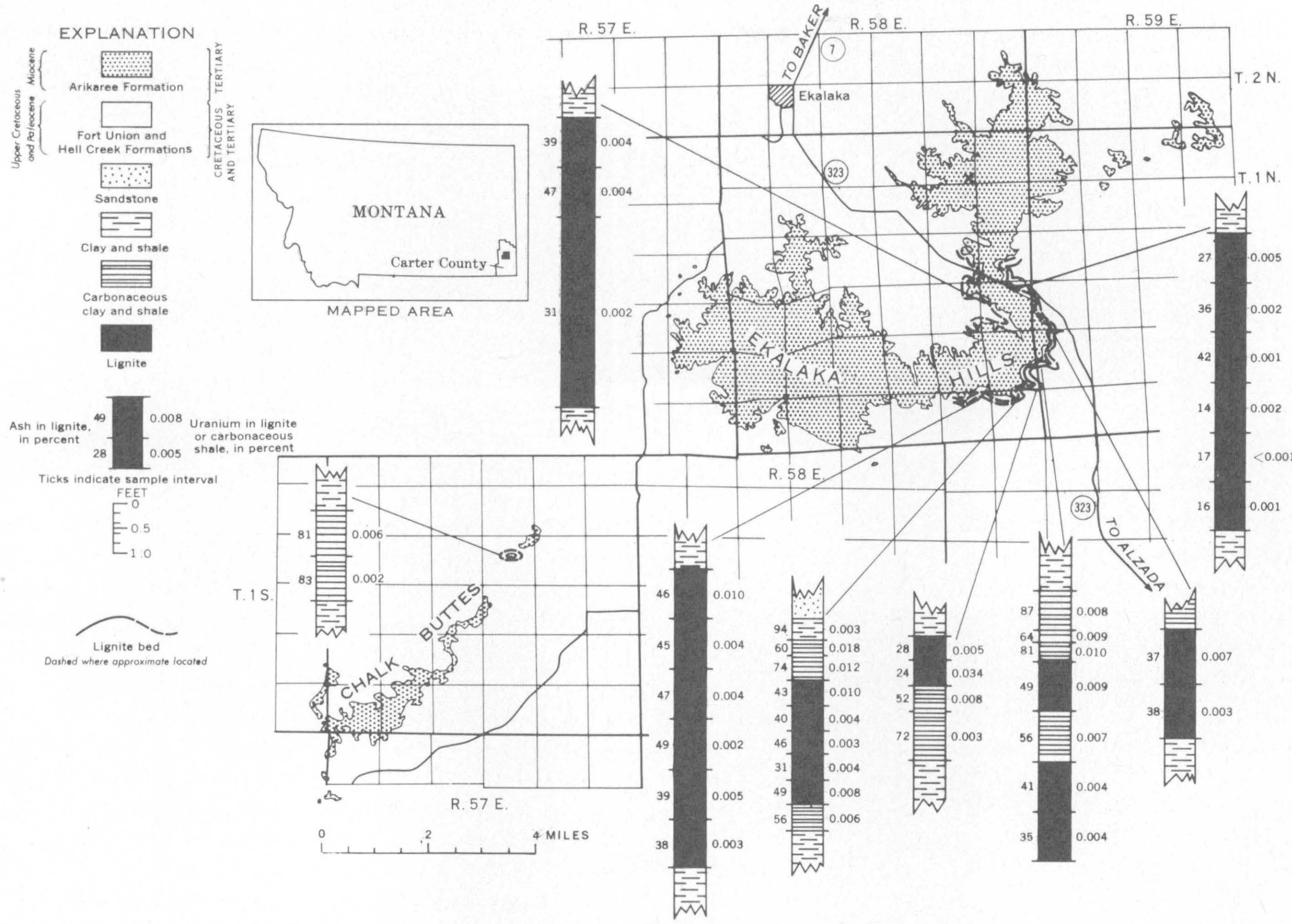



FIGURE 23.—Uranium occurrences in Ekalaka Hills area, Carter County, Mont.

reported by the laboratory are shown in the following table, on the graphic presentation of analyses (pls. 18 and 19, this report), and in tables 23–28 (Denson and Gill, 1965e).

*Group number notation used in recording semiquantitative spectrographic analyses in this report*

| *As reported by the laboratory* [1] | *Code number* | *Approximate range (percent)* |
|---|---|---|
| M | 1 | 10.0 – 100.0 |
| 7 | 2+ | 4.6 – 10.0 |
| 3 | 2 | 2.2 – 4.6 |
| 1.5 | 2– | 1.0 – 2.2 |
| .7 | 3+ | .46 – 1.0 |
| .3 | 3 | .22 – .46 |
| .15 | 3– | .10 – .22 |
| .07 | 4+ | .046 – .10 |
| .03 | 4 | .022 – .046 |
| .015 | 4– | .010 – .022 |
| .007 | 5+ | .0046 – .010 |
| .003 | 5 | .0022 – .0046 |
| .0015 | 5– | .0010 – .0022 |
| .0007 | 6+ | .00046 – .0010 |
| .0003 | 6 | .00022 – .00046 |
| .00015 | 6– | .00010 – .00022 |
| .00007 | 7+ | .000046– .00010 |
| .00003 | 7 | .000022– .00046 |
| .000015 | 7– | .000010– .000022 |

[1] Variations in reporting have been uniformly coded.

Table 6 lists the detection limits for the elements determined by the spectrographic method. Some combinations of elements affect the visual detection limits; thus, the detection limits listed here are approximate. In unusually favorable materials, concentrations somewhat lower than the values given may be detected. In unfavorable materials the given detectabilities may not be attained for some of the elements.

In those samples in which the element was "looked for but not found" a value half of the threshold or limit of visual detection was arbitrarily assigned for the purpose of determining the average composition of a group of samples (tables 7 and 8).

## ROCK SAMPLES

The abundances of the 33 or more elements detected by semiquantitative methods in 38 representative rock samples from the Chadron and Brule of Oligocene age, Arikaree of Miocene age, and Flaxville of Miocene or Pliocene age are shown graphically on plate 18. (Field and laboratory data for each sample analyzed are shown

TABLE 6.—*Visual detection limits for the elements determined by semiquantitative spectrographic method* [1]

[Asterisk (*) indicates that a different exposure in the red part of the spectrum is required for the sensitivities shown in parentheses. Asterisks (**) indicate that a separate exposure is required for the fluorine estimation]

| *Element* | *Percent* | *Element* | *Percent* | *Element* | *Percent* | *Element* | *Percent* |
|---|---|---|---|---|---|---|---|
| Si | 0.005 | Ce | .03 | *Li | .01 (0.00003) | Sr | .001 |
| Al | .0001 | Co | .001 | Lu | .005 | Sm | .008 |
| Fe | .0008 | Cr | .0006 | Mo | .0005 | Ta | .1 |
| Mg | .00003 | *Cs | .8 (0.01) | Nb | .001 | Tb | .01 |
| Ca | .01 | Cu | .00005 | Nd | .006 | Te | .08 |
| *Na | .01 (0.0003) | Dy | .006 | Ni | .001 | Th | .05 |
| *K | .1 (0.005) | Er | .003 | Os | .1 | Tl | .04 |
| Ti | .0005 | Eu | .003 | Pb | .001 | Tm | .001 |
| P | .07 | **F | .08 | Pd | .003 | U | .08 |
| Mn | .0007 | Ga | .001 | Pr | .01 | V | .001 |
| Ag | .00001 | Gd | .006 | Pt | .003 | W | .05 |
| As | .01 | Ge | .001 | *Rb | 7. (0.007) | Y | .001 |
| Au | .001 | Hf | .007 | Re | .04 | Yb | .0001 |
| B | .005 | Hg | .08 | Rh | .004 | Zn | .008 |
| Ba | .0005 | Ho | .001 | Ru | .008 | Zr | .0008 |
| Be | .00005 | In | .0004 | Sb | .01 | | |
| Bi | .005 | Ir | .03 | Sc | .0005 | | |
| Cd | .005 | La | .003 | Sn | .001 | | |

[1] The visual detection limits listed are those of the U.S. Geol. Survey, raw materials laboratory, Washington, D.C. Although the list refers to the visual detection limits of the elements for 1956, when most of the samples were analyzed, sensitivities for other periods are sufficiently similar for the purposes of this report.

in tables 22 and 23 (Denson and Gill, 1965c, 1965e). Of the 38 samples, 20 were also analyzed chemically by the rapid method of analyzing silicate rocks (Shapiro and Brannock, 1956), and the results of these analyses are listed in table 22 (Denson and Gill, 1965c) for comparison with the spectrographic analyses.)

A wide variety of rock types was analyzed, including volcanic ash, tuffaceous sandstone, claystone, bentonite, and arkose, to discover the variation in composition and trace-metal content of a series of mildly radioactive tuffaceous rocks which were probably the source of the uranium now concentrated in the underlying formations by the action of ground water. Analyses of similar rocks from correlative units in the White River Badlands of west-central South Dakota are described by Bump (1951, p. 44). Physical properties and analyses of bentonitic clays from the Chadron Formation in southwestern North Dakota are discussed by Clarke (1948).

The average composition of the tuffaceous rocks in the Williston basin and comparisons with the relative abundance of elements in the earth's crust as well as with those in the ashed samples of uranium-bearing lignite and fossil bone are presented on page 58.

### FOSSIL BONE

Fifteen samples of fossil bone were analyzed for uranium by chemical methods, and their trace-metal content was determined by semiquantitative spectrographic analyses (pl. 18, this report; and table 24 (Denson and Gill (1965e)). The samples contain from 0.003 to 0.79 percent uranium, whereas the rocks that enclose them contain only 0.001 percent or less of the element. Altschuler and others (1958, p. 66), in a discussion of the emplacement of uranium in bone, point out that fresh bones are generally nonuraniferous and that ground water charged by uranium may effect unusual concentrations of uranium in isolated bones resulting in an enrichment far greater than that of the enclosing rocks. They determined that although the phosphate (apatite) fraction, which is the principal receptor of the uranium in fossil bone, has a uniform composition throughout, the most uraniferous parts of the bone are the peripheral zones and the cavernous and highly permeable internal structures. Intermediate dense areas are of relatively low grade. From this evidence they concluded that the accessibility to solutions was the main control on the localization of the uranium.

Uraniferous fossil bones from Williston basin, in addition to uranium, calcium, and phosphorus, contain the following elements in quantities two or more times greater than the average amounts present in the earth's crust (Mason, 1958, p. 44): dysprosium (× 80), erbium (× 66), lanthanum (× 55), gadolinium (× 50), yttrium (× 50), cerium (× 39), ytterbium (× 33), molybdenum (× 10), lead (× 7), strontium (× 4), manganese (× 3), and beryllium (× 2).

The average composition of fossil bone from the Williston basin and comparisons with the relative abundance of elements in the earth's crust are shown in table 8.

### ASHED SAMPLES OF LIGNITE AND CARBONACEOUS SHALE

In the area of investigation analyses of 235 ashed samples of lignite and carbonaceous shale from the 3 members of the Fort Union Formation of Paleocene age were studied to determine those elements concentrated or introduced into the lignite and shale during uranium mineralization. This was done by determining the trace-metal content of relatively nonradioactive unmineralized lignite ash and by comparing the differences in composition between strongly mineralized and weakly mineralized beds from each of the three stratigraphic units studied. The distribution and range of elements detected by semiquantitative and chemical methods in ashed samples from the Ludlow Member in the Slim Buttes area, from the Tongue River Member in the Cave Hills area, and from the Sentinel Butte Member in the Little Missouri River escarpment area are shown on plate 18. (Pertinent field and laboratory data for each of the three groups of samples are shown in tables 25–28 (Denson and Gill, 1956e).)

### DIFFERENCES IN COMPOSITION BETWEEN STRONGLY MINERALIZED AND WEAKLY MINERALIZED URANIUM-BEARING LIGNITE AND CARBONACEOUS SHALE

Differences in the average abundance of elements in samples of strongly mineralized and weakly mineralized samples from each of the three members of the Fort Union Formation, possibly indicating elements introduced or leached during the period of uranium mineralization, are shown on figure 24. The following table lists those elements that show a positive correlation with uranium—that is, those elements whose increase or decrease in abundance is accompanied in most samples by a corresponding increase or decrease in uranium content.

*Correlation between uranium and other elements as determined by difference in composition between strongly mineralized and weakly mineralized ashed samples of uranium-bearing lignite and carbonaceous shale*

| Positive correlation with uranium | Negative correlation with uranium | No apparent correlation with uranium | Uncertain correlation with uranium |
|---|---|---|---|
| Arsenic[1] | Boron | Aluminum | Copper. |
| Barium[1] | Calcium | Chromium | Gallium. |
| Beryllium[1] | Lithium | Silicon | Iron. |
| Cobalt[1] | Magnesium | Tin | Niobium. |
| Germanium[2] | Maganese | Titanium | Phosphorus. |
| Lanthanum[1] | Potassium | | Sodium. |
| Lead[1] | Silver | | Strontium. |
| Molybdenum[2] | | | Vanadium[4]. |
| Nickel[2] | | | |
| Scandium[1] | | | |
| Selenium[3] | | | |
| Ytterbium[1] | | | |
| Yttrium[1] | | | |
| Zirconium[2] | | | |

[1] Element having a strong positive correlation in only two of the three groups of samples analyzed.
[2] Element having a strong positive correlation with uranium in all three groups of samples analyzed.
[3] Selenium determinations made by chemical analysis of 28 unashed samples of uranium-bearing lignite from Ludlow Member of the Fort Union Formation, Slim Buttes, S. Dak. (See Denson and Gill (1965), table 25.)
[4] Vanadium shows no apparent correlation with uranium in samples analyzed from Cave Hills and Little Missouri escarpment areas. A strong positive correlation, however, exists between vanadium and uranium in weakly mineralized samples from the Ludlow Member of the Fort Union Formation, Slim Buttes, S. Dak. (See fig. 24.)

Most of the elements showing a positive correlation with uranium have probably been introduced into the lignite from an outside source during the period of mineralization. Phosphorus, because of its relatively high limits of detection, was reported in so few samples that the positive correlation shown on figure 24 is of doubtful significance. Also listed are elements that show, in a majority of samples, a negative correlation with uranium, a fact which indicates that they may have been leached from the lignite during the introduction of the uranium. In this group there appears to be no well-defined or consistent relation for the elements removed or leached during mineralization. The elements listed show a strong negative correlation with uranium in only two of three groups of samples analyzed. Elements that appear unrelated to the mineralization of the lignite or show uncertain correlation with uranium are also shown.

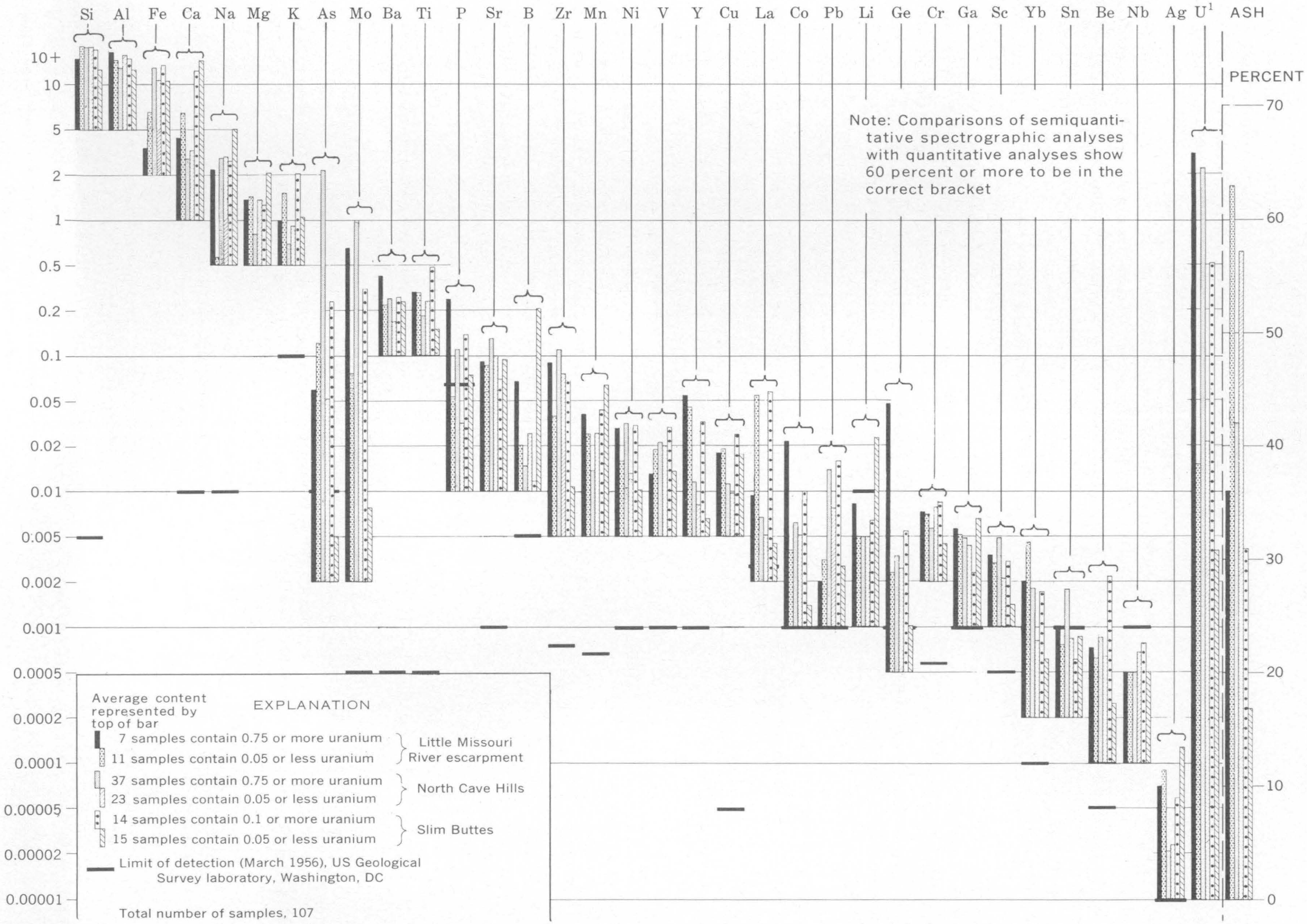
It is noteworthy that most elements showing a strong positive correlation with uranium in the carbonaceous rocks of Paleocene age in the Williston basin are also concentrated in uranium-vanadium ores in sandstones of Triassic and Jurassic age on the Colorado Plateau (Shoemaker and others, 1959, table 5).

Samples discussed in the foregoing paragraphs are mostly of weathered rock. Inasmuch as weathering may have resulted in significant changes in composition, 41 relatively unweathered core samples of lignite were selected for comparison with the weathered rock. These are listed separately (Denson and Gill, 1965e, table 26), and are graphically shown on plate 19.

The unweathered radioactive lignite (average uranium content, 0.052 percent) contains greater amounts of arsenic, cobalt, germanium, iron, lanthanum, molybdenum, and nickel than does the unweathered nonradioactive lignite (average uranium content, 0.003 percent). Most of these elements also occur in greater amounts in strongly mineralized than in weakly mineralized samples collected from outcrop in other areas in the Williston basin (pl. 18*C–E*). This fact indicates that the metal content of mineralized beds is probably not appreciably affected by weathering.

### AVERAGE PERCENTAGES OF ELEMENTS IN URANIUM-BEARING LIGNITE AND CARBONACEOUS SHALE

The average abundance of elements in the ashed samples from each of the three members of the Fort Union Formation is listed in table 7. Marked differences in abundance of some elements, for example the greater molybdenum, zirconium, and arsenic contents of samples from the Tongue River and Sentinel Butte Members as compared to samples from the Ludlow Member, seem related to the degree of mineralization inasmuch as samples from the first two units contain about six times more uranium than samples from the Ludlow member. Furthermore, the relatively large amount of calcium, lithium, and boron in the weakly mineralized samples from the Ludlow Member may also be a function of the degree of mineralization, as these elements appear to occur in increasing abundance with decreasing uranium content in most samples.




[1]Uranium by chemical analyses

**FIGURE 24.**—Differences in composition between strongly mineralized and weakly mineralized uranium-bearing lignite and carbonaceous shale ash from North Dakota and South Dakota.

### AVERAGE PERCENTAGES OF ELEMENTS IN RELATIVELY NONRADIOACTIVE LIGNITE

The following tabulation lists in order of decreasing abundance the average amounts of elements detected by spectrographic methods in 14 core samples of ashed lignite containing 0.003 percent uranium from the Ludlow Member of the Fort Union Formation at Slim Buttes, S. Dak. This list shows the order of magnitude of the trace-metal content of relatively nonradioactive unmineralized lignite ash and is useful for evaluating the changes in composition that took place during uranium mineralization.

| *Element* | *Average percent* | *Element* | *Average percent* |
|---|---|---|---|
| Calcium | [1] M (50) | Zirconium | 0.01 |
| Silicon | M (36) | Gallium | .007 |
| Aluminum | M (29) | Molybdenum | .007 |
| Sodium | 5.0 | Yttrium | .007 |
| Iron | 3.0 | Ytterbium | .006 |
| Magnesium | 2.0 | Arsenic | [2] .005 |
| Potassium | 1.0 | Lanthanum | .005 |
| Phosphorus | [2] .80 | Chromium | .004 |
| Barium | .3 | Lead | .004 |
| Boron | .2 | Cobalt | .002 |
| Titanium | .2 | Scandium | .002 |
| Strontium | .10 | Germanium | .001 |
| Manganese | .08 | Tin | [2] .001 |
| Copper | .02 | Beryllium | .0003 |
| Lithium | .02 | Silver | .0001 |
| Vanadium | .02 | Uranium [3] | .003 |
| Nickel | .01 | Ash | 16 |

[1] M indicates major constituent. Number in parentheses is percent of samples containing more than 10 percent of the element.
[2] Element detected in only a few samples. Average content listed has doubtful significance.
[3] Average uranium content by chemical analyses.

In discussing the composition of coal ash, Francis (1954, p. 498) stated:

> It is generally found that more than 95 percent of the inorganic constituents of coal consists of the three minerals kaolinite, calcite, and pyrites or their near relatives, and that more than 95 percent of the coal ash consists of alumina, silica, iron oxide, and lime. The remaining 5 percent of the coal ash consists mainly of magnesia, sodium, and potassium oxides, titanium oxide, as basic constituents, and chloride, sulphate, and phosphorus as acidic constituents.

These observations seem in accord with the relative abundance of elements detected in the lignite ash, as shown in the foregoing tabulation.

Francis (1954, p. 498), Nekrasova (1957, p. 34), and others, however, have pointed out that some coals contain relatively high proportions of other elements, some of which have considerable value, which apparently infiltrated the deposit from outside sources. In the Dakota areas field relations indicate that the uranium was introduced into the lignite by ground water carrying uranium and other elements. Some of these elements may have been derived from the overlying tuffaceous rocks (Harder, 1955, p. 6; Denson and Gill, 1956, p. 417). The spectrographic analyses summarized by plate 18*C*–*E* and the data on the geochemistry of ground water presented later in this report suggest that arsenic, molybdenum, zirconium, cobalt, nickel, germanium, lead, ytterbium, yttrium, vanadium, and other elements were introduced into the lignite with uranium.

In addition to the semiquantitative analyses summarized above, chemical analyses were made for selenium in 28 unashed samples of lignite and carbonaceous shale from the Ludlow Member of the Fort Union Formation (Denson and Gill, 1965e, table 25). Study of these analyses suggests that selenium ranges from 10 to 100 ppm in the samples and is most highly concentrated in samples having a high uranium content.

### ASH CONTENT AND ITS RELATION TO URANIUM MINERALIZATION

In the region studied the higher grade uranium deposits occur in carbonaceous beds that contain an average of about 35 to 40 percent ash. (See table 7.) In beds containing less than 35 percent ash, as those sampled at Slim Buttes, the more highly uraniferous samples have more ash than the weakly mineralized ones. (See pl. 18*C*.) For carbonaceous materials containing 40 percent or more ash, as those from the Cave Hills and Little Missouri River escarpment areas, a reverse relation holds; samples containing higher ash contents generally contain smaller amounts of uranium. (See pl. 18*D* and *E*.)

The relation of ash to uranium in the samples containing less than 35 percent ash may be explained by the greater relative permeability of lignites containing greater ash contents, which would permit easier access to the mineralizing solutions than would less permeable low-ash lignites. For those samples containing more than 40 percent ash, the relations observed are probably a direct function of the amount of carbon present, which acted as the principal agent to concentrate the uranium in organouranium complexes or ionic organouranium compounds (Breger and others, 1955, p. 226).

Field studies in the region have shown that the higher grade deposits are in lignite and carbonaceous beds 2 feet or less thick. Lignite beds much in excess of this thickness generally have ash contents lower than 40 percent and thus, because they are almost impervious, do not easily admit mineralizing solutions.

### CRUSTAL ABUNDANCE AND AVERAGE COMPOSITIONS OF TERTIARY TUFFACEOUS ROCKS, ARKOSE, LIGNITE ASH, AND FOSSIL BONE

The average compositions of dominant rock types concerned were determined for comparisons with relative abundance of elements in the earth's crust. These comparisons are shown in table 8. The following summary shows the factor by which certain elements exceed average crustal abundance. The only elements listed are those which exceed average crustal abundance by a factor of two or more in samples from Oligocene, Miocene, and Pliocene units and by a factor of four or more in samples of uraniferous lignite ash.

TABLE 7.—*Average amounts, in percent, of elements detected by semiquantitative methods in ashed*

[See pl. 18*C–E*. M, major constituent; number in parentheses is percent of samples containing more than 10 percent of the element.

| Stratigraphic unit | Area sampled (see fig. 1) | Number of samples analyzed | Average ash content | Average uranium content [1] in unashed sample | Average uranium content in ashed sample | Silicon | Aluminum | Iron | Calcium | Sodium | Magnesium | Potassium | Arsenic | Molybdenum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sentinel Butte Member; beds 1,500 ft above base of Fort Union Formation. | Little Missouri River escarpment, North Dakota. | 32 | 43 | 0.34 | 0.78 | M (72) | M (59) | M (25) | 4.7 | 2.0 | 1.5 | 1.0 | 0.1 | 0.3 |
| Tongue River Member; beds 650 ft above base of Fort Union Formation. | North Cave Hills S. Dak. | 134 | 45 | .39 | .86 | M (78) | M (49) | M (33) | 3.5 | 3.0 | 1.0 | .8 | .7 | .4 |
| Ludlow Member; beds 200 ft above base of Fort Union Formation. | Slim Buttes, S. Dak. | 69 | 23 | .03 | .13 | M (59) | M (46) | M (36) | M (44) | 4.0 | 2.0 | 1.0 | [2] .08 | .1 |

[1] Average uranium content by chemical analyses. (See Denson and Gill, 1965e, tables 25–28).
[2] Element detected in only a few samples. Average content is of doubtful significance.

*Factors by which certain elements exceed crustal abundance in samples from Tertiary tuffaceous rocks and in uraniferous lignite ash*

| | Pliocene tuffaceous rocks | Miocene tuffaceous rocks | Oligocene tuffaceous rocks | Oligocene arkosic rocks | Uraniferous lignite ash |
|---|---|---|---|---|---|
| Arsenic | ---------- | ---------- | ---------- | ---------- | 1,450 |
| Boron | ---------- | 27 | 17 | 13 | 233 |
| Barium | ---------- | 3 | ---------- | 2 | 6 |
| Beryllium | ---------- | ---------- | ---------- | ---------- | 5 |
| Cerium | 3 | ---------- | ---------- | ---------- | ---------- |
| Cobalt | ---------- | ---------- | ---------- | ---------- | 4 |
| Copper | ---------- | ---------- | ---------- | ---------- | 4 |
| Germanium | ---------- | ---------- | ---------- | ---------- | 30 |
| Lanthanum | 3 | ---------- | ---------- | ---------- | 11 |
| Lithium | ---------- | ---------- | ---------- | ---------- | 4 |
| Molybdenum | 6 | ---------- | ---------- | ---------- | 2,800 |
| Lead | ---------- | ---------- | ---------- | ---------- | 6 |
| Scandium | ---------- | 2 | ---------- | ---------- | 6 |
| Tin | 2 | ---------- | ---------- | ---------- | ---------- |
| Strontium | ---------- | 2 | ---------- | ---------- | 4 |
| Uranium | 2 | 2 | ---------- | ---------- | 2,950 |
| Yttrium | ---------- | ---------- | ---------- | ---------- | 5 |
| Ytterbium | 2 | 2 | ---------- | ---------- | 6 |
| Zirconium | ---------- | ---------- | ---------- | ---------- | 4 |

As previously inferred some of the elements that are abundant in the lignite ash also occur in relatively large amounts in the overlying tuffaceous rocks and arkose and may have been derived from them. These include boron, barium, scandium, strontium, ytterbium, and uranium. Other elements such as molybdenum, arsenic, germanium, lead, yttrium, and beryllium are abundant in the ash of uraniferous lignite and carbonaceous shale but not in the tuffaceous rocks or arkose. The relatively low concentration of the aforementioned elements in these rocks does not necessarily exclude them as a possible source for these elements. The elements may be present but in amounts below the limits of detection, possibly as a result of extensive leaching. For example, arsenic was not detected in any of the samples of tuffaceous rocks or arkose, yet chemical analyses of ground water draining these rocks show abnormally high concentrations of this element. (See fig. 25.) On the other hand, some of these elements may have been indigenous to the deposits. In some deposits perhaps both sources were important contributors.

## GEOCHEMISTRY OF GROUND WATER

During the investigations 330 samples of water were collected mostly from seeps, wells, and springs and were analyzed for uranium. The acidity of the water was determined in the laboratory with a glass-electrode pH meter. The uranium content was determined by the ethyl acetate extraction method described by Grimaldi, May, and Fletcher (1952, p. 7). The probable limits of accuracy of this method range from about 1 ppb for samples containing 10 ppb to about 10 ppb for samples containing 100 ppb.

Results of 221 analyses and the locations from which the samples were collected are shown on maps for the areas in which detailed studies were undertaken. The uranium contents of ground water show marked variations. Concentrations ranging from 20 to 500 ppb occur generally in areas near known uranium deposits. Greater than normal concentrations of uranium ranging from about 10 to 160 ppb are found in ground water from the tuffaceous sedimentary rocks of Oligocene and Miocene age, and only a few parts per billion are present in nontuffaceous terranes that are not near uranium deposits.

Scott and Barker (1958, p. 155) reported that of 486 samples of ground water analyzed from the 10 geotectonic regions in the United States samples from the part of the central stable region lying west of the divide between the Missouri and Mississippi Rivers contained the largest amounts of uranium. All the areas of uranium-bearing lignite described in this report lie within this region. Inasmuch as their sampling program specifically omitted samples of ground water from known *samples of uranium-bearing lignite and carbonaceous shale from Williston basin*

In averaging, elements reported as "looked for but not found" have arbitrarily been assigned a value half the visual detection limit]

| Barium | Titanium | Strontium | Zirconium | Phosphorus | Vanadium | Boron | Manganese | Nickel | Lead | Copper | Yttrium | Cobalt | Lanthanum | Chromium | Gallium | Lithium | Scandium | Germanium | Ytterbium | Tin | Beryllium | Niobium | Silver |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.2 | 0.3 | 0.07 | 0.08 | [2]0.10 | 0.02 | 0.04 | 0.06 | 0.02 | 0.004 | 0.02 | 0.03 | 0.01 | 0.03 | 0.007 | 0.005 | [2]0.006 | 0.003 | 0.01 | 0.003 | [2]0.0009 | 0.0007 | [2]0.0005 | 0.00007 |
| .3 | .2 | .1 | .09 | [2].06 | .03 | .02 | .02 | .02 | .02 | .01 | .01 | .009 | .008 | .006 | .005 | [2].005 | .004 | .003 | .002 | [2].001 | .0009 | [2].0005 | [2].00003 |
| .3 | .3 | .1 | .03 | [2].10 | .02 | .1 | .05 | .02 | .007 | .02 | .02 | .01 | [2].02 | .006 | .005 | .02 | .002 | .004 | .002 | [2].0008 | .001 | [2].0006 | .0001 |

ore bodies, the relatively high uranium content of the water was attributed by these authors to the volcanic ash and to the large amounts of material weathered from granitic rocks in the aquifers of the region.

In the area of this report the relatively large amount of uranium in water from the Oligocene and Miocene rocks is probably due to the availability of uranium in the large quantities of tuffaceous constituents. Owing to the high porosity and permeability of these rocks, water circulates easily and thus there are excellent opportunities for solution and transportation of the contained uranium.

Summarized in the following table are the analytical results of samples from wells and springs in six areas in which detailed investigations for uranium were carried out. (See fig. 1.)

*Summary of uranium content of 221 water samples from eastern Montana and adjacent parts of North and South Dakota*

[Tables referred to are in Denson and Gill (1965d)]

| Rocks from which water was sampled | Number of springs and wells sampled | Uranium content (ppb) | | pH | |
|---|---|---|---|---|---|
| | | Average | Range | Average | Range |
| **Slim Buttes, S. Dak.** [See pl. 12 and table 16] | | | | | |
| Oligocene and Miocene | 83 | 34 | 2-200 | 8.8 | 7.7-9.5 |
| Cretaceous and Paleocene | 26 | 3 | 1- 11 | 8.4 | 7.0-9.9 |
| Mineralized areas [1] | 6 | 60 | 24-110 | 8.2 | 7-2-8.6 |
| Total | 115 | | | | |
| **Short Pine Hills, S. Dak.** [See pl. 14 and table 17] | | | | | |
| Oligocene and Miocene | 30 | 8 | 2- 29 | 8.2 | 7.5-8.9 |
| Cretaceous | 7 | 4 | 1- 8 | 8.2 | 7.5-8.9 |
| Mineralized areas | 4 | 187 | 20-598 | 8.2 | 7.7-8.8 |
| Total | 41 | | | | |

*Summary of uranium content of 221 water sample from eastern Montana and adjacent parts of North and South Dakota*—Con.

| Rocks from which water was sampled | Number of springs and wells sampled | Uranium content (ppb) | | pH | |
|---|---|---|---|---|---|
| | | Average | Range | Average | Range |
| **Chalky Buttes, N. Dak.** [See pl. 11 and table 13] | | | | | |
| Oligocene | 1 | 29 | ---------- | ---------- | ---------- |
| Paleocene | 10 | 5 | 1- 10 | ---------- | ---------- |
| Mineralized areas | 4 | 43 | 27- 55 | ---------- | ---------- |
| Total | 15 | | | | |
| **Little Badlands, N. Dak.** [See pl. 10 and table 11] | | | | | |
| Oligocene | 6 | 16 | 13- 19 | 8.6 | 7.7-8.9 |
| Paleocene and Eocene | 4 | 2 | 1- 5 | 8.2 | 7.8-8.5 |
| Mineralized areas | 1 | 40 | 40 | 8.0 | 8.0 |
| Total | 11 | | | | |
| **Long Pine Hills, Mont.** [See pl. 15 and table 19] | | | | | |
| Oligocene and Miocene | 11 | 15 | 2- 93 | 8.1 | 7.5-8.8 |
| Cretaceous and Paleocene | 12 | 6 | 2- 13 | 8.2 | 7.8-8.5 |
| Minealized areas | 3 | 35 | 29- 46 | 8.6 | 8,4-8.8 |
| Total | 26 | | | | |
| **Ekalaka Hills, Mont.** [See pl. 17 and table 21] | | | | | |
| Miocene | 6 | 7 | 3- 17 | ---------- | ---------- |
| Paleocene | 5 | 7 | 2- 11 | 8.0 | 7.6-8.2 |
| Mineralized areas | 2 | 22 | 21- 23 | 7.9 | 7.8-8.0 |
| Total | 13 | | | | |

[1] Selected water samples containing 20 ppb uranium or more from lignite-bearing sequence of the Fort Union and Hell Creek Formations. These samples, in general, are from wells and springs within 1½ miles of known occurrences of uranium.

About 100 samples of ground and surface water for uranium determinations were collected from widely separated areas in North and South Dakota where detailed

TABLE 8.—*Crustal abundance and average amounts of elements, in percent, in Tertiary tuffaceous rocks, arkose, lignite ash, and fossil bone from Williston basin*

[All elements except uranium detected by semiquantitative spectrographic methods; uranium detected by chemical analyses. In averaging, elements reported as "looked for but not found" have arbitrarily been assigned a value half of threshold. M indicates a major constituent and number in parentheses is percent of samples containing more than 10 percent of the element; n.d. indicates element not detected]

| Element | Crustal abundance (Mason, 1958, p. 44)[1] | Tuffaceous rocks (see pl. 18*A*) | | | Oligocene arkosic rocks (5 samples, see pl. 18*A*) | Lignite ash[2] (235 samples, see pl. 18*C–E*) | Fossil bones (15 samples, see pl. 18*B*) |
|---|---|---|---|---|---|---|---|
| | | Upper Miocene and Pliocene (5 samples) | Miocene rocks (19 samples) | Oligocene rocks (9 samples) | | | |
| Silicon | 27.72 | M (100) | M (100) | M (100) | M (100) | M (70) | 3.3 |
| Aluminum | 8.13 | M (40) | M (16) | 8.0 | M (40) | M (51) | .7 |
| Iron | 5.00 | 1.9 | 1.5 | 1.7 | 0.5 | M (31) | 1.3 |
| Calcium | 3.63 | M (40) | 4.0 | M (33) | .6 | 4.0 | M (100) |
| Sodium | 2.83 | 2.4 | 3.0 | 1.9 | 1.2 | 3.0 | .9 |
| Potassium | 2.59 | 3.0 | 3.4 | 2.4 | 1.5 | 1.0 | n.d. |
| Magnesium | 2.09 | 2.0 | 1.3 | 1.7 | 1.0 | 1.5 | .4 |
| Titanium | .44 | .2 | .3 | .2 | .2 | .28 | .02) |
| Phosphorus | .118 | n.d. | n.d. | n.d. | n.d. | [3].10 | M (94) |
| Manganese | .100 | .05 | .06 | .07 | .02 | .04 | .30 |
| Strontium | .045 | .02 | .07 | .03 | .02 | .10 | .4 |
| Barium | .040 | .06 | .10 | .05 | .08 | .26 | .004 |
| Chromium | .020 | .004 | .003 | .005 | .003 | .007 | .002 |
| Zirconium | .016 | .02 | .02 | .01 | .01 | .06 | .02 |
| Vanadium | .011 | .001 | .009 | .01 | .005 | .020 | .01 |
| Nickel | .008 | .002 | n.d. | .001 | [3].0006 | .02 | .002 |
| Cerium | .0046 | .015 | n.d. | n.d. | n.d. | n.d. | .18 |
| Copper | .0045 | .003 | .003 | .003 | .001 | .02 | .03 |
| Yttrium | .0040 | .005 | .004 | .002 | .0005 | .02 | .20 |
| Lithium | .0030 | [3].01 | n.d. | n.d. | n.d. | [3].01 | n.d. |
| Neodymium | .0024 | n.d. | n.d. | n.d. | n.d. | n.d. | .09 |
| Niobium | .0024 | .002 | n.d. | n.d. | n.d. | [3].0005 | n.d. |
| Cobalt | .0023 | .0009 | n.d. | .0008 | n.d. | .01 | .002 |
| Lanthanum | .0018 | .005 | n.d. | n.d. | n.d. | .02 | .10 |
| Lead | .0015 | .001 | .002 | .001 | .002 | .010 | .01 |
| Gallium | .0015 | .001 | .001 | .001 | [3].002 | .005 | n.d. |
| Thorium | .0010 | n.d. | n.d. | n.d. | n.d. | n.d. | [3].05 |
| Samarium | .0007 | n.d. | n.d. | n.d. | n.d. | n.d. | [3].02 |
| Gadolinium | .0006 | n.d. | n.d. | n.d. | n.d. | n.d. | .03 |
| Scandium | .0005 | .0007 | .0010 | .0010 | n.d. | .003 | .008 |
| Dysprosium | .0005 | n.d. | n.d. | n.d. | n.d. | n.d. | .04 |
| Tin | .0003 | .0006 | n.d. | n.d. | n.d. | [3].001 | n.d. |
| Boron | .0003 | [3].003 | [3].008 | .005 | [3].004 | .070 | [3].004 |
| Ytterbium | .0003 | .0005 | .0005 | .0004 | .0002 | .0020 | .01 |
| Erbium | .0003 | n.d. | n.d. | n.d. | n.d. | n.d. | .02 |
| Germanium | .0002 | n.d. | n.d. | n.d. | n.d. | .006 | n.d. |
| Beryllium | .0002 | .0002 | n.d. | n.d. | n.d. | .001 | .0004 |
| Arsenic | .0002 | n.d. | n.d. | n.d. | n.d. | .29 | n.d. |
| Uranium | .0002 | .00055 | .0005 | .0002 | [3].00015 | .59 | .14 |
| Molybdenum | .0001 | .0006 | n.d. | n.d. | n.d. | .28 | .001 |
| Silver | .00001 | n.d. | n.d. | n.d. | n.d. | .00002 | n.d. |

[1] Converted from parts per million with rounding.
[2] Average ash content of sample is 34 percent.
[3] Element detected in only a few samples. Average content is of doubtful significance.

studies and mapping were not undertaken. Most of these samples are from areas known to contain uranium-bearing carbonaceous rocks. They may be useful in prospecting at localities where the water has abnormally high contents of uranium. The locations from which these samples were collected are not shown on maps accompanying this report. They were located in the field on aerial photographs or county road maps and are listed in the following table to the nearest quarter section.

*Analyses for uranium in water samples from wells and springs in Harding and Perkins Counties, S. Dak.*

[Analysts: G. T. Burrow, R. Daywitt, E. J. Fennelly, Mary Finch, J. Johnson, J. McClure, and J. P. Schuch]

| Source of sample | Special No. | Location | | | Uranium content (ppb) | pH | Formation |
|---|---|---|---|---|---|---|---|
| | | Sec. | Township north | Range east | | | |
| **Harding County** | | | | | | | |
| Well | 232442 | NE¼ 21 | 16 | 4 | 1 | 8.3 | Hell Creek. |
| Spring | 234963 | NE¼ 4 | 20 | 5 | 2 | 7.6 | Fort Union. |
| Well | 235786 | SE¼ 31 | 20 | 6 | [1]< 1 | 7.9 | Hell Creek. |
| Spring | 236918 | NE¼ 36 | 21 | 4 | 5 | 7.8 | Fort Union. |
| Do | 919 | NE¼ 36 | 21 | 4 | 4 | 8.0 | Do. |
| Reservoir | 217616 | NW¼ 4 | 21 | 5 | 26 | 8.5 | Do. |
| Well | 231944 | NW¼ 15 | 21 | 5 | 12 | 8.0 | Hell Creek. |
| Reservoir | 236917 | SW¼ 15 | 21 | 5 | 8 | 8.3 | Fort Union. |
| Well | 231954 | NE¼ 19 | 21 | 5 | 31 | 8.0 | Do. |
| Spring | 236927 | NW¼ 28 | 21 | 5 | 3 | 8.1 | Do. |
| Do | 231946 | SE¼ 30 | 21 | 5 | 8 | 7.5 | Do. |
| Do | 945 | NE¼ 33 | 21 | 5 | 6 | 7.8 | Do. |
| Spring | 233525 | NW¼ 8 | 22 | 4 | 1 | 8.8 | Do. |
| Do | 526 | NW¼ 8 | 22 | 4 | 50 | 8.9 | Do. |
| Do | 527 | NW¼ 8 | 22 | 4 | 1 | 8.9 | Do. |
| Do | 234972 | SE¼ 5 | 22 | 4 | 2 | 8.1 | Do. |
| Well | 236920 | NW¼ 1 | 22 | 5 | 4 | 7.9 | Do. |
| Spring | 921 | SE¼ 2 | 22 | 5 | 1 | 7.7 | Do. |
| Do | 234971 | SE¼ 3 | 22 | 5 | 3 | 8.3 | Do. |
| Spring | 964 | SW¼ 9 | 22 | 5 | 6 | 7.6 | Do. |
| Do | 233528 | SW¼ 10 | 22 | 5 | 3 | 8.2 | Do. |
| Do | 236922 | NW¼ 11 | 22 | 5 | 11 | 7.7 | Do. |
| Do | 924 | SW¼ 11 | 22 | 5 | <1 | 8.3 | Do. |
| Do | 221924 | SW¼ 15 | 22 | 5 | 3 | 8.1 | Do. |
| Do | 233518 | NE¼ 15 | 22 | 5 | 1 | 8.8 | Do. |
| Do | 231947 | SW¼ 15 | 22 | 5 | 18 | 7.8 | Do. |
| Do | 949 | SE¼ 15 | 22 | 5 | 8 | 7.7 | Do. |
| Do | 953 | NE¼ 15 | 22 | 5 | 17 | 8.0 | Do. |
| Do | 958 | NE¼ 15 | 22 | 5 | 5 | 7.7 | Do. |
| Reservoir | 234975 | SE¼ 16 | 22 | 5 | 10 | 7.8 | Do. |
| Spring | 965 | NW¼ 16 | 22 | 5 | 1 | 7.9 | Do. |
| Do | 966 | SW¼ 16 | 22 | 5 | 1 | 8.2 | Do. |
| Do | 967 | SE¼ 17 | 22 | 5 | 5 | 8.7 | Do. |
| Do | 968 | SW¼ 18 | 22 | 5 | 17 | 8.6 | Do. |
| Do | 969 | SE¼ 19 | 22 | 5 | 1 | 7.7 | Do. |
| Do | 233521 | NE¼ 20 | 22 | 5 | 1 | 9.3 | Do. |
| Do | 522 | NE¼ 20 | 22 | 5 | 32 | 9.1 | Do. |
| Do | 523 | NE¼ 20 | 22 | 5 | 1 | 8.9 | Do. |
| Do | 524 | NW¼ 21 | 22 | 5 | 1 | 9.0 | Do. |
| Reservoir | 234974 | NE¼ 21 | 22 | 5 | 2 | 7.7 | Do. |
| Spring | 231948 | NE¼ 22 | 22 | 5 | 27 | 7.8 | Do. |
| Do | 950 | NE¼ 22 | 22 | 5 | 27 | 7.8 | Do. |
| Do | 951 | NE¼ 22 | 22 | 5 | 70 | 7.9 | Do. |
| Do | 952 | C 22 | 22 | 5 | 3 | 7.8 | Do. |
| Do | 222840 | NW¼ 22 | 22 | 5 | 2 | 8.2 | Do. |
| Do | 234252 | SE¼ 22 | 22 | 5 | [1]3 | 8.3 | Do. |
| Do | 230309 | NW¼ 22 | 22 | 5 | [1]15 | 7.8 | Do. |
| Do | 233529 | SW¼ 23 | 22 | 5 | 34 | 8.4 | Do. |
| Do | 231957 | SW¼ 23 | 22 | 5 | 20 | 8.0 | Do. |
| Do | 956 | NW¼ 26 | 22 | 5 | 290 | 7.7 | Do. |
| Reservoir | 236925 | SW¼ 26 | 22 | 5 | 2 | 7.4 | Do. |
| Spring | 926 | NW¼ 26 | 22 | 5 | 128 | 8.2 | Do. |
| Do | 235674 | NW¼ 26 | 22 | 5 | [1]245 | 7.7 | Do. |
| Do | 233531 | NW¼ 27 | 22 | 5 | 13 | 8.7 | Do. |
| Do | 217618 | NW¼ 27 | 22 | 5 | 15 | 8.4 | Do. |
| Do | 234251 | NE¼ 27 | 22 | 5 | [1]12 | 8.8 | Do. |
| Reservoir | 217619 | NE¼ 28 | 22 | 5 | 1 | 8.1 | Do. |
| Spring | 234970 | NE¼ 33 | 22 | 5 | 5 | 8.4 | Do. |

See footnote at end of table.

*Analyses for uranium in water samples from wells and springs in Harding and Perkins Counties, S. Dak.*—Continued

| Source of sample | Sample No. | Location: Sec. | Location: Township north | Location: Range east | Uranium content (ppb) | pH | Formation |
|---|---|---|---|---|---|---|---|
| **Harding County—Continued** | | | | | | | |
| Reservoir | 973 | SW¼ 34 | 22 | 5 | 124 | 7. 9 | Fort Union. |
| Do | 976 | SE¼ 34 | 22 | 5 | 28 | 9. 6 | Do. |
| Spring | 977 | SE¼ 34 | 22 | 5 | 2 | 8. 6 | Do. |
| Do | 236923 | NW¼ 36 | 22 | 5 | 22 | 8. 0 | Do. |
| **Perkins County** | | | | | | | |
| Reservoir | 216375 | NW¼ 28 | 17 | 15 | 1 | 7. 8 | Fort Union. |
| Well | 236650 | SE¼ 8 | 18 | 11 | 1 | 8. 2 | Do. |
| Spring | 216353 | C 10 | 18 | 13 | 1 | 7. 7 | Do. |
| Well | 352 | SW¼ 10 | 18 | 13 | 1 | 8. 1 | Hell Creek. |
| Do | 236649 | SW¼ 34 | 18 | 16 | 1 | 8. 1 | Do. |
| Do | 216372 | NE¼ 35 | 19 | 14 | 1 | 8. 1 | Fort Union. |
| Do | 377 | C 12 | 21 | 11 | 11 | 7. 6 | Do. |
| Spring | 361 | SE¼ 12 | 21 | 11 | 83 | 7. 4 | Do. |
| Do | 367 | C 2 | 21 | 12 | 1 | 7. 0 | Do. |
| Do | 363 | SW¼ 15 | 21 | 12 | 83 | 8. 0 | Do. |
| Reservoir | 364 | NE¼ 15 | 21 | 12 | 38 | 7. 6 | Do. |
| Do | 362 | NE¼ 30 | 21 | 16 | 5 | 8. 0 | Do. |
| Spring | 369 | NW¼ 20 | 22 | 9 | 22 | 8. 0 | Do. |
| Well | 373 | NE¼ 33 | 22 | 12 | 38 | 7. 5 | Do. |
| Well | 354 | NW¼ 23 | 23 | 15 | 3 | 7. 3 | Do. |

[1] Sample analyzed for selected trace elements. (See tables 10 and 11.)

*Analyses for uranium in water samples from wells and springs in Adams, Billings, Bowman, Dunn, Golden Valley, Grant, Hettinger McKenzie, Slope, and Stark Counties, N. Dak.*

[Analysts: J. McClure and J. P. Schuch]

| Source of sample | Sample No. | Location: Sec. | Location: Township north | Location: Range west | Uranium content (ppb) | pH | Formation |
|---|---|---|---|---|---|---|---|
| **Adams County** | | | | | | | |
| Well | 221934 | SW¼ 23 | 130 | 97 | 31 | 8. 1 | Fort Union. |
| Do | 933 | SE¼ 24 | 131 | 97 | 1 | 8. 5 | Do. |
| Do | 932 | SE¼ 19 | 132 | 98 | 5 | 8. 0 | Do. |
| **Billings County** | | | | | | | |
| Well | 236661 | NE¼ 5 | 137 | 100 | 11 | 8. 3 | Fort Union. |
| Spring | 662 | SE¼ 28 | 137 | 100 | 1 | 7. 9 | Do. |
| Do | 230231 | SE¼ 28 | 137 | 100 | 12 | 7. 7 | Do. |
| Do | 233519 | SW¼ 29 | 137 | 100 | 13 | 8. 6 | Do. |
| **Bowman County** | | | | | | | |
| Well | 221919 | NE¼ 36 | 132 | 102 | 8 | 7. 8 | Fort Union. |
| Do | 248416 | SE¼ 11 | 131 | 102 | [1] 6 | 9. 6 | Hell Creek. |
| **Dunn County** | | | | | | | |
| Spring | 222833 | SE¼ 3 | 146 | 96 | 6 | 8. 1 | Arikaree. |
| Do | 832 | SE¼ 3 | 146 | 96 | 1 | 8. 1 | Golden Valley. |
| Do | 829 | SE¼ 16 | 147 | 96 | 1 | 8. 4 | Fort Union. |
| Well | 830 | SW¼ 36 | 147 | 96 | 1 | 8. 2 | Do. |
| Spring | 831 | SW¼ 36 | 147 | 96 | 2 | 8. 1 | Do. |

See footnote at end of table.

*Analyses for uranium in water samples from wells and springs in Adams, Billings, Bowman, Dunn, Golden Valley, Grant, Hettinger, McKenzie, Slope, and Stark Counties, N. Dak.*—Continued

| Source of sample | Sample No. | Location | | | | Uranium content (ppb) | pH | Formation |
|---|---|---|---|---|---|---|---|---|
| | | Sec. | | Township north | Range west | | | |
| **Golden Valley County** | | | | | | | | |
| Well | 222838 | SW¼ | 21 | 140 | 104 | 4 | 9. 0 | Fort Union. |
| **Grant County** | | | | | | | | |
| Stream | 221935 | NW¼ | 9 | 130 | 90 | 4 | 8. 1 | Fort Union. |
| Do | 936 | NW¼ | 3 | 131 | 90 | 1 | 8. 3 | Do. |
| **Hettinger County** | | | | | | | | |
| Well | 221936 | SW¼ | 22 | 135 | 91 | 1 | 8. 9 | Fort Union. |
| Do | 915 | NE¼ | 36 | 135 | 94 | 1 | 4. 2 | Do. |
| Do | 916 | NW¼ | 12 | 135 | 95 | 11 | 7. 8 | Do. |
| Spring | 914 | SW¼ | 9 | 136 | 93 | 28 | 7. 9 | Do. |
| Well | 913 | SE¼ | 3 | 136 | 94 | 3 | 7. 7 | Do. |
| **McKenzie County** | | | | | | | | |
| Spring | 222828 | SE¼ | 13 | 149 | 99 | 1 | 8. 3 | Fort Union. |
| Well | 221922 | SW¼ | 5 | 150 | 101 | 1 | 8. 8 | Do. |
| **Slope County** | | | | | | | | |
| Spring | 233530 | SW¼ | 10 | 134 | 100 | 5 | 8. 5 | Fort Union. |
| Do | 222839 | NW¼ | 22 | 134 | 101 | 1 | 8. 2 | Do. |
| Do | 221917 | NE¼ | 19 | 135 | 98 | 8 | 8. 1 | Chadron. |
| Do | 918 | NW¼ | 19 | 135 | 98 | 6 | 8. 0 | Do. |
| Well | 233520 | SW¼ | 11 | 136 | 102 | 8 | 9. 2 | Fort Union. |
| **Stark County** | | | | | | | | |
| Spring | 221912 | SW¼ | 19 | 137 | 92 | 2 | 7. 8 | Fort Union. |
| Well | 911 | SW¼ | 16 | 139 | 91 | 2 | 8. 5 | Do. |
| Do | 910 | NW¼ | 11 | 139 | 92 | 1 | 7. 9 | Do. |

[1] Sample analyzed for selected trace elements, (See table 11.)

#### TRACE ELEMENTS IN BULK WATER SAMPLES

Trace elements other than uranium were determined by chemical and spectrographic analyses of residues obtained by evaporating large samples of ground water. The amounts of the various elements in the water were computed from the amounts in the residue. Ground water was analyzed from each of the following terranes: (1) acidic tuffs or tuffaceous sedimentary rocks of Oligocene and Miocene age that normally overlie the uranium deposits, (2) nontuffaceous rocks of Paleocene age that contain known occurrences of uranium, and (3) nontuffaceous rocks of Late Cretaceous and Paleocene age that are not near known uranium deposits. Results of these analyses are shown in tables 9–11. For comparative purposes each group of samples was averaged and plotted to show general relations in composition of ground water from each of the three terranes (fig. 25). Some of the relations are as follows: Water from all three terranes is alkaline, having a pH range of 8.2 to 8.8. The amount of dissolved solids varies markedly; the water from the tuff contains less than half the amount of dissolved solids found in water from nontuffaceous rocks. Water from the tuffs contains relatively high contents of uranium, vanadium, silicon, molybdenum, strontium, arsenic, and selenium. Most of these elements are also present in greater amounts in water from mineralized areas than those from barren areas.

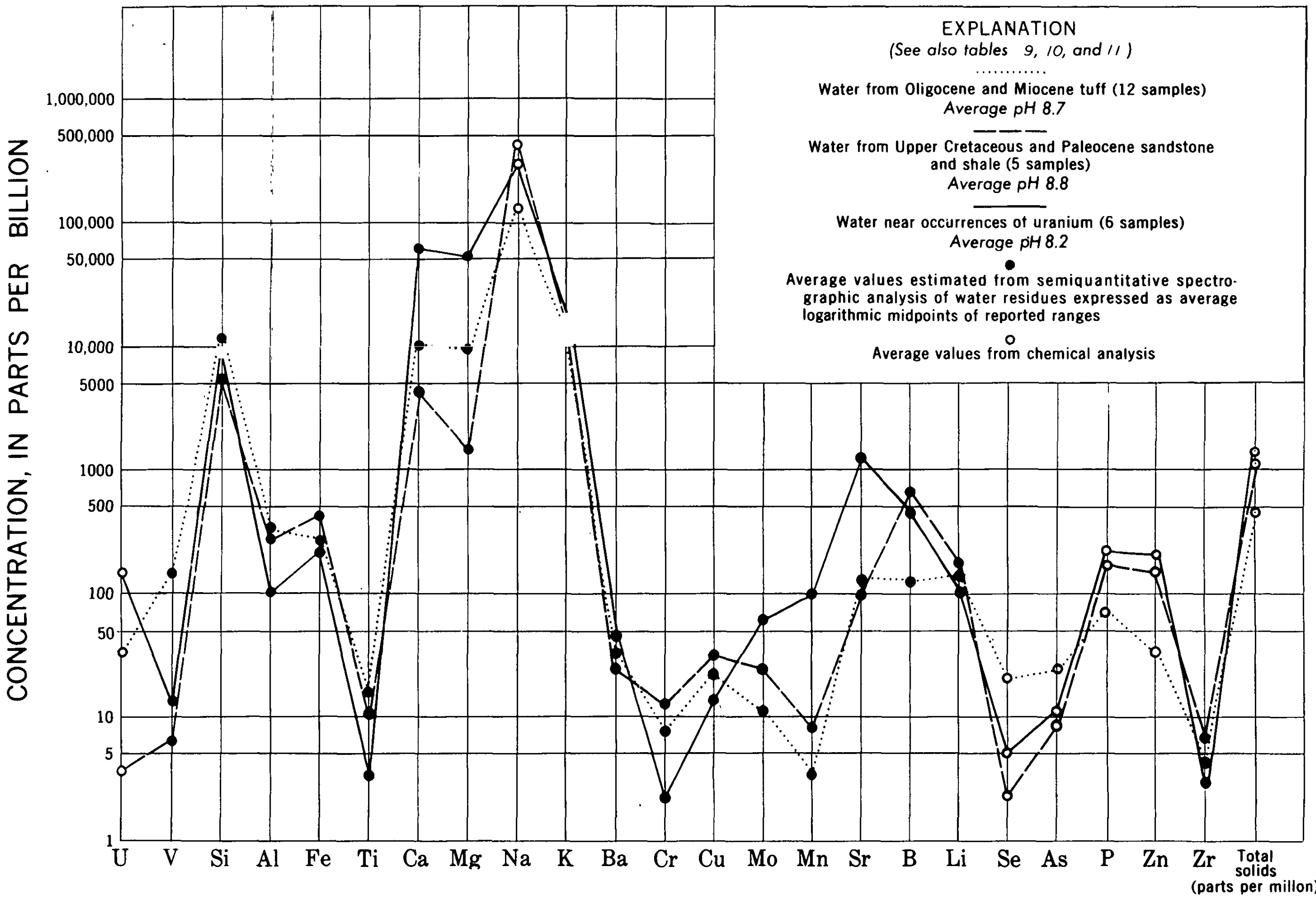



FIGURE 25.—Average composition of some water samples from eastern Montana and the Dakotas.

Scott and Barker (1958, p. 154) in their study of the radium and uranium content of ground water of the United States pointed out that although neither radium nor uranium correlates well with concentrations of the more common constituents of ground water, uranium tends to be somewhat more concentrated in water containing large amounts of the bicarbonate ion. Quality-of-water analyses of two large samples from uraniferous springs issuing near the base of the tuffaceous rocks in the Slim Buttes area of Harding County, S. Dak., show high contents (367 and 544 ppm) of bicarbonate ($HCO_3$) (Denson and others, 1959, p. 22). High alkalinity and high carbonate contents of ground water have been suggested to be an effective geochemical environment for solution of uranium from volcanic rocks (R. M. Garrels in U.S. Geol. Survey, 1957a, p. 554). The data presented herein indicate such a geochemical environment in the ground waters of the tuffaceous rocks and suggest that such waters may have been important uranium-bearing mineralizing solutions.

## SUMMARY OF GEOLOGIC AND GEOCHEMICAL RELATIONS OF URANIUM AND DISCUSSION OF ORIGIN

Uranium-bearing lignite and carbonaceous shale in the southwestern part of the Williston basin is widespread and occurs at many horizons throughout about 2,500 feet of basin-fill continental deposits ranging from Late Cretaceous to Eocene in age. A summary of analytical and stratigraphic data from 26 areas containing uranium-bearing carbonaceous rocks is presented in table 12, which indicates that the uraniferous beds average about 2 feet in thickness and contain about 0.008 to 0.2 percent uranium. Subsurface and surface data are not available to fully appraise the uranium potential of the region; however, reserves of rock containing greater than 0.1 percent of uranium are estimated to be in excess of 1 million tons. Much of these reserves are overlain by overburden thin enough to permit development by stripping methods.

The richer deposits are alined about north-south along the axis of the Williston basin. The more important uranium deposits occur in the North Cave Hills

TABLE 12.—*Summary of principal areas containing uranium-bearing carbonaceous rocks in Williston basin*

[All figures are in feet except as indicated. Elevations are as follows: AMS, Army Map Service 1:250,000 map series; alt, single-base altimetry; TS, U.S. Coast and Geodetic Survey or U.S. Geol. Survey triangulation station or bench mark; est, estimated from AMS map]

| Area | | | Formation containing deposits | Member | Principal bed containing uranium | | | | | | | Tuffaceous rocks (Oligocene and (or) Miocene) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Name | Location | Elevation of highest point | | | Name | Average thickness | Average uranium content (percent) | Elevation | Interval from bed to base of member or formation | Interval from bed to top of Pierre shale | Interval from bed to Precambrian | Total thickness | Elevation at base | Interval between base and mineralized bed |
| **NORTH DAKOTA** | | | | | | | | | | | | | | |
| **Billings County** | | | | | | | | | | | | | | |
| Bullion Butte | T. 137 N., R. 102 W. | 3,366 AMS | Fort Union | Sentinel Butte | Nunn [1] | 4.8 [1] | [1] 0.007 | 3,200 | 425 | 2,000 | 13,200 | 20 | 3,345 | 145 |
| Rocky Ridge | T. 137 N., R. 100 W. | 3,105 alt | do | do | Rocky Ridge | 2.0 | .200 | 2,900 | 350 | 2,000 | 13,200 | Absent | 3,125± | [2] 225± |
| Saddle Butte | T. 141 N., R. 99 W. | 2,840 alt | do | do | Unnamed | 2.0 | .200 | 2,630–2,760 | ? | 2,100 | 14,400 | Absent | [2] 2,900+ | [2] 200+ |
| **Bowman County** | | | | | | | | | | | | | | |
| Medicine Pole Hills | T. 130 N., R. 104 W. | 3,430 TS | Fort Union | Tongue River | Harmon [3] | 3.0 [3] | [3] 0.013 | 3,350 | 130 | 1,250 | 11,200 | 20 | 3,410 | 60 |
| **Dunn County** | | | | | | | | | | | | | | |
| Killdeer Mountains | T. 146 N., R. 96 W. | 3,314 TS | Golden Valley | | Unnamed | 1.0 | 0.006 | 2,700 | ? | 2,450 | 15,700 | 265 | 3,055 | 355 |
| **Golden Valley County** | | | | | | | | | | | | | | |
| Flat Top Butte | T. 139 N., R. 103 W. | 3,345 AMS | Fort Union | Sentinel Butte | Bed No. 3 [4] | 1.5 [4] | [4] 0.059 | 3,110± | 345± | 2,000± | 13,800 | 35 | 3,310 | 200± |
| Sentinel Butte | T. 139 N., R. 104 W. | 3,430 TS | do | do | Bed No. 5 [1] | 4.4 [1] | [1] .007 | 3,295 | 335 | 2,050 | 13,800 | 40 | 3,390 | 95 |
| **Grant County** | | | | | | | | | | | | | | |
| Coffin Butte | T. 131 N., R. 90 W. | 2,820 alt | Fort Union | Tongue River | Unnamed | 1.0 | 0.021 | 2,675 | ? | 1,400 | 9,800 | 100 | 2,680 | 5 |
| **Slope County** | | | | | | | | | | | | | | |
| Chalky Buttes | T. 134 N., R. 101 W. | 3,530 AMS | Fort Union | Sentinel Butte | Chalky Buttes [1] | 1.9 [1] | [1] 0.008 | 3,160 | 160 | 1,850 | 12,500 | 330+ | 3,200 | 40 |
| H T Butte | T. 134 N., Rs. 101–102 W. | 3,468 TS | do | do | Slide Butte [1] | 1.8 [1] | [1] .015 | 3,215 | 110 | 1,800 | 12,400 | 15 | 3,410 | 195 |
| Rainy Buttes | T. 135 N., R. 98 W. | 3,360 AMS | do | do | Unnamed | | | 2,850 | ? | 1,750 | 12,600 | 235 | 3,125 | 275 |
| Slide Butte | T. 134 N., R. 101 W. | 3,340 alt | do | do | Slide Butte [1] | 2.3 [1] | [1] .024 | 3,185 | 90 | 1,800 | 12,400 | 60 | 3,280 | 95 |
| **Stark County** | | | | | | | | | | | | | | |
| Little Badlands | Tps. 137–139 N., Rs. 97–98 W. | 3,061 TS | Golden Valley | | Unnamed | 0.5 | 0.09 | 2,660 | ? | 2,000 | 13,700 | 280 | 2,600–2,850 | 80 |
| **SOUTH DAKOTA** | | | | | | | | | | | | | | |
| **Harding County** | | | | | | | | | | | | | | |
| Bar H (Slim Buttes) | T. 19 N., R. 8 E. | 3,624 TS | Fort Union | Ludlow | Bar H [3] | Upper 5 ft of 12-ft bed.[3] | [3] 0.010 | 3,125 | ? | 950 | 9,700 | 404 | 3,220 | 95 |
| Cedar Canyon (Slim Buttes). | T. 16 N., R. 8 E. | 3,685 AMS | do | do | Bed X | 1.7 | .100 | 3,220 | ? | 700 | 9,300 | 365 | 3,260 | 45–60 |
| East Short Pine Hills | Tps. 16–17 N., Rs. 3–4 E. | 4,015 AMS | Hell Creek | | Unnamed | .8 | .100 | 3,470 | 500± | 550 | 9,000 | 515 | 3,500 | 30 |
| North Cave Hills | Tps. 21–22 N., R. 5 E. | 3,440 alt | Fort Union | Tongue River | Bed E [5] | 2.0 [5] | [5] .270 | 3,300 | 100 | 1,050 | 10,300 | 20 | 3,430 | 130 |
| South Cave Hills | Tps. 20–21 N., Rs. 4–5 E. | 3,430 alt | do | Ludlow | Lonesome Pete [5] | .5 [5] | [5] .160 | 3,240 | 275 | 800 | 9,900 | 50 | 3,380 | 140 |
| Table Mountain | T. 22 N., R. 4 E. | 3,607 TS | do | do | Bed D [6] | 2 [6] | [6] .008 | 3,455 | 370 | 1,050 | 10,400 | Absent | [2] 3,610± | [2] 155+ |

See footnotes at end of table.

TAALE 12.—*Summary of principal areas containing uranium-bearing carbonaceous rocks in Williston basin*—Continued

[All figures are in feet except as indicated. Elevations are as follows: AMS, Army Map Service 1:250,000 map series; alt, single-base altimetry; TS, U.S. Coast and Geodetic Survey of U.S. Geol. Survey triangulation station or bench mark; est, estimated from AMS map]

| Area | | | Formation containing deposits | Member | Principal bed containing uranium | | | | | | | Tuffaceous rocks (Oligocene and (or) Miocene) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Name | Location | Elevation of highest point | | | Name | Average thickness | Average uranium content (percent) | Elevation | Interval from bed to base of member or formation | Interval from bed to top of Pierre shale | Interval from bed to Precambrian | Total thickness | Elevation at base | Interval between base and mineralized bed |
| **Perkins County** | | | | | | | | | | | | | | |
| Johnson Outlier | T. 21 N., R. 11 E. | 3,020 alt | Fort Union | Tongue River | Harmon [3] | Upper 3 ft of 6.0-ft beds.[3] | [3] 0.010 | 2,990 | ? | 1,000 | 10,000 | Absent | [2] 3,025± | [2] 35± |
| Lodgepole Area | T. 21 N., R. 12 E. | 3,050 AMS | do | do | do [3] | 4 [3] | [3] .010 | 2,910 | ? | 1,000 | 9,800 | do | [2] 3,050− | [2] 140− |
| **MONTANA** | | | | | | | | | | | | | | |
| **Carter County** | | | | | | | | | | | | | | |
| Ekalaka Hills | T. 1 N., Rs. 58–59 E. | 4,115 AMS | Fort Union | Ludlow | Cleveland [7] | 1.5 [7] | [7] 0.016 | 3,870 | ? | 1,100 | 11,000 | 215 | 3,800–3,900 | 30 |
| Long Pine Hills | Tps. 1–3 S., Rs. 60–62E | 4,130 AMS | Hell Creek | | Unnamed | .5 | .10 | 3,685 | 450± | 500 | 9,200 | 430 | 3,700–3,950 | 190 |
| **Fallon County** | | | | | | | | | | | | | | |
| Ollie Area | T. 10 N., Rs. 60–61 E. | 3,285 alt | Fort Union | Tongue River | Unnamed [8] | 1.0 | 0.18 | 3,195 | ? | 1,150 | 11,900 | Absent | [2] 3,500± | [2] 300± |
| **Powder River County** | | | | | | | | | | | | | | |
| Bay Horse | T. 9 S., R. 50 E. | 4,320 AMS | Fort Union | | Unnamed | 2.0 | 0.016 | 3,850 | ? | 2,750 | 10,800 | Absent | [2] 4,800± | [2] 470± |
| **Wibaux County** | | | | | | | | | | | | | | |
| Blue Butte | T. 17 N., R. 59 E. | 3,075± est | Fort Union | Sentinel Butte | Unnamed [4] | 0.5 [4] | [4] 0.009 | 3,000± | 150± | 1,850± | 13,800 | Absent | [2] 3,200± | [2] 200± |

[1] Moore, Melin, and Kepferle (1959).
[2] Where tuffaceous rocks are absent, the elevation at the base and the interval from base to the mineralized bed are inferred.
[3] Zeller and Schopf (1959).
[4] Beroni and Bauer (1952).
[5] Pipiringos, Chisholm, and Kepferle (1964).
[6] Denson, Bachman, and Zeller (1959).
[7] Gill (1959).
[8] Towse (1957).

and Slim Buttes (Cedar Canyon area), Harding County, S. Dak., and along the Little Missouri River escarpment in the vicinity of Saddle Butte and Rocky Ridge in eastern Billings County and in northwestern Stark County, N. Dak.

In these areas the relatively thin lenticular carbonaceous beds, which are the principal host for uranium, contain about 35 to 40 percent ash and have relatively low heating values. The thicker and more persistent lignite beds at most places contain less ash, but because they are less pervious, they do not easily admit mineralizing solutions. With few exceptions the richest and largest deposits in the basin are overlain by massive thick porous sandstone beds. These sandstone beds, some of which are more than 200 feet thick, have probably conducted the mineralizing solutions laterally for long distances. Local shallow troughs have probably been of primary importance in concentrating the flow of the ground water to the sites of deposition.

Downward and laterally migrating ground waters appear to have leached uranium from tuffaceous materials in the Oligocene and Miocene rocks and redeposited it in the carbonaceous rocks in the region. The tuffaceous rocks contain small quantities of uranium and other trace metals including arsenic, selenium, vanadium, copper, and phosphorus. Analyses of waters draining remnants of volcanic rocks show them to be high in bicarbonate-ion ($HCO_3$) content and alkaline (average pH, 8.5), and to contain 20 ppb or more uranium. In unmineralized areas, ground water from the underlying rocks is also alkaline and, although it carries more than twice the dissolved solids found in water from the volcanic rocks, its uranium content is generally not more than 3 ppb.

Carbonaceous material in the host rocks of the Williston basin is probably the primary reducing agent that caused uranium to precipitate from solution. Other reducing agents, such as hydrogen sulfide in natural gases, may have entered the ground-water system along faults or surfaces of unconformities near the crests of anticlines, and may also have been active in precipitating uranium. The fact that hydrogen sulfide is highly soluble in water suggests it could have been transported by ground water over wide areas. Furthermore, large volumes of natural gas are present at shallow depths (500 to 900 ft) at many localities along the Cedar Creek anticline 15 to 70 miles west of the principal uranium occurrences (Dobbin and Larsen, 1934; Erdmann and Larsen, 1934). Tectonic movements along this and other anticlines in the basin that formed after middle and late Tertiary time may have permitted natural gases, which may have contained hydrogen sulfide, to escape into the ground-water system. If so, uranium deposits may not be restricted to the carbonaceous rocks of the region but may eventually be found in commercial quantities in the thick arkosic sandstone beds which are barren of carbonaceous materials. For data on the role of hydrogen sulfide as a reducing agent in the precipitation of uranium, and its possible influence on the origin of certain uranium deposits in noncarbonaceous rocks in the intermontane Tertiary basin areas of south-central Wyoming, the reader is referred to Gruner (1952), Miller (1955), and Grutt (1957).

The occurrence of Pliocene (?) fossils in pediment deposits flanking the Ekalaka Hills and of Pleistocene fossils in similar deposits at the base of Slim Buttes suggests that at least in parts of the Williston basin much of the tuffaceous rocks of Oligocene and Miocene age had been removed by erosion by late Tertiary time. The age and physiographic relations of the volcanic materials to the known uranium deposits in the underlying rocks indicate that uranium mineralization may have started in late Miocene and in some areas where the volcanic materials have not been removed by erosion may still be going on today.

The structural and stratigraphic setting of the uranium deposits in the Williston basin has counterparts in many areas in the northern Great Plains and adjacent intermontane basins. It seems likely, therefore, that further prospecting of the thick arkosic sandstone beds and associated carbonaceous rocks in the region will reveal additional commercially important reserves of uranium.

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# INDEX

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(Continued on next card)

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