Geology and Mineral Deposits of the Carlile Quadrangle Crook County, Wyoming

By M. H. BERGENDAHL, R. E. DAVIS, *and* G. A. IZETT

CONTRIBUTIONS TO ECONOMIC GEOLOGY

GEOLOGICAL SURVEY BULLETIN 1082-J

Prepared on behalf of the Atomic Energy Commission and published with permission of the Commission

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1961

UNITED STATES DEPARTMENT OF THE INTERIOR

FRED A. SEATON, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington 25, D.C.

CONTENTS

ILLUSTRATIONS

[Plates 34-38 in pocket]

TABLES

CONTRIBUTIONS TO ECONOMIC GEOLOGY

GEOLOGY AND MINERAL DEPOSITS OF THE CARLILE QUADRANGLE, CROOK COUNTY, WYOMING

By M. H. Bergendahl, R. E. Davis, and G. A. Izett

ABSTRACT

The Carlile quadrangle is along the northwestern flank of the Black Hills uplift in Crook County, Wyo. The area is primarily one of canyons and divides that are a result of downcutting by the Belle Fourche River and its tributaries through an alternating succession of sandstone, siltstone, and mudstone or shale beds. The present topography is also influenced by the regional structure, as reflected by the beds that dip gently westward and by the local structural features such as anticlines, domes, synclines, basins, and terraces, which are superimposed upon the regional setting.

Rocks exposed include shale and thin limestone and sandstone beds belonging to the Redwater shale member of the Sundance formation and to the Morrison formation, both of Late Jurassic age; sandstone, siltstone, and mudstone of the Lakota and Fall River formations of Early Cretaceous age; and shale and sandstone of the Skull Creek shale, Newcastle sandstone, and Mowry shale, also of Early Cretaceous age. In the southwestern part of the quadrangle rocks of the Upper Cretaceous series are exposed. These include the Belle Fourche shale, Greenhorn formation, and Carlile shale. Gravel terraces, landslide debris, and stream alluvium comprise the surficial deposits.

The Lakota and Fall River formations, which make up the Inyan Kara group, contain uranium deposits locally in the northern Black Hills. These formations were informally subdivided in order to show clearly the vertical and lateral distribution of the sandstone, siltstone, and mudstone facies within them. The Lakota was subdivided into a sandstone unit and an overlying mudstone unit; the Fall River was subdivided, in ascending order, into a siltstone unit, a mudstone unit, a sandstone unit, and an upper unit. The lithologic character of the Lakota changes abruptly locally and the units are quite inconsistent with respect to composition, thickness, and extent. This is in contrast to a notable consistency in the lithologic character and thickness among all the Fall River units, with the exception of the upper unit. Petrographic studies on selected samples of units from both formations show differences in composition between Lakota and Fall River rocks.

The Carlile quadrangle lies immediately east of the monocline that marks the outer limit of the Black Hills uplift, and the rocks in this area have a regional dip of less than 2° outward from the center of the uplift. Superimposed upon the regional uplift are many subordinate structural features—anticlines, synclines, domes, basins, and terraces—which locally modify the regional

features. The most pronounced of these subordinate structural features are the doubly-plunging Pine Ridge, Oil Butte, and Dakota Divide anticlines, and the Eggie Creek syncline. Stress throughout the area was relieved almost entirely through folding; only a few small nearly vertical normal faults were found within the quadrangle.

Uranium has been mined from the Carlile deposit, owned by the Homestake Mining Co. The ore minerals, carnotite and tyuyamnuite occur in a sandstone lens that is enclosed within relatively impermeable clayey beds in the mudstone unit of the Lakota formation. The ore also includes unidentified black vanadium minerals and possibly coffinite. Uranium minerals are more abundant in and adjacent to thicker carbonaceous and silty seams in the sandstone lens. A mixture of fine-grained calcium carbonate and calcium sulfate fills the interstices between detrital quartz grains in mineralized sandstone. Selenium and arsenic are more abundant in samples that are high in uranium.

Drilling on Thorn Divide, about 1 mile west of the Carlile mine has roughly outlined concentrations of a sooty black uranium mineral associated with pyrite in two stratigraphic intervals of the Lakota formation. One is in the same sandstone lens that contains the ore at the Carlile mine; the other is in conglomeratic sandstone near the base of the Lakota. These deposits are relatively deep, and no mining has been attempted.

The mineralogy of the Carlile deposits and the lithologic features of the sandstone host rock suggest that uranium and vanadium were transported in the high-valent state by carbonate or sulfate solutions, were extracted from solution by organic material, and were reduced to low-valent states to form an original assemblage of oxides and silicates. These primary minerals were oxidized in place, and the present carnotite-tyuyamunite assemblage was formed. In general, radioactivity analyses correspond fairly closely with chemical analyses of uranium, thus it is believed that only minor solution and migration of uranium has occurred since the present suite of oxidized minerals was formed.

The factors responsible for ore localization are not clear, but probably a combination of three lithologic and structural elements contributed to provide a favorable environment for precipitating uranium from aqueous solutions: abundant carbonaceous material or pyrite in a thin, permeable sandstone enclosed within relatively thick impermeable clays; local structural basins; and a regional structural setting involving a broad syncline between two anticlines. The structural features controlled the regional flow of ground water and the lithologic features controlled the local rate of flow and provided the proper chemical environment for uranium deposition.

Bentonite has been mined from an opencut in the Mowry shale in the southwest part of the quadrangle. A bentonite bed in the Newcastle sandstone also seems to be of minable thickness and quality.

Exploration for petroleum has been unsuccessful within the quadrangle; however, some wells that yielded oil were recently drilled on small anticlines to the west and southeast. It is possible that similar structural features in the Carlile area, that were previously overlooked, may be equally productive.

INTRODUCTION

LOCATION

The Carlile quadrangle occupies approximately 54 square miles in southwestern Crook County, Wyo. (fig. 58). It is bounded by latitudes 44°22′30″N. and 44°30′N. and by longitudes 104°45′W. and 104°52′30″W. Carlile, the only settlement within the area, is in the

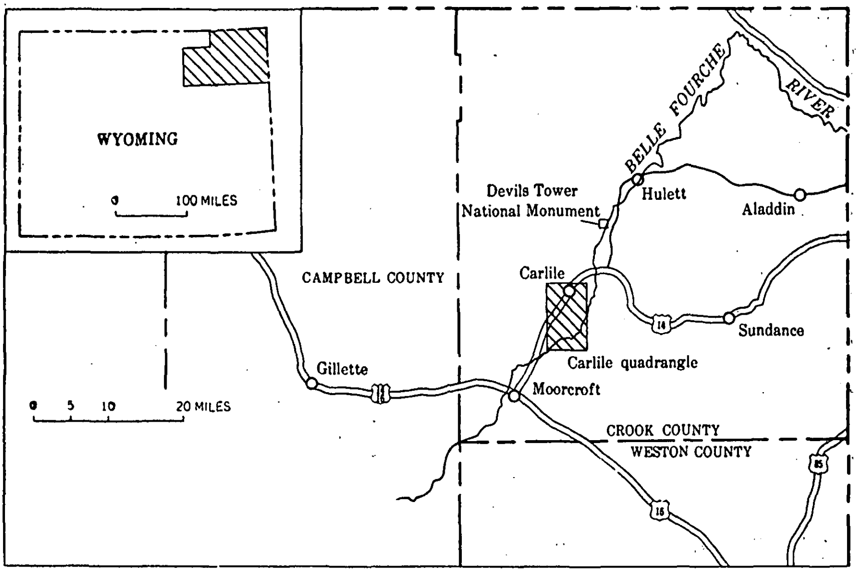


FIGURE 58.—Index map showing location of Carlile quadrangle, Wyoming.

northern part of the quadrangle and is about 18 miles north of Moorcroft on U.S. Highway 14. Devils Tower National Monument is approximately 9 miles north-northeast of Carlile.

PURPOSE AND SCOPE OF THE INVESTIGATION

Geologic mapping of the Carlile quadrangle, which includes one of several uranium-producing areas in northeastern Wyoming, was undertaken to provide a detailed geologic map that could be used as an aid to further exploration for uranium deposits; to study in detail the known uranium deposits to determine whether or not there are any relations among structure, stratigraphy, lithology, and uranium deposits; and to outline, insofar as possible, areas favorable for more detailed exploration for uranium.

Fieldwork was conducted by Bergendahl and Davis during the summer of 1955 and by Bergendahl and Izett during 1956. The work included geologic mapping of the quadrangle at a scale of 1:12,000, plane-table mapping of the surface workings of the Carlile mine and adjacent areas, and mapping of the underground workings of the mine.

The work was done on behalf of the Division of Raw Materials of the U.S. Atomic Energy Commission.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to the Homestake Mining Co. for granting permission to publish information concerning the Carlile mine and to Shannon Oil Co. for permitting publication of data on the Thorn Divide deposit. To Mr. James O. Harder, chief Geologist, and Mr. Robert Sargent, geologist, of Homestake Mining Co., to geologists of the Atomic Energy Commission, members of Defense Minerals Exploration Administration field teams, and to their colleagues of the U.S. Geological Survey, the authors extend their thanks. All these people gave freely of their time and information and cooperate fully in various phases of the project.

The authors also gratefully acknowledge the analytical work done by the following members of the U.S. Geological Survey: C. G. Angelo, C. Annell, G. T. Burrow, N. M. Conklin, Mary Finch, J. Haffty, J. C. Hamilton, Claude Huffman, H. H. Lipp, D. L. Schafer, J. P. Schuch, James Wahlberg, and J. E. Wilson.

PREVIOUS WORK

The first systematic study of the geology of the northern Black Hills region was made by N. H. Darton and his colleagues. The Carlile quadrangle was not part of any of the 30-minute quadrangles mapped by Darton, but it was included in his regional map of the northern Black Hills (Darton, 1909, pl. IV), which was published at a scale of 1:250,000. The general geologic features of the Black Hills region, many of which are represented in the Carlile area, were described by Darton (1905, 1909) and by Dayton and O'Harra (1905, 1907). Several years later V. H. Barnett (1915) mapped and briefly described the geology of the Moorcroft oil field, which includes the extreme western margin, the northwest corner, and the southwest quarter of the quadrangle. His small-scale geologic map shows the general pattern of outcrop and the structure of that area.

During the period 1922–24 the northern and western flanks of the Black Hills were mapped by W. W. Rubey and his associates; the Carlile quadrangle was included in this work. Although the maps were not published, Rubey has described certain aspects of the regional geology (Rubey, 1929, 1931).

More recently, as part of their studies of the bentonite deposits of the Missouri River basin, Knechtel and Patterson (1955) remapped a part of the northern Black Hills area using stratigraphic nomenclature proposed by Rubey (1931).

In 1954 and 1955, the mapping of Rubey and his associates, along with that of Knechtel and Patterson, was compiled, locally modified, and expanded by C. S. Robinson, W. J. Mapel, M. H. Bergendahl, and P. K. Theobald. Maps showing the geology and the major structural elements of the northern and western flanks of the Black Hills have recently been published (Mapel and others, 1959), and a report on the geology of the mapped area is in preparation.

A brief examination was made of the uranium deposits at the Carlile mine by the U.S. Atomic Energy Commission (R. H. Olson and A. C. Tennissen, 1952, written communication) and by W. A. Braddock of the U.S. Geological Survey, and uranium minerals in samples collected from the mine were described by Bodine (1954).

GEOGRAPHY

The upwarped rocks that encircle the central Black Hills exert considerable influence on the present surface features and to some extent on the drainage. Minor anticlines and synclines superimposed on the regional doming also are expressed by the topography. This structural control is shown in the Carlile quadrangle.

The eastern half of the quadrangle is characterized by broad undulating areas sloping gently to the west and dissected by canyons cut by the Belle Fourche River and its tributaries (pl. 34). Local relief between canyons and divides is commonly 300 to 400 feet. Green Hill, a small mesa about 250 feet higher than the surrounding area, is a conspicuous landmark in the north-central part of the quadrangle. In the western part of the quadrangle, the canyon and divide surface rises abruptly to a northwestward-trending ridge formed by the coalescent Pine Ridge and Oil Butte anticlines. The crest of the ridge stands as much as 500 feet higher than the flat areas on either side. A number of short deep canyons are cut into the steeply dipping limbs of these anticlines. In the southwestern corner of the quadrangle, soft shale beds have been eroded into a rolling plain that is interrupted locally by northwestward-trending hogbacks formed by more resistant limestone and sandstone.

Total relief in the quadrangle is about 800 feet; the altitudes range from 3,940 feet in the valley of Cabin Creek in the northeast corner to about 4,750 feet on the Oil Butte anticline near the western boundary.

The principal stream in the area is the Belle Fourche River, which meanders in a general northeastward direction across the southern and eastern margins of the quadrangle. Keyhole Dam, in the southeastern part of the quadrangle, impounds the Belle Fourche in Keyhole Reservoir, which fills the river valley and floods the lower reaches of Deer Creek, Eggie Creek, and dry tributary canyons along the southern boundary of the quadrangle. Several small tributary streams, most of them intermittent, flow southeast toward the Belle Fourche. These include Deer Creek, Eggie Creek, Spring Creek, and Black Gulch Creek. Cabin Creek and Dry Cabin Creek, in the northeastern part, flow eastward and northeastward into the Belle Fourche River.

The climate of the northwestern Black Hills area is semiarid with hot summers and cold winters. The average annual precipitation is about 15.5 inches, measured at Keyhole Dam, in the southeast corner of the quadrangle, and at Devils Tower, north of the quadrangle (U.S. Dept. of Commerce, 1951). Most of the precipitation occurs during the period from late spring to early fall.

The mean annual temperature, also taken from records at Keyhole Dam and Devils Tower, is slightly more than 42°F; temperatures range from more than 100°F to less than −30°F.

Canyon rims, as well as higher ridges, northward-facing slopes, and sheltered canyon sides support heavy stands of tall pine and juniper. Sage brush, native grasses, and some prickly pear are common on the flatlands. South-facing slopes and exposed canyon sides are bare of tall trees and generally are covered with grass and a few stunted pines.

Carlile (population 2), near the northern boundary of the quadrangle, consists of a general store and a U.S. Post Office. The area is well settled but thinly populated; the chief activities are cattle raising, farming, and occasional small-scale logging and sawmill operations. Much of the land is used as natural pasture, but on the flat divides and in the valley of the Belle Fourche River, crops such as alfalfa, wheat, oats, and corn are raised.

GENERAL GEOLOGY

The Carlile quadrangle is an area of sedimentary rocks that range in age from Late Jurassic to Recent. The total thickness of these rocks is about 1,850 feet. Uranium deposits occur in sandstones of the Inyan Kara group, of Early Cretaceous age, and for this reason, considerable emphasis is given to the stratigraphy and lithologic characteristics of this group.

The Carlile quadrangle is along a segment of the northwestern margin of the Black Hills uplift, immediately east of the Black Hills monocline that marks the outer limit of the uplift. The general features of the regional structure have been described by Darton (1909, p. 62–66) and are shown on a map by Mapel and others (1959).

The distribution of the formations, a summary of their lithologic characteristics, and the geologic structure are shown on plate 34.

STRATIGRAPHY

Most of the formations in the Carlile quadrangle are marine, but outcrops of these rocks occur only along the western edge, and in a discontinuous band extending from north to south in the central part, and in a narrow strip on the eastern edge along the valley of the Belle Fourche River. The rocks exposed throughout the greater part of the quadrangle are of continental or fluviomarine origin.

Marine deposition in Late Jurassic time is represented by the Sundance formation. The sea receded, toward the end of the Jurassic period, and an environment of alternating continental and, probably, estuarine conditions prevailed well into Early Cretaceous time. Deposition during this interval is represented by the Morrison, Lakota, and Fall River formations. A return to marine conditions followed the deposition of the Fall River formation and continued, with minor interruption during Newcastle time, throughout the remainder of the Early Cretaceous and most of the Late Cretaceous. A thick section, predominantly of dark shales, comprising the Skull Creek shale, part of the Newcastle sandstone, Mowry shale, Belle Fourche shale, Greenhorn formation, and Carlile shale was deposited during this submergence.

The formations are conformable with two exceptions; a disconformity occurs between the Lakota and Fall River formations, and between the Lakota and Morrison formations. These disconformities represent rather brief periods of nondeposition.

UPPER JURASSIC SERIES

SUNDANCE FORMATION

The Sundance formation, which is about 350 feet thick in this region, is the oldest rock unit exposed in the Carlile quadrangle. The rocks of the Sundance are of marine origin and consist predominantly of greenish-gray shale with many sandstone beds, the thicker beds persisting over large areas.

The Sundance formation in the Black Hills was first described and named by Darton (1899, p. 387–393). Imlay (1947) subdivided the formation in the Black Hills into the following members in ascending order: Canyon Springs sandstone, Stockade Beaver shale, Hulett sandstone, Lak, and Redwater shale members. In the Carlile quadrangle, exposures of the Sundance formation are limited to the upper part of the Redwater shale member.

The Redwater shale member forms gentle slopes, grass-covered and broken by outcrops of thin limestone and sandstone beds that form resistant ledges. Locally slope wash from the overlying Morrison and Lakota formations effectively conceals much of it. Soil formed on the Redwater shale member is easily recognized by its characteristic dark-greenish-gray color and by the presence of fossiliferous limestone fragments.

The total thickness of the Redwater shale member in this region is about 175 feet. In the northeastern corner of the quadrangle, along the lower reaches of Cabin Creek east of its junction with Dry Cabin Creek, the Redwater shale is exposed on the lower slopes above the alluvium and lower stream terraces. These exposures continue intermittently southward along the eastern margin of the quadrangle to the mouth of Black Gulch. It is exposed locally at lower elevations along the Belle Fourche River in secs. 10 and 11, T. 51 N., R. 66 W., and at the south end of the Pine Ridge anticline where the river has cut its channel across the southward-plunging anticlinal axis.

The Redwater shale member is composed of dark-greenish-gray glauconitic shale with several coquinoid limestone beds from 1 foot to 3 feet thick that occur chiefly in the upper half. A few thin calcareous and glauconitic sandstone beds from 6 inches to 3 feet thick also are present in the upper part. Gray limestone concretions, which range from a few inches to 2 feet in diameter, are common in the shale, and in many places the slopes are littered with belemnite fragments that have weathered out of the shale.

The uppermost bed of the Redwater shale member is a buff-colored, fine-grained, very friable, calcareous sandstone from 4 to 7 feet thick. Some of the quartz grains appear oolitic, owing to concentric deposition of thin layers of calcite around a quartz nucleus. Most of the quartz is etched and corroded by the interstitial calcite, and some quartz grains are almost completely replaced by calcite. Plagioclase feldspar and chert comprise a minor fraction of the detrital grains in the sandstone.

At two localities (sec. 35, T. 52 N., R. 66 W., and sec. 2, T. 51 N., R. 66 W.) the buff sandstone is overlain by a bed of massive white gypsum, which is also assigned to the Redwater. The gypsum bed is at least 5 feet thick and forms a narrow, northwestward-trending lens about 600 feet wide and at least one-half mile long. In sec. 2, T. 51 N., R. 66 W., the gypsum can be seen to pinch out to the south.

The contact of the Redwater shale member with the Lak member is not exposed in the mapped area. Imlay (1947, p. 260) reports the basal contact of the Redwater as sharp, with glauconitic sandstone resting on the nonglauconitic redbeds of the Lak; however, C. S. Robinson and others (written communication, 1957) state that locally the contact between the Lak and Redwater members may be gradational through a 2- to 3-foot interval of interbedded, nonglauconitic sandstone and greenish-gray shale.

The contact of the Redwater shale member of the Sundance with the overlying Morrison formation is fairly sharp. The buff sandstone grades upward through a few inches to a thin crinkly limestone that is the basal bed of the Morrison in this area. Where gypsum is the uppermost unit of the Redwater, the contact with the Morrison also is gradational but fairly sharp.

Late Jurassic marine fossils are abundant in the Redwater shale member, and Imlay (1947, p. 262–263) has published faunal lists from his collections in the Black Hills.

MORRISON FORMATION

The Morrison formation is the uppermost unit of the Upper Jurassic series in the Carlile quadrangle. It consists of variegated claystone beds containing minor thin lenses of sandstone and fresh water limestone. It was first described in the Black Hills by Darton (1899, p. 393–394) as the Beulah shales.

The Morrison formation forms moderately steep slopes that extend upward from the more gentle slopes underlain by the Redwater shale member of the Sundance. Slumped blocks of sandstone from the overlying Lakota formation commonly cover the upper part. The soil cover is thin, clayey, and contains chips of weathered claystone.

The thickness of the Morrison ranges from 80 to 100 feet in the Carlile quadrangle. It is exposed in the northeastern corner of the quadrangle, in the eastern part in a narrow band along the valley of the Belle Fourche River, at Keyhole Reservoir, and in several of the deeper canyons eroded into the limbs of the Pine Ridge and Oil Butte anticlines.

The bulk of the Morrison formation consists of maroon, green, gray, and yellow claystone. The upper 10–15 feet of the formation is dark-brown claystone that probably contains finely divided carbonaceous material and, locally, as in Black Gulch (sec. 34, T. 52 N., R. 66 W.), contains barite nodules ½ inch to 2 inches in diameter; thin papery seams of soft yellow clay occur in the uppermost few feet. The claystone in the upper 15 to 20 feet of the formation is noncalcareous. X-ray determinations of the clay minerals of Morrison samples were made by A. J. Gude, 3d. Illite, chlorite, and montmorillonite are the major constituents of both the calcareous and noncalcareous claystones. Calcite, quartz, and kaolinite are present in minor and trace amounts.

Beds of gray, sublithographic, slightly sandy limestone, less than 1.5 feet thick, occur in the calcareous part of the Morrison. The calcite is cryptocrystalline, and the sand grains are predominantly quartz, with minor amounts of chert and feldspar. The limestone beds are distinctive in that they weather into white irregular blocks and nodules.

Light-gray to white, fine-grained, calcareous sandstone lenses occur in the lower one-third of the formation. In any section measured not more than one sandstone bed was found, and none of them could be traced laterally for more than a mile. The thicknesses of the sandstone lenses range from a few inches to 8 feet; crossbedding at angles of 4° to 12° is conspicuous in the thicker parts. Stringers and galls of green clay are common along planes of stratification. The sand grains are quartz, with minor chert, microcline, and plagioclase feldspar; crystalline calcite is the intergranular material. The sand grains are etched and corroded by the calcite to such an extent that grain boundaries do not join.

At most exposures a bed of well indurated sandy limestone, 6 inches to 1.5 feet thick, is the basal unit of the Morrison. Wavy laminae less than 1 inch thick are characteristic of this unit. Pyrite cubes less than three-eighths of an inch across and veinlets of crystalline calcite are present locally.

The lower contact of the Morrison is rather sharp. An interval of 3 to 4 inches of sandy claystone separates the wavy-laminated limestone from the buff sandstone of the Redwater shale member of the Sundance. Where the limestone bed is absent, the buff sandstone of the Redwater grades from an iron-stained layer in the top 2 inches upward through 4 inches of structureless sandy claystone to a relatively sand-free claystone.

The upper contact of the Morrison is sharp and unconformable at most places. The basal conglomeratic sandstone of the Lakota formation lies on carbonaceous claystone of the Morrison with no gadational interval. Locally, as in the SW¼ SE¼ sec. 19, T. 51 N., R. 66 W., the lowermost 3–5 feet of the Lakota is composed of gray, thin-bedded, carbonaceous siltstone that weathers into platy chips. It is underlain by 2–3 feet of gray claystone assigned to the Morrison. The dark-brown carbonaceous claystone unit of the Morrison is exposed on the slopes below.

Although in the past the Morrison formation was regarded by some as Early Cretaceous in age (Darton, 1909, p. 37), Reeside (1952, p. 22) states that in recent years opinion is heavily in favor of assigning the Morrison to the Upper Jurassic. Vertebrate and invertebrate fossils have been found in the Morrison throughout the northern Black Hills. Darton and O'Harra (1907, p. 3) and Darton (1909, p. 40) reported dinosaur bones of Late Jurassic or Cretaceous age in the Morrison at various localities. Darton (1909, p. 40) also reported ostracodes belonging to the family *Cypridae* from the upper part of the formation. Yen (1952) describes the molluscan fauna of the Morrison, but none of his collections were from the Black Hills. Robinson and others (written communication, 1957) report saurian bones, ostracodes, charophytes, and the mollusk *Unio nucalis* Meek and Hayden from various exposures in the northwestern Black Hills. In the Carlile quadrangle, Morrison outcrops yielded only a few unidentifiable bone fragments and microscopic fragments of tests, presumably of ostracodes.

In the following four sections, measured at various localities in the Carlile quadrangle, the lithology of the Morrison formation is given in detail.

Morrison formation, NE¼, NW¼ sec. 29, T. 51 N., R. 66 W., Crook County, Wyo.

Lakota formation. Covered.	
Morrison formation:	*Feet*
8. Claystone, greenish-brown, carbonaceous; contains papery seams of yellow clay in upper 1 ft; contact with Lakota formation not exposed, but unslumped sandstone of Lakota crops out less than 2 ft above top of this interval	15
7. Claystone, variegated maroon and dark-greenish-gray; slightly sandy in upper part	13.6
6. Claystone, variegated maroon and green, calcareous; four beds, less than 1 ft thick, of gray sublithographic limestone that weathers into white nodules in this interval	48.4
5. Limestone, gray, slightly sandy, massive, blocky; weathers to white; contains green clay parting 0.1 ft thick, 0.5 ft below top	1.5
4. Limestone, gray, sandy; composed of wavy laminate with green clay partings	1.3
3. Mudstone, greenish-gray, calcareous, thinly laminated	1.1
2. Sandstone, grayish-tan, very fine-grained, calcareous, firmly cemented; composed of wavy laminae; thin limonite and calcite veinlets at base	.4
Total thickness of Morrison formation (rounded)	81
Sundance formation, Redwater shale member (in part):	
1. Sandstone, buff, very fine-grained; grains isolated in calcareous matrix; very friable, slightly crossbedded; contact with overlying unit is sharp	2.4

Morrison formation, NE¼, SE¼ sec. 19, T. 51 N., R. 66 W., Crook County, Wyo.

Lakota formation (in part):	
12. Sandstone, light-gray, fine- to coarse-grained; contains lenses of chert granules; forms a cliff; contact with underlying unit not exposed	30+
Morrison formation:	
11. Claystone, dark-green, brown in upper part	12.0
10. Covered	23.7
9. Claystone, variegated greenish-gray and maroon; calcareous	11.0
8. Siltstone, greenish-gray, clayey, calcareous; contains partings of green clay	.4
7. Claystone, variegated maroon and green; calcareous	13.8
6. Sandstone, light-greenish-gray, very fine-grained, calcareous, thin-bedded, massive- cross-stratified; green clay galls, and stringers along bedding	8.5
5. Claystone, variegated maroon and greenish-gray; calcareous	21.7
4. Claystone, greenish-gray, calcareous; contains several beds of gray sublithographic white-weathering limestone less than 1 ft thick; poorly exposed	5.5
3. Limestone, gray, slightly sandy, laminated; contains pyrite cubes, ¼ in across, and veinlets of calcite	1.2
2. Claystone, dark-gray, sandy, calcareous	.3
Total thickness of Morrison formation (rounded)	98
Sundance formation, Redwater shale number (in part):	
1. Sandstone, buff, very fine-grained, calcareous, friable, thick-bedded	2.4

Morrison formation, SE¼, NE¼ sec. 10, T. 51 N., R. 66 W., Crook County, Wyo.

Lakota formation. Sandstone, gray, medium-grained.	
Morrison formation:	*Feet*
7. Claystone, variegated maroon, blue-gray; calcareous in lower part; very poorly exposed; unslumped sandstone of Lakota formation exposed at top	65
6. Claystone, dark greenish-gray in lower 19.5 ft; variegated maroon and light greenish-gray in upper 8 ft; calcareous; chips of concretionary barite in float	27.5
5. Claystone, dark greenish-gray, calcareous; bed of gray sublithographic limestone 4 in thick at top; limestone weathers into white nodules	2.4
4. Sandstone, light-gray, very fine-grained, calcareous, firmly cemented	.5
3. Covered	2
2. Claystone, greenish-gray, sandy, gypsiferous	2.5
Total thickness of Morrison formation (rounded)	100
Sundance formation, Redwater shale member (in part):	
1. Sandstone, buff, very fine-grained, calcareous, friable to firmly cemented; lower 1 ft contains shale partings; upper 1 ft contains intergranular gypsum; upper 2 in is iron-stained; gradational through 4 in with overlying unit	7.3

Morrison formation, NW¼, NW¼ sec. 15, T. 52 N., R. 66 W., Crook County, Wyo.

Lakota formation (in part):	
7. Sandstone, gray, medium- to coarse-grained; conglomeratic lenses composed of chert granules; limonite stained in lower 6–8 in; forms a rounded cliff	25+
Morrison formation:	
6. Claystone, dark-maroon; becomes dark brown and carbonaceous in upper 1 ft; sharp contact with overlying unit	30
5. Claystone, variegated maroon, purple, grayish-green, yellow, calcareous; contains several beds of gray limestone less than 1 ft thick that weather to white nodules	34.5
4. Sandstone, light-gray, fine-grained, calcareous; low-angle cross-bedding in middle 6 in; green clay galls ⅜ in. in diameter, and bone fragments along bedding; forms a bench	2.5
3. Claystone, variegated maroon, grayish-green, calcareous; contains two beds of white-weathering gray sublithographic limestone, 6–8 in thick	15.5
Total thickness of Morrison formation (rounded)	82
Sundance formation, Redwater shale member (in part):	
2. Shale, dark-green and buff, silty, calcareous sandstone; thinly interlaminated shale and silty sandstone is interbedded with sandstone in units 2–4 in thick	2.5
1. Sandstone, buff, fine-grained, calcareous, very friable; contains scattered wavy lenses of chert less than ½ in thick; poorly exposed	1.5
Measured thickness of Redwater shale member	4

LOWER CRETACEOUS SERIES

INYAN KARA GROUP

Throughout the Black Hills, the lowermost rocks of Cretaceous age are those of the Inyan Kara group—a controversial collection of enigmatic units with a shadowy past and an uncertain future. The group is composed of complexly interfingering sandstones, mudstones, claystones, and siltstones of continental and possibly fluviomarine origin, underlain by the Morrison formation and overlain by the Skull Creek shale.

The group was named by Rubey (1931, p. 5) from exposures along Inyan Kara Creek in southern Crook County, Wyo., and he included within it, in ascending order, the Lakota sandstone and the Fuson formation of Darton (1901, p. 526–531) and the Fall River formation of Russell (1928, p. 136), which he called the Fall River sandstone.

Owing primarily to the discovery of uranium in the Inyan Kara group in recent years, the U.S. Geological Survey has been engaged in large-scale mapping in areas underlain by this group. The complex lateral and vertical lithologic changes and the inconsistency of the boundaries of the subdivisions as originally defined by Darton (1901, p. 526–531) were magnified on this enlarged scale of mapping; thus it soon became apparent to field parties in the Black Hills that it was impossible to retain the threefold subdivision of the Inyan Kara group.

As a result of a regional study of the Inyan Kara group made by K. M. Waagé (1959) in 1955 and 1956, a twofold subdivision was recommended, wherein the terms Fall River and Lakota were retained, but Fuson was dropped. The present authors recognize the twofold subdivision of the Inyan Kara group as the most practical solution from the viewpoint of the field geologist, and the revised nomenclature as proposed by Waagé (1959, p. 32, 33) is adopted herein.

In the Carlile quadrangle, the Fall River formation is equivalent to rocks that Darton and O'Harra (1907, p. 3–4) mapped as Dakota sandstone in the adjoining Devils Tower quadrangle and probably to part of their Fuson formation. The upper part of the Lakota formation in this report includes beds probably equivalent to those that Darton and O'Harra interpreted as belonging to the lower part of their Fuson near Cabin Creek, in the Devils Tower quadrangle (Darton and O'Harra, 1907, p. 3).

LAKOTA FORMATION

The Lakota formation, the lowermost unit of the Inyan Kara group, is comopsed of lenticular sandstone, claystone, and mudstone beds deposited in a continental environment. It was first mentioned by Darton (1899, p. 387), who described it in more detail in a later report (Darton, 1901, p. 526–529), although the location of a type section was not given.

The Lakota formation is well exposed throughout much of the quadrangle, especially in the dissected areas. The thicker sandstone units form rounded cliffs or steep slopes overlain by softer claystone and mudstone layers that locally weather back to form benches. The Lakota crops out almost continuously along the valley cut by the Belle Fourche River and for considerable distances up Cabin Creek, Dry Cabin Creek, Black Gulch, and Spring Creek. On the southern half of the Pine Ridge anticline, the formation is exposed across the crest; it is exposed also in numerous canyons eroded into the limbs of the Pine Ridge and Oil Butte anticlines. Within the quadrangle boundaries, measured sections of the Lakota range from 81 to 166 feet in thickness. The thickness throughout most of the quadrangle is between 120 and 140 feet; the formation thins abruptly towards the southwest corner.

Within the mapped area, the Lakota was informally subdivided into two units designated as the sandstone unit and the mudstone unit. The distribution and generalized lithologic character of these units are depicted in plate 35.

SANDSTONE UNIT

The sandstone unit is the basal unit of the Lakota formation in the quadrangle. It is essentially a composite sandstone lens, characteristically massive, that weathers into rounded cliffs. It ranges in thickness from 25 to 110 feet; the thinnest part is in the SE¼ NW¼ sec. 30, T. 51 N., R. 66 W. Throughout the remainder of the quadrangle the thickness ranges between 80 and 110 feet.

In some places the sandstone unit is composed of a single sandstone bed; elsewhere three or more sandstone lenses may be separated by thin beds of fissile carbonaceous siltstone or silty sandstone. The bulk of the sandstone is light gray fine to medium grained, quartzose, friable, poorly sorted, and contains lenses composed of granules and pebbles of chert and quartzite. Locally, as in the SW¼ sec. 15, T. 52 N., R. 66 W., pebbles and cobbles of fine-grained sandstone occur. The sandstone contains very little interstitial clay or iron oxides, and carbonaceous material is absent except in the silty partings and, locally, in the finer grained part near the top. At most exposures, the uppermost 3 to 10 feet is very fine grained, firmly cemented, and iron stained on the weathered surface. Stratification is thin and irregular, and sets of cross strata are abundant throughout.

A petrographic study was made of the sandstones of both the Lakota and Fall River formations, and the details of this study are given on pages 660–667.

MUDSTONE UNIT

The mudstone unit, which overlies the sandstone and forms steep slopes above the sandstone cliffs, is a heterogeneous assortment of variegated claystone, unconsolidated mudstone, and beds of very fine grained sandstone, mostly less than 5 feet thick. The thickness of the mudstone unit ranges from 25 to 110 feet, and it is thickest where the underlying sandstone is thin.

The claystone beds within the unit are variegated in shades of maroon, purple, and yellow. Locally near the base and near the top of the unit, the claystone beds are black, owing to finely divided carbonaceous material. The variegated claystone beds have swelling properties, and weathered slopes commonly have a "popcornlike" surface encrustation.

X-ray determinations of the minerals of the clay-size fraction of the mudstone unit were made by Gude. Montmorillonite and kaolinite commonly were the most abundant constituents. In a few samples a mixture of montmorillonite and chlorite or montmorillonite, chlorite, and illite were the major minerals. Quartz was present in nearly all samples in minor or trace amounts. Mica was a trace constituent in a few samples.

The sandstone beds in the mudstone unit, most relatively thin, differ from those in the underlying sandstone unit in that they are rarely conglomeratic, contain less chert, and locally contain abundant carbonaceous material. A prominent sandstone lens, 15 to 40 feet thick, occurs in the northeastern quarter of the quadrangle. This lens is the uranium-bearing unit at the Carlile mine and is designated on the maps of the mine and mine area as the upper sandstone subunit (pls. 36 and 37). It has an area extent of about 4.5 square miles and is elliptical in plan, with the long axis trending approximately northward. This is by far the thickest and most extensive sandstone layer in the mudstone unit.

In the lower part of the mudstone unit, beginning a few feet above the sandstone unit and extending upward for at least 10 feet, the unconsolidated mudstone contains highly polished pebbles and cobbles of quartzite and chert. These are scattered randomly or are arranged as stringers in a matrix of clay, silt, and sand. The pebbles are dull gray to red and range from less than one inch to more than 4 inches in maximum diameter. An assortment of these pebbles and cobbles is shown in plate 39.

These polished pebbles and cobbles, which characteristically occur in poorly sorted fine clastic deposits have a wide distribution in continental sediment of Early Cretaceous age throughout the western interior of the United States. They occur at various horizons in the Lakota throughout the northern and southern Black Hills (C. S. Robinson and K. M. Waagé, written communications, 1956). From the Cedar Mountain formation, of Early Cretaceous age, in eastern Utah, Stokes (1952, p. 1771–1773) reports "peculiar pebbles known as 'gastroliths' "; about 8 miles south of Morrison, Colo., Waagé (1955, p. 22) recorded in a measured section of the Lytle formation "rare polished pebbles ('gastroliths') as much as 3 inches in diameter" in a red silty claystone near the base; and in the Bighorn Canyon—Hardin area, Wyoming and Montana, Richards (1955, p. 43), in describing the middle member of the Cloverly formation, mentions numerous gastroliths occurring in red shale beds that overlie the Pryor conglomerate member.

The upper 10 feet of the mudstone unit is composed either of claystone or silty claystone, which is moderately iron stained. This interval contains scattered limonite and siderite nodules or pellets, most 1 to 2 millimeters in diameter; the pellets are more abundant in the upper 2 or 3 feet. Locally the upper 3 or 4 feet may be yellow or white, resembling a weathered zone, in contrast to the variegated hues in the slopes below.

STRATIGRAPHIC RELATIONS AND AGE

The conglomeratic sandstone of the lower, or sandstone, unit rests sharply on the carbonaceous claystone of the Morrison formation throughout most of the quadrangle. Locally, channels probably were cut into the Morrison; in sec. 16, T. 52 N., R. 66 W., along the northwest side of Dry Cabin Creek, angular blocks of gray silty claystone, which could be of Morrison origin, are incorporated into the lower part of the massive conglomeratic sandstone unit of the Lakota.

The upper contact probably is disconformable, according to K. M. Waagé (1956, written communication). The claystone and silty claystone in the upper few feet of the mudstone unit commonly is impregnated with the siderite pellets and may be moderately stained with limonite. A change from claystone of the Lakota to laminated sandy siltstone of the Fall River formation generally is evident immediately above the zone of leached claystone and iron accumulation. C. S. Robinson and others (written communication, 1957) cite additional information on the regional characteristics of the Lakota–Fall River contact throughout the northwestern Black Hills.

Although no fossils were found in the Lakota in this area, remains of ferns, conifers, and cycads have been collected by others at various exposures throughout the Black Hills from beds probably equivalent to the Lakota. These plants have been identified as Early Cretaceous in age (Ward, 1894, 1899). K. M. Waagé (written communications, 1957) reported unidentified ostracodes from claystone in the lower part of the Lakota in the area near Sturgis, S. Dak. Darton (1901, p. 527) found saurian bones in the Lakota near Buffalo Gap. S. Dak.

FALL RIVER FORMATION

The Fall River formation is the uppermost formation of the Inyan Kara group, and it represents a transition from the continental environment of deposition shown by the Lakota to a shallow marine environment indicated by the black shale beds of the overlying Skull Creek shale. The Fall River is a sequence of relatively evenbedded sandstone units separated by siltstone or mudstone layers that locally are fissile. This formation differs from the Lakota in that the lithologic units are more consistent in composition, lateral extent, and thickness.

The Fall River formation generally is well exposed over most of the quadrangle except where it has been eroded away in the deeper canyons and in the Belle Fourche River valley, and where it disappears beneath the younger Cretaceous rocks in the southwestern part of the quadrangle. Extending for miles along the canyon rims is a thick ledge-forming sandstone, below which is a moderately steep slope formed by shaly mudstone. A sandy siltstone unit at the base of the Fall River forms a less prominent ledge below the mudstone. The thickness of the formation ranges from 125 to more than 150 feet in this area. It is thickest in the northeastern part of the quadrangle.

The Fall River was informally subdivided into four mappable lithologic units in this investigation. These are, in ascending order, the siltstone unit, the mudstone unit, the sandstone unit, and the upper unit (pls. 34 and 35).

SILTSTONE UNIT

The siltstone unit is the basal unit of the Fall River formation in the Carlile quadrangle. It is composed of a sequence of thin beds and laminae of sandy siltstone intercalated with clayey siltstone and claystone laminae; its thickness ranges from 22 to 38 feet. Sandy siltstone strata are tan in color and range from less than 1 inch to 5.5 feet in thickness, although most beds are less than 1 foot thick. The clayey laminae are dark gray and do not exceed a few inches in thickness. Wavy stratification is a distinctive feature of the thinner bedded portions of this unit. Although planes of stratification are undulatory, individual beds maintain a fairly uniform thickness. These beds are cross laminated on a very small scale. It is possible that the wavy stratification is caused by superimposed sets of cross laminae.

The uppermost beds of the siltstone unit commonly are impregnated with hematite, forming a very dense hard rock that crops out throughout much of the quadrangle as a ledge 2 to 5 feet thick. Beds in the lower part of the unit are coated with limonite along bedding planes.

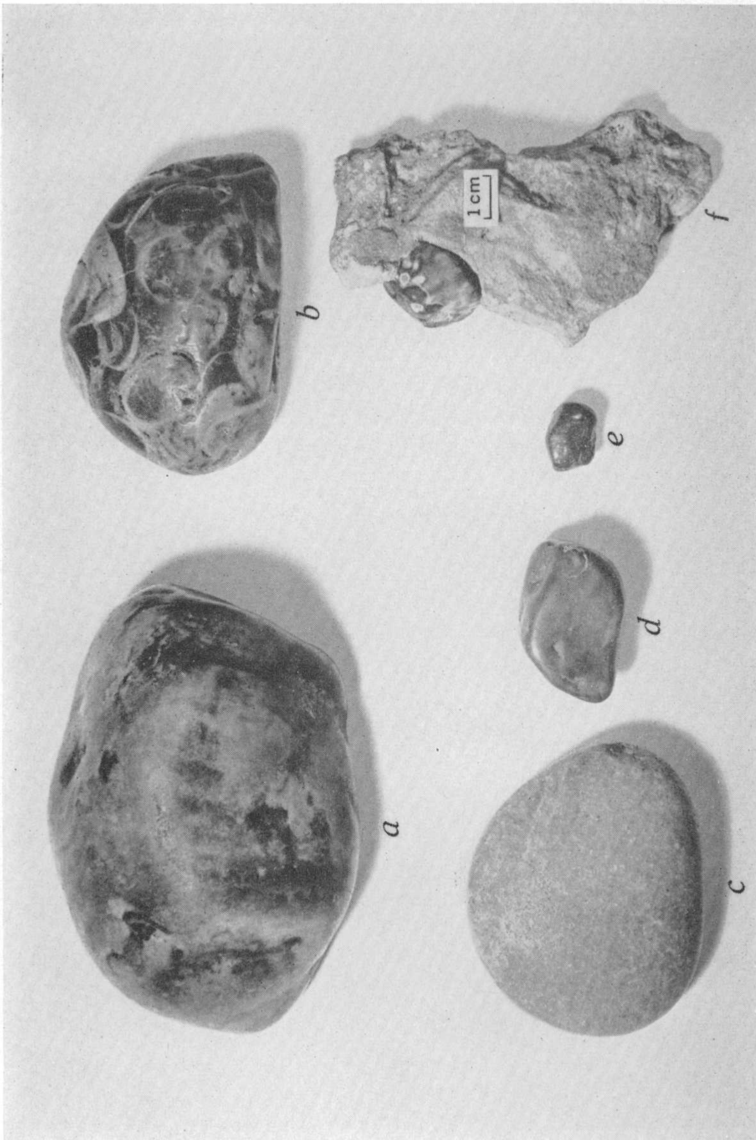
Detrital quartz and clay are the most abundant constituents of this unit. Mica is a conspicuous, though minor component. Carbonaceous material occurs as small scattered fragments in the siltstone and as finely divided disseminations in the clayey siltstone and claystone.

The siltstone unit is characterized by an abundance of structural features that resemble trails, burrows, and castings of worms or other soft-bodied organisms. Some are narrow vertical tubes filled with silt; most of them, however, occur along bedding planes.

Throughout most of the area the siltstone unit is fairly consistent in lithologic character and thickness with one exception—a narrow ribbon of sandstone that extends diagonally from the northeast to the southwest across the quadrangle. This sandstone ribbon, which resembles a stream channel fill, is only 150 to 250 feet wide, and grades laterally into the siltstone along either side. The sandstone is light gray, fine grained, friable, massive, crossbedded, and locally contains finely divided fragments of carbonaceous material. From the eastern margin of the quadrangle, in the NW¼ sec. 35, T. 52 N., R. 66 W., the sandstone extends beneath Thorn Divide, bearing about S. 75° W., to Black Gulch, where it is exposed in the SW¼ sec. 34, T. 52 N., R. 66 W. Here the bearing changes to S. 40° W. and is maintained for a distance of at least 5 miles, as shown by outcrops seen in the tributary canyons of Spring Creek (W. ½ sec. 4, T. 51 N., R. 66 W. and the SE¼ sec. 5, T. 51 N., R. 66 W.) and again in the SE¼ sec. 13, T. 51 N., R. 67 W., on the westward-dipping limb of the Pine Ridge anticline. Here the Fall River formation disappears beneath younger rocks, and the channel fill sandstone is not further traceable.

MUDSTONE UNIT

The mudstone unit is a drab, slope-forming sequence of very thin bedded sandy siltstone, silty claystone, and claystone rocks. The coarser grained rocks are laminated; the more clayey portions are subfissile to fissile. This unit maintains a uniform thickness of about 45 feet throughout the Carlile quadrangle. The overall color is dull brownish gray, although some clayey beds are black because they contain finely divided carbonaceous material, and the sandy beds generally are buff to brown. The sandy siltstone and siltstone laminae are less than 3 inches thick and commonly are calcareous. Locally, 25 to 30 feet above the base of the unit, iron-



POLISHED PEBBLES AND COBBLES FROM THE MUDSTONE UNIT OF THE LAKOTA FORMATION, CARLILE QUADRANGLE, WYOMING

a, silicified wood; *b*, fossiliferous chert; *c*, quartzite; *d*, and *e*, chert; *f*, chert pebble imbedded in clayey siltstone.

oxide-impregnated sandy siltstone crops out as a ledge about 1 foot thick. Contacts of this unit with the siltstone unit below and the sandstone unit above are garadational through a thickness of about 2 feet.

SANDSTONE UNIT

The sandstone unit is the most conspicuous subdivision of the Fall River formation in this area. It is the rimrock of the canyons in the eastern part of the quadrangle, and it forms steeply dipping, dissected hogbacks along the flanks of the Pine Ridge and Oil Butte anticlines in the western part of the area. It ranges from 30 to 52 feet in thickness, and in most places it is composed of firmly cemented sandstone that weathers to a vertical cliff. Locally, in the northeastern part of the area, two sandstone units are separated by about 10 feet of thin-bedded sandstone, clayey siltstone, and silty claystone.

The sandstone is tan to light gray. Very fine grained detrital quartz is the most abundant constituent, and mica, chert, and feldspar occur in very minor amounts. Feathery seams of carbonaceous material are present locally. Although the unit is thin-bedded, it weathers as a single massive cliff. Prominent vertical joint surfaces are coated with limonite, and spherical limonite concretions, as much as 6 inches in diameter, are abundant throughout the sandstone. Spherical concretionary bodies of calcite-cemented sandstone that range from a few inches to more than 5 feet in diameter are common. The lowermost 6 inches to 1.5 feet of sandstone is cemented with calcite and is crossbedded on a small scale. The upper 2 to 3 feet of the unit is slightly coarser grained and contains more abundant carbonaceous material in the form of irregular fragments of wood and remains of roots, which, on a weathered surface, give the sandstone a pitted or pock-marked appearance. Locally, in the upper 1 to 2 feet, abundant carbonaceous material colors the sandstone black.

The contact of the sandstone unit with the upper unit is sharp.

UPPER UNIT

Overlying the sandstone unit is a varied interval of thin-bedded sandstone, siltstone, and silty claystone that covers much of the intercanyon areas. It ranges from 6 feet to more than 30 feet in thickness, although locally it either pinches out or changes to sandstone indistinguishable from the underlying unit. It is thickest on Thorn Divide, but it thins abruptly to the west, and for a short distance along the eastern side of Green Hill it is absent. Northwest of Green Hill, the upper unit reappears for several miles, but in the northwest corner of the quadrangle it could not be recognized.

Throughout the remainder of the quadrangle the upper unit has an average thickness of about 20 feet.

The lowermost 6 inches to 1 foot of this unit is a bed of charred wood fragments. This bed rests on the sandstone of the underlying unit and is overlain by soft clayey silt and laminated brittle sandy siltstone with some carbonaceous, micaceous, fine-graned sandstone. A layer of sandstone, 2 to 6 inches thick, is the top bed of this unit at most places. Predominant colors in this unit are various shades of gray that contrast with the tan hues of the underlying sandstone unit.

Lenticular fine-grained sandstone beds of varied thickness occur locally in this unit. They are crossbedded on a small scale, and some of them contain many clay galls or abundant carbonaceous material. Along the western side of the Pine Ridge anticline, one of these beds can be traced from sec. 13, T. 51 N., R. 67 W., northwestward to sec. 2, T. 51 N., R. 67 W. From here northward the bed thickens until it makes up the bulk of the upper unit, with only the layer of carbonized wood fragments marking the base. At some places the sandstone lens can be seen as fills of scours in the layer of carbonized wood.

The silt and clay characteristic of the upper unit are absent in the northwestern corner of the quadrangle. Here the Skull Creek shale is in sharp contact with an interval of silty beds, less than 2 feet thick, that is underlain by a massive sandstone bed that was mapped as the sandstone unit of the Fall River formation. Possibly the upper part of this sandstone is equivalent to the upper unit; however, the layer of carbonaceous material that generally marks the base of the upper unit elsewhere in the quadrangle is not present throughout 3 square miles in this area.

STRATIGRAPHIC RELATIONS AND AGE

The contact of the Fall River formation with the superjacent Skull Creek shale is gradational in most places. Transitional beds composed of dark-bluish-gray or dull-gray silty clay form a unit ranging in thickness from a few inches to less than 2 feet between the highest micaceous sandstone that can be unquestionably assigned to the Fall River and the lowest black shale of the Skull Creek.

No fossils were found in the Fall River formation in this investigation, but W. W. Rubey (written communication) reported part of a scute of a crocodile (identification by J. B. Reeside, Jr.) from the "uppermost bed of the upper Dakota" in the south-central part of sec. 29, T. 52 N., R. 66 W. One-half mile to the north of the quadrangle, in the center of sec. 10, T. 52 N., R. 66 W., W. J. Mapel (written communication, 1957) found the fresh water pelecypod *Protelliptio douglassi* (Stanton), identified by W. A. Cobban as of

Early Cretaceous age. This pelecypod was collected from the lower 1 foot of the formation.

Rubey (written communication, 1957) considers the upper part of the Fall River formation to be of marine origin, based on plesiosaurian remains (identified by C. W. Gilmore in 1923) collected from what he called in 1923 the upper Dakota in sec. 36, T. 55 N., R. 66 W., Crook County, Wyo., and from a locality 5.5 miles northeast of Upton, Weston County, Wyo. The upper Dakota, according to Rubey (written communication, 1957), consists of a

> widely persistent unit of relatively non-resistant, tan, regularly bedded and thin-bedded, sandy siltstone and sandstone that occupied the stratigraphic interval, commonly about 15 to 25 feet thick, between the highest strongly resistant ledge of "Dakota" sandstone and the base of the black Skull Creek shale.

The following measured sections of the Inyan Kara group give additional details on the thickness and lithological characteristics of the formations of this group in the Carlile quadrangle.

Partial section of Fall River formation, NE¼ sec. 28, T. 51 N., R. 66 W., Crook County, Wyo. (section 1, pl. 35)

	Feet
Fall River formation:	
Upper unit (part):	
9. Claystone, gray, fissile, silty, poorly exposed; forms a slope	10.0
8. Carbonized wood	1.0
Sandstone unit:	
7. Sandstone, gray, fine-grained, micaceous, porous; contains fragments of carbonized wood; grain size is gradational from underlying unit into this unit through a thickness of 10 ft; stained with iron oxides near top; carbonaceous material gradually disappears downward through 3 ft; weathers to pitted, rough surface; forms ledge	2.5
6. Sandstone, yellowish-gray, very fine grained, micaceous, thin-bedded, massive; cross laminated at low angle[1]; contains iron oxide concretions, siltstone partings; forms cliff	26.4
Mudstone unit:	
5. Siltstone, dark-gray, clayey, carbonaceous; covered near top	46.5
Siltstone unit (part):	
4. Ironstone (iron oxide cemented sandstone), brown, very fine grained, micaceous, poorly bedded; grades upward into unconsolidated very fine grained sandstone; forms a ledge	1.5
3. Siltstone, dark-gray, clayey, fissile; interlaminated with very fine grained sandstone; forms slope	1.0
2. Siltstone, yellowish-gray, sandy, micaceous, slightly carbonaceous; stained with iron oxides on some bedding planes; contains tracks and tubes resembling worm borings; forms ledge	6.3
1. Siltstone, dark-gray, micaceous, carbonaceous; weathers to rounded ledge	4.6
Measured thickness of Fall River formation (rounded)	100

[1] A quantitative use of the terms "bedded" and "laminated" is followed in this report as suggested by McKee and Weir (1953, p. 383) and implies thickness as well as layering.

Fall River and Lakota formations, SE¼ sec. 21, T. 51 N., R. 66 W., Crook County, Wyo. (section 2, pl. 35)

Skull Creek shale.

Fall River formation:

	Feet
Upper unit:	
31. Siltstone, dark-gray, slightly clayey, brittle, fissile, poorly exposed; thin beds of fine-grained sandstone, less than 6 in thick interbedded with siltstone in upper 5 ft; Skull Creek shale rests on thin sandstone bed	8.5
30. Sandstone, partly covered, tan, fine-grained; interbedded with gray, sandy, siltstone	3.6
29. Claystone, dark-gray, silty, somewhat fissile; lower part carbonaceous	6.5
28. Carbonized wood or peat	0.8
Sandstone unit:	
27. Sandstone, light-gray, fine-grained, friable, limonite-stained; contains disseminated carbonaceous material in upper 1 ft coloring the sandstone dark gray to black; root fragments in upper 1 ft; upper surface is firmly cemented with iron oxide	2.3
26. Sandstone, light-gray, very fine-grained, micaceous; thin-bedded with local small scale crossbedding, massive, seams of carbonaceous material in lower 10 ft; weathers to buff; vertical joints strike N. 70° W.; joint surfaces coated with limonite; forms cliff	29.3
Mudstone unit:	
25. Claystone, dark-grayish-brown, silty, fissile; upper 7 to 8 ft is siltstone; veinlets of limonite along bedding in upper 4½ ft; finely divided carbonaceous material throughout interval, but less abundant in upper 6 ft	36.0
24. Siltstone, grayish-brown, sandy, calcareous, thinly laminated; weathers in thin plates; forms bench	1.3
23. Partly covered; mostly sandy, brown siltstone, interbedded with dark-grayish-brown, clayey, fissile siltstone; slightly calcareous	8.0
Siltstone unit:	
22. Siltstone, gray, micaceous, interbedded with laminae of clayey silt and seams of carbonaceous material; contains several vertical silt-filled tubes resembling worm borings	1.7
21. Partly covered, mostly gray siltstone and grayish-tan, subfissile, silty claystone; grades into overlying unit through 6 in.	5.5
20. Siltstone, gray, sandy, micaceous, thin-bedded; contains fragments of carbonized wood and vertical silt-filled tubes resembling worm borings	2.3
19. Partly covered; clayey siltstone, interlaminated with sandy siltstone	3.6
18. Siltstone, light-gray, sandy, slightly micaceous, contains small fragments of carbonized wood; forms ledge	1.0
17. Partly covered, mostly tan splintery siltstone	6.8
16. Siltstone, tan and gray, sandy, micaceous; thin, wavy bedding; contains clayey partings; limonite cemented along bedding planes; trails probably made by soft-bodied organisms along bedding and silt filled tubes perpendicular to bedding	3.7

Fall River and Lakota formations, SE¼ sec. 21, T. 51 N., R. 66 W., Crook County, Wyo. (section 2, pl. 35)—Continued

	Feet
Fall River formation—Continued	
Siltstone unit—Continued	
15. Siltstone, dark-gray; thinly interlaminated with buff, sandy siltstone; contains small fragments of carbonized wood; aggregates of laminae are wavy	3.5
14. Siltstone, dark-gray, sandy, massive, blocky; upper 3 in. impregnated with iron oxides	2.5
Total thickness of Fall River formation (rounded)	127
Lakota formation (part):	
Mudstone unit:	
13. Claystone, dark-gray, silty, blocky; contains fragments of carbonized wood	5.2
12. Carbonized wood or peat, slightly silty	1.5
11. Claystone, dark-gray, becoming black in upper 1 ft; sandy, silty, carbonaceous	5.2
10. Sandstone, massive, light-gray, very fine grained, contains small limonite nodules; limonite stained on surface, rough weathering	2.0
9. Covered	7.0
8. Sand, clayey, dark-gray, carbonaceous	.2
7. Sandstone, gray, slightly clayey; contains granules of black chert; unconsolidated, but locally weakly cemented	1.5
6. Claystone, greenish-gray, silty; contains scattered grains of mica; slightly sandy in upper part	8.8
5. Claystone, dark-gray, sandy; contains sparse gypsum	.5
4. Mudstone, dark-gray, limonite stained; contains stringers of gypsum; weakly cemented	3.7
3. Sandstone, gray, very fine grained; contains lenses of chert granules	.8
2. Mudstone, dark-gray; matrix is clay; coarse fraction is quartz sand with dark-brown chert granules	6.4
Sandstone unit (part):	
1. Sandstone, light-gray, medium-grained, friable; contains conglomeratic lenses and stringers of chert; upper 1 ft fine grained, firmly cemented; rough weathering; forms a cliff	45.0
Measured thickness of Lakota formation (rounded)	88

Section of Fall River formation, SE¼ sec. 15, T. 51 N., R. 66 W., Crook County, Wyo. (section 3, pl. 35)

Stream terrace sand.	
Fall River formation:	
Upper unit (part):	
8. Covered	13.0
7. Sandstone, light-gray and tan, very fine-grained, thin-bedded; contains abundant root remains; incompletely exposed	1.7
6. Claystone, dark bluish-gray, slightly silty, fissile, interbedded with sandstone in upper part; incompletely exposed	6.3
5. Carbonized wood	.4

Section of Fall River formation, SE¼ sec. 15, T. 51 N., R. 66 W., Crook County, Wyo. (section 3, pl. 35)—Continued

	Feet
Fall River formation—Continued	
Sandstone unit:	
4. Sandstone, buff, very fine grained, micaceous, thin-bedded; contains partings of silty clay and stringers and fragments of carbonized wood	3.3
3. Sandstone, buff, very fine grained, micaceous, carbonaceous, slightly limonite stained; forms a minor ledge	1.5
2. Siltstone, dark-gray, clayey, carbonaceous; interbedded with buff, very fine grained thinly laminated sandstone	2.8
1. Sandstone, gray, very fine grained, micaceous, thin-bedded, massive; abundant spherical pyrite concretions; local accumulations of carbonaceous material in thin seams; beds in lower 3½ ft cross laminated on small scale; unit contains two sets of vertical joints that strike N. 35° W., and N. 40° E.; forms a cliff	31.2
Measured thickness of Fall River formation (rounded)	60

Partial section of Lakota and Fall River formations, center sec. 10, T. 51 N., R. 66 W., Crook County, Wyo. (section 4, pl. 35)

Fall River formation:	
Sandstone unit (part):	
29. Sandstone, yellowish-gray, very fine grained, micaceous, thin-bedded, massive; cross stratified on medium scale; forms a cliff	35.0
Mudstone unit:	
28. Partly covered; mostly dark-gray clayey subfissile siltstone with interlaminated very fine grained sandstone	45.0
Siltstone unit:	
27. Siltstone, yellowish-gray, sandy, micaceous, thin-bedded; contains disseminated carbonized wood fragment; upper part cemented by iron oxides; forms ledge	3.0
26. Partly covered, mostly dark-gray carbonaceous siltstone	4.2
25. Siltstone, yellowish-gray, sandy, micaceous, thick-bedded, massive; some limonite stained beds near top; forms ledge	7.0
24. Siltstone, dark-gray, clayey, carbonaceous; two minor very fine grained sandstone ledges near middle; forms recession in larger cliff	3.2
23. Siltstone, buff, sandy, micaceous, thin, wavy-bedded; cross stratified on small scale; upper 3 ft impregnated with iron oxides; thin partings of silt; forms ledge	6.0
22. Siltstone, yellowish gray, sandy, micaceous; intercalated with dark-gray, fissile clayey siltstone; thin bedded with wavy bedding planes; vertical tubes and trails along bedding resembling worm borings and trails; forms ledge	5.5
21. Siltstone, gray, sandy, micaceous, thinly cross laminated; contain clayey partings; forms ledge	.5
20. Siltstone, gray, clayey, fissile to subfissile; forms slope	.8

Partial section of Lakota and Fall River formations, center sec. 10, T. 51 N., R. 66 W., Crook County, Wyo. (section 4, pl. 35)—Continued

Fall River formation—Continued	
Siltstone unit—Continued	*Feet*
19. Siltstone, gray, sandy, slightly micaceous; thin-bedded with minor small-scale cross lamination; contains disseminated particles of carbonized wood; forms ledge	2.4
Measured thickness of Fall River formation (rounded)	113
Lakota formation:	
Mudstone unit:	
18. Claystone, dark-gray, silty and sandy, massive, carbonaceous, forms covered slope	1.5
17. Covered slope	35.0
16. Mudstone, sandy and silty; variegated in dark gray, brownish gray, and black; fissile in places; carbonaceous, a heterogeneous unit of clay, silt, and sand; weathers to crusty surface; forms slope	36.6
15. Partly covered, mostly variegated claystone with some very fine grained calcareous sandstone near middle; forms slope	14.0
14. Claystone, gray, sandy, structureless, contains thin siltstone lenses; forms slope	16.5
13. Claystone, dark-gray, slightly silty, forms slope	5.8
Sandstone unit:	
12. Sandstone, gray, fine-grained, carbonaceous; composed of beds as much as 2 ft thick; interbedded with dark-gray silty claystone; forms cliff	19.0
11. Sandstone, gray, thin-bedded, massive; medium-grained near base, gradually becoming fine-grained near top; carbonaceous debris in seams as much as 3 ft thick; forms cliff	7.5
10. Siltstone, dark-gray, carbonaceous, brittle, subfissile, limonite stained; forms slope	2.4
9. Sandstone, gray, massive, thin-bedded; medium-grained near base, becomes fine-grained at top; contains scattered fragments and lenses of carbonized wood; laminated near base; forms ledge	2.4
8. Siltstone, gray, carbonaceous, brittle; forms slope	1.8
7. Siltstone, dark-gray, dense, brittle; contains carbonized wood as fragments and in seams as much as 4 in thick; forms ledge	4.0
6. Sandstone, yellowish-gray, medium-grained; becomes very fine grained in upper 2.5 ft; thick-bedded, massive, contains conglomeratic stringers of chert, quartzite, and quartz; forms cliff	17.9
5. Covered	3.5
4. Sandstone, gray, fine-grained, jarosite-stained, sharp contact with underlying claystone, forms covered slope	1.5
Total thickness of Lakota formation (rounded)	170
Morrison formation (part):	
3. Claystone, dark-brown, silty, very brittle, structureless; weathered fragments coated with jarosite; contains weathered pyrite concretions; forms slope	2.0

Partial section of Fall River and Lakota formations, SE¼ sec. 34, T. 52 N., R. 66 W., Crook County, Wyo. (section 5, pl. 35)—Continued

	Feet
Morrison formation (part)—Continued	
2. Claystone, calcareous, variegated in light grayish green, dark green, and pale reddish purple; contains a few thin lenticular beds of dense gray limestone; forms a slope	68.0
1. Sandstone, light-gray, very fine grained, thin, wavy bedded, calcareous; forms ledge	3.0
Measured thickness of Morrison formation	73

Partial section of Fall River and Lakota formations, SE¼ sec. 34, T. 52 N., R. 66 W., Crook County, Wyo. (section 5, pl. 35)

	Feet
Stream terrace gravel.	
Fall River formation:	
Upper unit (part):	
13. Partly covered, but mostly claystone, gray, slightly silty, fissile, with several thin gray siltstone beds	6.0
12. Carbonized wood	1.0
Sandstone unit:	
11. Sandstone, light-gray to buff, very fine grained, micaceous, friable, thin-bedded, massive; crossbedded on small scale; abundant weathered pyrite concretions with outer layers of limonite and calcareous sand; thin seams of silt and papery laminae of carbonaceous material in lower 12 feet; topmost bed is fine-grained sandstone 2 ft thick containing abundant carbonized wood fragments; upper surface rough and pitted; closely-spaced vertical joints strike N. 55°–65° W., N. 10° E.; forms cliff	39.2
Mudstone unit:	
10. Siltstone, dark-gray to black, clayey, subfissile to fissile; contains a few platy siltstone beds 2 to 3 in thick; thin sandstone beds present in upper 5 ft and increase in number and thickness near top; uppermost sandstone bed is impregnated with iron oxide	44.3
9. Sandstone, buff, very fine grained, silty; thinly interlaminated with dark-gray silt	.4
8. Siltstone, dark-gray, sandy and clayey, subfissile; blocky in places; contains fragments of carbonized wood along bedding	1.0
Siltstone unit:	
7. Siltstone, brown, sandy, micaceous, thin-bedded; very fine cross-lamination; iron oxide staining along bedding planes; iron oxides cement; top beds; contain small fragments of carbonized wood, vertical tubes resembling worm borings; forms ledge	4.5
6. Siltstone, buff, clayey, micaceous, thin-bedded; interlaminated with dark-gray subfissile, silty claystone and very fine grained sandstone; contains small particles of carbonized wood	9.1

Partial section of Lakota and Fall River formations, center sec. 10, T. 51 N., R. 66 W., Crook County, Wyo. (section 4, pl. 35)—Continued

	Feet
Fall River formation—Continued	
Siltstone unit—Continued	
5. Siltstone, tan, sandy, micaceous, wavy-bedded; groups of papery seams of gray clayey silt, less than 1 in thick, occur throughout; abundant small fragments of carbonized wood; three beds in lower 1 ft impregnated with iron oxides; forms a ledge	14.8
4. Siltstone, dark-gray, slightly fissile; interbedded with buff, laminated, sandy siltstone; wavy-bedded, lenticular beds 2 in or less in thickness; abundant carbonaceous material throughout	4.3
Measured thickness of Fall River formation (rounded)	125
Lakota formation (part):	
Mudstone unit (part):	
3. Siltstone, dark-brown, blocky, faintly laminated; selenite occurs along fractures; abundant iron oxide staining and local impregnation; abundant fragments of carbonized wood; irregular cobble-size angular blocks of gray siltstone incorporated in this unit	7.6
2. Siltstone, dark-gray, clayey, subfissile to blocky; carbonaceous fragments along bedding; locally cemented by iron oxides	2.8
1. Siltstone, dark-gray, clayey, blocky; contains a few thin laminae of sandy buff siltstone and abundant carbonaceous material; considerable iron oxide concentration and nodules of limonite in lower 1 ft	1.5
Measured thickness of Lakota formation (rounded)	12

Partial section of Fall River formation, NW¼ sec. 22, T. 52 N., R. 66 W., Crook County, Wyo. (sec. 7, pl. 35)

Fall River formation:	
Upper unit (part):	
7. Covered, but at base, black carbonaceous claystone beneath soil	12.0
Sandstone unit:	
6. Partly covered, but mostly buff fine-grained thin-bedded sandstone, interlaminated with gray siltstone	11.4
5. Sandstone, gray, very fine grained, thinly laminated and cross-laminated, calcareous; weathers to a platy ledge	2.7
4. Sandstone, buff, very fine grained, micaceous, thin-bedded; interlaminated with gray fissile silty claystone in lower 2 ft; forms minor ledge	13.4
3. Sandstone, buff to light-gray, very fine grained, micaceous, thin-bedded, massive; calcareous in lower 6 ft; spherical calcareous sandstone concretions as much as 18 in. in diameter scattered through interval; a few smaller weathered pyrite concretions; top bed is cemented with iron oxides; ripple-marked on upper surface; prominent set of vertical joints strike N. 85° E.; less prominent set strikes N. 20° E.; forms a cliff	24.9

Partial section of Fall River formation, NW¼ sec. 22, T. 32 N., R. 66 W., Crook County, Wyo. (sec. 7, pl. 35)—Continued

	Feet
Fall River formation—Continued	
Mudstone unit:	
2. Siltstone, dark-gray, clayey, subfissile to fissile, carbonaceous; contains a few platy beds of sandy siltstone; bed of sandy siltstone cemented with iron oxide near top	44.5
Siltstone unit:	
1. Siltstone, gray, sandy, micaceous, thin-bedded; interbedded with clayey siltstone in thin wavy beds and laminae	38.0
Lakota formation.	
Measured thickness of Fall River formation (rounded)	147

Partial section of Lakota and Fall River formations, SW¼ sec. 15, T. 52 N., R. 66 W., Crook County, Wyo. (section 8, pl. 35)

Fall River formation:	
Sandstone unit (part):	
13. Sandstone, buff, very fine grained, micaceous, thin-bedded, massive; some fine carbonized wood disseminated throughout; calcareous crossbedded sandstone bed 6 in thick near base; a few seams of carbonaceous material, ¼ in thick, in lower part; forms cliff	18.0
Mudstone unit:	
12. Claystone, dark-gray, fissile, becomes silty in upper part	11.0
11. Siltstone, gray, sandy, micaceous, laminated; interbedded with gray clayey, micaceous siltstone; a few thin beds impregnated with iron oxides	12.0
10. Siltstone, dark-gray, clayey, fissile; gray calcareous siltstone bed 1 ft thick 16 ft above base	29.5
Siltstone unit:	
9. Siltstone, buff and gray, sandy, micaceous, thin-bedded; contains finely divided carbonaceous material; several beds impregnated with iron oxides; gray clayey siltstone partings between sandy siltstone beds; upper 10 feet is clayey, fissile, with a few thin beds of buff silty, very fine grained sandstone; abundant trails and borings(?) of soft-bodied organisms	21.5
8. Siltstone, dark-gray, clayey, stained by iron oxides	7.0
Measured thickness of Fall River formation	99
Lakota formation (part):	
Mudstone unit:	
7. Claystone, light-gray; contains tiny limonite-filled pores; sharp contact with overlying unit 8	0.5
6. Mudstone, dull-gray; reddish 4 ft below contact with unit 7; unconsolidated; matrix, clay and silt; coarse quartz sand grains and chert granules abundant; a few lenses of friable, medium-grained sand; lens of chert granules 4 ft thick occurs 5 ft above base	71.5
5. Sandstone, light-gray, medium-grained, unconsolidated; contains abundant pebbles and granules of chert; somewhat clayey	22.5

Partial section of Lakota and Fall River formations, SW¼ sec. 15, T. 52 N., R. 66 W., Crook County, Wyo. (section 8, pl. 35)—Continued

	Feet
Lakota formation (part)—Continued	
Sandstone unit (part):	
4. Sandstone, dark-gray, silty, with scattered small pebbles of chert	2.0
3. Conglomerate, gray, friable; mostly pebbles and cobbles of chert and fine-grained quartzose sandstone; medium and coarse-grained quartz sand a minor constituent	16.0
2. Sandstone, dark-gray, fine-grained, poorly sorted; contains much charred plant material; uneven contact with unit 3	8.0
1. Sandstone, brown to black, medium to coarse-grained, weakly cemented, thin-bedded, crossbedded; contains granules and small pebbles of chert, quartz; much charred wood in upper 1.5 ft	12.5
Measured thickness of Lakota formation	133

Partial section of Fall River formation, NE¼ sec. 29, T. 51 N., R. 66 W., Crook County, Wyo. (section 9, pl. 35)

Fall River formation:	
Upper unit (part):	
4. Carbonized wood	1.0
Sandstone unit:	
3. Sandstone, fine-grained, friable; tan to black and cemented with iron oxides in upper part; contains abundant fragments of carbonized wood and remains of roots; vertical joints 5 to 30 ft apart strike N. 80° W. and extend through unit 2; forms upper part of cliff	2.6
2. Sandstone, buff, very fine grained, micaceous, friable, thin-bedded, massive; becomes fine grained in upper part; small scale crossbedding in lower 12 ft; carbonaceous material occurs locally in thin seams; calcareous in lower 3 in; stained by iron oxides on joint faces; forms cliff	28.5
Mudstone unit (part):	
1. Siltstone, buff, sandy, micaceous; interlaminated with thin beds of bluff, very fine-grained sandstone	3.0
Measured thickness of Fall River formation (rounded)	35

Partial section of Fall River formation, center sec. 8, T. 51 N., R. 66 W., Crook County, Wyo. (section 10, pl. 35)

Skull Creek shale:	
Fall River formation:	
Upper unit:	
7. Sandstone, yellowish-gray, micaceous, very fine grained; forms minor ledge; sharp contact with overlying Skull Creek shale	0.4
6. Siltstone, gray, slightly sandy, subfissile; forms slope	3.5
5. Siltstone, brown, slightly sandy, subfissile; cemented with iron oxides; forms prominent ledge	1.8
4. Siltstone, gray, clayey, micaceous, fissile; becomes subfissile upward; forms slope	4.5

Partial section of Fall River formation, center sec. 8, T. 51 N., R. 66 W., Crook County, Wyo. (section 10, pl. 35)—Continued

	Feet
Fall River formation—Continued	
Upper unit—Continued	
3. Siltstone, gray, slightly sandy, micaceous, contains fragments of carbonaceous material; subfissile; jarosite stained at contact with unit 2; grades upward into unit 4; forms slope	9.3
2. Carbonized wood	2.0
Sandstone unit (part):	
1. Sandstone, gray, fine-grained, micaceous, carbonaceous, friable; contains remains of roots; weathers to pitted, rough surface; forms bench	1.0
Measured thickness of Fall River formation (rounded)	22

Partial section of Fall River formation, NW¼ sec. 5, T. 51 N., R. 66 W., Crook County, Wyo. (section 11, pl. 35)

Fall River formation:	
Upper unit (part):	
17. Sandstone, light-gray, very fine grained, micaceous, thin-bedded; interlaminated with sandy gray siltstone with clay partings	5.7
16. Carbonized wood	.4
Sandstone unit:	
15. Sandstone, light-gray, very fine grained, micaceous, friable, thin-bedded, massive; becomes fine-grained in upper 20 feet; vertical joints 15 to 30 feet apart strike N. 77° W.; joint surfaces stained with iron oxides; forms cliff; weathers to buff	35.0
14. Sandstone, gray, very fine grained, calcareous, thin-bedded; low-angle, small-scale cross lamination; forms resistant ledge	1.7
13. Sandstone, gray, micaceous, friable, thin-bedded, cross-laminated; silty partings in upper 1.3 ft; limonite stained in upper 2 in	3.9
12. Sandstone, gray, very fine grained, calcareous, micaceous, firmly cemented, thin-bedded, cross laminated; forms ledge	1.0
Mudstone unit:	
11. Covered, predominantly gray laminated to fissile sandy siltstone and clayey siltstone	42.0
Siltstone unit:	
10. Siltstone, yellowish-gray, sandy, micaceous, thin-bedded; contains flakes of carbonized wood; some beds impregnated with iron oxides; forms ledge	3.0
9. Siltstone, dark-gray, clayey, laminated, carbonaceous	1.0
8. Siltstone, yellowish-gray, sandy, micaceous; thin-bedded with wavy laminae, contains fine carbonaceous material and vertical tubes resembling worm borings; forms ledge	6.0
7. Siltstone, same as unit 9	1.3
6. Siltstone, yellowish-gray, sandy, structureless, massive	2.0

Partial section of Fall River formation, NW¼ sec. 5, T. 51 N., R. 66 W., Crook County, Wyo. (sec. 11, pl. 35)—Continued

	Feet
Fall River formation—Continued	
Mudstone unit (part):	
5. Siltstone, same as unit 9	0.5
4. Siltstone, yellowish-gray, sandy, micaceous; wavy laminated; interbedded with dark-gray, thin-bedded, carbonaceous siltstone; forms ledge	10.0
3. Siltstone, dark-gray, clayey, micaceous, carbonaceous, subfissile; interlaminated with gray, sandy siltstone; forms recession in larger cliff	1.9
2. Siltstone, yellowish-gray, sandy, micaceous, carbonaceous, poorly stratified; stained with jarosite; forms ledge	3.0
1. Siltstone, dark gray, clayey, carbonaceous; mostly poorly stratified, subfissile in parts; forms break in slope	1.2
Measured thickness of Fall River formation (rounded)	120

Partial section of Fall River formation, NW¼ sec. 32, T. 52 N., R. 66 W., Crook County, Wyo. (section 12, pl. 35)

	Feet
Skull Creek shale.	
Fall River formation:	
Upper unit:	
12. Partly covered, mostly dark-gray thinly laminated sandy siltstone	4.0
11. Siltstone, dark-gray, slightly sandy, subfissile	6.0
10. Carbonized wood	.4
9. Sand, clayey, dark-reddish-gray	.5
Sandstone unit:	
8. Sandstone, light-gray, micaceous, very fine grained, friable, thin-bedded, contains finely divided carbonaceous material	8.3
7. Covered, probably buff, very fine grained sandstone	11.4
6. Sandstone, light-gray, very fine grained, micaceous, friable, thin-bedded, massive; calcareous in lower 8 inches; contains spherical calcareous sandstone concretions 3 in to 5½ ft in diameter and a few small limonite-cemented sandstone concretions; two thin lenses of carbonized wood in this interval; forms a cliff	22.6
5. Siltstone, light-gray, friable; thinly interlaminated with very fine grained sandstone	.8
4. Sandstone, dark-brown, very fine grained, dense; impregnated with iron oxides	.3
3. Sandstone, buff, very fine grained, micaceous	1.4
2. Sandstone, gray, very fine grained, hard, calcareous, cross-laminated; forms bench	1.0
Mudstone unit (part):	
1. Siltstone, dark-gray, sandy, interlaminated with light-gray, very fine grained micaceous sandstone	4.0
Measured thickness of Fall River formation (rounded)	61

Section of Fall River formation, partial section of Lakota formation, SE¼ sec. 20, T. 52 N., R. 66 W., Crook County, Wyo. (section 13, pl. 35)

	Feet
Skull Creek shale.	
Fall River formation:	
Upper unit:	
16. Claystone, dark-gray, silty, fissile; a few thin beds of tan siltstone; uppermost bed is tan, silty, micaceous, very fine grained sandstone, 2 in thick, overlain abruptly by brownish gray Skull Creek shale; forms gentle slope	6.0
15. Carbonized wood	.5
14. Clay, dark-gray, silty, slightly stained by iron oxides	.5
Sandstone unit:	
13. Sandstone, gray to buff, very fine grained, locally friable, micaceous, thin-bedded; massive in lower 28 ft; calcareous, cross-laminated sandstone lenses in lower 3 ft; partings of sandy siltstone in upper 15 ft; forms cliff	41.0
Mudstone unit:	
12. Siltstone, tan to gray; thin beds as much as 2 in thick separated by shaly silt partings ¼ in thick	5.0
11. Partly covered, mostly dark-gray, fissile, silty, claystone, becoming silty at top	39.5
10. Covered, probably gray friable, sandy siltstone	5.0
9. Siltstone, brown to gray, sandy, micaceous; contains woody material; beds 4 in to 1 ft thick separated by thin clayey partings	3.5
8. Siltstone, brown; interbedded with tan, very fine grained micaceous sandstone	2.0
7. Covered, probably same as unit 8	4.0
6. Siltstone, tan to gray, sandy, micaceous, thick-bedded, massive	3.0
5. Siltstone, tan and brown, clayey	.8
4. Siltstone, tan and light-gray, sandy, thin, wavy-bedded; crossbedded on small scale; some beds calcareous; contains carbonaceous material; beds are separated by clay partings ¼ in to 2 in thick; thin beds of limonite-stained gray siltstone in upper 5½ ft	11.5
3. Siltstone, gray, fissile, interlaminated with gray and tan sandy siltstone; some beds calcareous; some beds crossbedded on small scale; contains carbonaceous material	1.5
Total thickness of Fall River formation (rounded)	124
Lakota formation (part):	
Mudstone unit (part):	
2. Covered	15.0
1. Mudstone, dark to light-gray, buff, tan; fissile in places; carbonaceous; limonite stained in places; a few beds are silty, others are sandy	5.5
Measured thickness of Lakota formation	20.5

Section of Lakota formation, NW¼ sec. 30, T. 51 N., R. 66 W., Crook County, Wyo.

	Feet
Fall River formation.	
Lakota formation:	
Mudstone unit:	
8. Covered, mostly silty claystone; weathered slabs of siltstone of Fall River formation at top	6.0
7. Sandstone, brown, very fine grained, firmly cemented; contains fragments of carbonized wood; weathers to rough surface; poorly exposed	3.5
6. Covered	5.5
Sandstone unit:	
5. Sandstone, gray; medium-grained with conglomeratic seams; thick-bedded with small scale cross-stratification; conglomeratic lenses made up of chert granules and pebbles; bench at top	11.0
4. Claystone, brown, silty, subfissile, carbonaceous; a few thin beds of gray siltstone; upper 3 ft is covered	14.3
3. Poorly exposed, mostly dark grayish-brown, subfissile, carbonaceous siltstone and gray fine-grained sandstone	29.0
2. Poorly exposed, mostly gray medium-grained sandstone, with conglomeratic stringers of chert	12.0
Total thickness of Lakota formation (rounded)	81
Morrison formation (part):	
1. Claystone, dark-brown, carbonaceous	7+

Partial section of Lakota and Fall River formations, SW¼ sec. 8, T. 52 N., R. 66 W., Crook County, Wyo.

Fall River formation:	
Siltstone unit (part):	
8. Siltstone, yellowish-gray, micaceous, carbonaceous; thinly laminated to thin-bedded with small scale cross-lamination, giving effect of wavy bedding; interlaminated with dark-gray siltstone; trails and vertical tubes resembling worm borings	4.6
7. Siltstone, dark-gray, clayey; contains finely divided carbonaceous fragments and lenses of sandy siltstone; forms recession in larger edge	1.1
6. Siltstone, yellowish-gray, micaceous; carbonaceous fragments are abundant along stratification planes; beds are thin, wavy, with small-scale cross-lamination; minor dark-gray siltstone partings; forms ledge	3.0
5. Siltstone, dark-gray, carbonaceous; interlaminated with yellowish-gray sandy siltstone; forms recession	1.6
4. Siltstone, light-gray, thin-bedded; contains carbonized wood fragments; stained with iron oxides; forms ledge	.2
Measured thickness of Fall River formation (rounded)	10

Partial section of Lakota and Fall River formations, SW¼ sec. 8, T. 52 N., R. 66 W., Crook County, Wyo.—Continued

	Feet
Lakota formation (part):	
Mudstone unit (part):	
3. Claystone, sandy, structureless, massive, hard; mottled pale reddish-purple and light gray; weathered limonite or siderite pellets in upper 1 ft; forms cliff	8.0
2. Claystone, pale reddish-purple, sandy, structureless; weathers to uneven crust; forms bare slope	11.5
1. Claystone; variegated in light greenish gray, dark greenish gray, pale reddish purple and dark gray; sandy; polished gray chert and red quartzite pebbles as much as 4 in across in float; weathers to uneven crust; forms bare slope	17.0
Measured thickness of Lakota formation (rounded)	36

Partial section of Fall River formation, center E½ sec. 15, T. 51 N., R. 66 W., Crook County, Wyo.

Fall River formation:	
Upper unit (part):	
3. Covered	8.0
2. Sandstone, buff and gray, fine-grained, thin-bedded, cross-bedded; abundant fragments of carbonized wood; clay and silt galls as much as 2 inches in diameter are abundant; stained with iron oxides	11.4
1. Claystone, dark-gray to black, carbonaceous, rests sharply on underlying sandstone unit	2.0
Sandstone unit:	
Measured thickness of Fall River formation (rounded)	21

Partial section of Fall River formation, center sec. 18, T. 52 N., R. 66 W., Crook County, Wyo.

Fall River formation:	
Upper unit (part):	
5. Claystone, pale-yellowish-brown, silty, micaceous, subfissile; forms lope	6.0
4. Claystone, pale-yellowish-brown, silty, micaceous, fissile; iron-impregnated siltstone concretions and lenses weather out in upper 1 ft; forms slope	6.0
3. Carbonized wood	.6
Sandstone unit (part):	
2. Sandstone, yellowish-gray, very fine grained, micaceous, friable, thin-bedded, massive; contains disseminated carbonaceous fragments; limonite-stained on weathered surface; forms ledge	3.0
1. Sandstone, yellowish-gray, very fine grained, micaceous, thin, even-bedded, massive, ripple marked; forms cliff	6.0
Measured thickness of Fall River formation (rounded)	21

Partial section of Fall River formation, SW¼ sec. 20, T. 52 N., R. 66 W., Crook County, Wyo.

	Feet
Skull Creek shale (part):	
7. Shale, black, with a few silty laminae; forms slope	15.0
Fall River formation:	
Sandstone unit:	
6. Covered, contact with Skull Creek shale not exposed	3.0
5. Sandstone, yellowish-gray, very fine grained, micaceous, thick-bedded; cross-stratified on small scale; contains disseminated carbonaceous fragments and abundant root remains; limonite stained on weathered surface; weathers to pitted, rough surface; forms a ledge	7.5
4. Sandstone, yellowish-gray, very fine grained, micaceous; thick-bedded with low-angle medium-scale crossbedding; wavy bedded; interbedded with a few thin dark-gray siltstone beds; forms ledge	11.0
3. Siltstone, dark-gray, clayey, fissile, micaceous, interlaminated with very fine grained sandstone beds; forms slope	11.8
2. Sandstone, yellowish-gray, very fine grained, micaceous, thick-bedded, with low angle medium scale cross bedding; contains calcareous concretions as much as 3 feet in diameter; forms cliff	14.0
1. Sandstone, yellowish-gray, very fine grained, micaceous, thin-bedded, forms break in slope	6.0
Mudstone unit:	
Measured thickness of Fall River formation (rounded)	53

SKULL CREEK SHALE

The Skull Creek shale is the lowermost unit of the thick Cretaceous marine section. It is a conspicuous black shale that contrasts sharply with the underlying arenaceous beds of the Inyan Kara group. The Skull Creek was named by Collier (1922, p. 79) and defined as the lowest member of the Graneros shale. Reeside (1944) elevated the Skull Creek shale, along with the younger Newcastle, Mowry, and Belle Fourche members of the Graneros shale to formations; consequently, the term Graneros is no longer used where these formations are recognizable.

In the Carlile quadrangle, the Skull Creek shale weathers to gentle slopes that generally are covered with sage brush, but that locally support a growth of pine trees. Notable exceptions to the gentle slopes occur in places, as at Green Hill, where the shale is protected by a cap of resistant Newcastle sandstone. The soil formed from the Skull Creek is thin, dark gray and dries to a wrinkled crust.

The Skull Creek shale ranges from 250 to 260 feet in thickness. It is exposed in the western half of the quadrangle, where remnants occur on the flat areas overlying the Fall River formation. Along the west flanks of the Oil Butte and Pine Ridge anticlines the westward-dipping Skull Creek is exposed in a northwestward-trending strip about half a mile wide. Complete thicknesses of the formation are exposed at Green Hill (secs. 29 and 30, T. 52 N., R 66 W.) and at Oil Butte (sec. 35, T. 52 N., R. 67 W.).

The formation is composed predominantly of black fissile claystone. Several lenticular beds of dark-gray, laminated, calcareous or ferruginous siltstone, less than 8 inches thick, commonly are present in the lower 35 feet. Some of these beds contain bone fragments. Calcite concretions are abundant locally in the black shale. These weather readily, and in places blue and tan chips and fragments of calcite litter the slopes. In the vicinity of Green Hill, cone-in-cone calcite concretions are abundant.

X-ray analyses of the black shale were made by Gude. The major constitutent in all samples is montmorillonite. Kaolinite is present in minor amounts, and quartz and mica are trace minerals.

The Skull Creek is in sharp contact with the overlying Newcastle sandstone. At most places the lower massive sandstone of the Newcastle rests on the black shale of the Skull Creek but in the NE¼ sec. 14, T. 51 N., R. 67 W., the Skull Creek shale is overlain by red clay that is assigned to the Newcastle.

The Skull Creek contains a relatively sparse marine fauna. Robinson and others (written communication, 1957) report pleosaurian remains, fish teeth and bones, and a scattered assemblage of pelycypods and brachiopods from various localities in Crook County, Wyo.

Crowley (1951, p. 85) reports a microfauna from the Skull Creek shale consisting of the following genera: *Verneuilina*, *Ammobaculites*, *Ammobaculoides*, *Haplophragmoides*, *Ammomarginulina*(?) *Haplositche*(?), *Spiroplectammina*, *Textularia*, *Quinqueloculina*, *Rebulus*, *Rzehakina*, *Cornuspira*.

The following section of the Skull Creek shale was measured in the Carlile quadrangle by W. J. Mapel.

Skull Creek shale at Oil Butte, NW¼ sec. 35, T. 52 N., R. 67 W., Crook County, Wyo.

	Feet
Newcastle sandstone.	
Skull Creek shale:	
8. Covered	9.0
7. Partly covered; soft grayish-black shale in scattered, discontinuous exposures	147.0
6. Shale, grayish-black, soft, noncalcareous; contains beds of dark, red-weathering siderite concretions near base and middle; concretions locally septarian with veinlets of light-gray barite	38.0
5. Partly covered; shale, similar to unit 6, in scattered discontinuous exposures	45.0

Skull Creek shale at Oil Butte, NW¼ sec. 35, T. 52 N., R. 67 W. Crook County, Wyo.—Continued

	Feet
Skull Creek shale—Continued	
4. Shale, grayesh-black; contains thin irregular lenses and laminae of light olive-gray siltstone in upper part and a bed of silty grayish-red limestone concretions near top; bed of yellowish-orange bentonite 1 in thick, 7 ft above base	14.0
3. Shale, soft; grayish-black in lower part, dark purplish-red in upper part; contains a bed of grayish-red calcareous siltstone about 6 in thick near top	6.0
Thickness of Skull Creek shale	259
Fall River formation:	
Sandstone unit (part):	
2. Sandstone, light-gray, fine-grained; contains many dark-gray siltstone partings; thin and irregularly bedded	1.5
1. Sandstone, light-gray, weathers yellowish gray, fine to medium-grained, well-sorted, porous, ripple-marked, noncalcareous, massive; forms a broad dip slope	5+
Measured thickness of Fall River formation	6+

NEWCASTLE SANDSTONE

Superjacent to the Skull Creek shale is the Newcastle sandstone, an aggregate of lenticular sandstone, siltstone, and claystone beds. The presence of significant amounts of petroleum in the sandstone lenses has led to extensive investigation and study of this formation. The formation was named by Hancock (1920, p. 38–40) from exposures near Newcastle, Weston County, Wyo. Details of the Newcastle lithology and stratigraphy are given by Summerford and others (1949, 1950) and by Crowley (1951).

In the Carlile quadrangle, the Newcastle forms a resistant cap on Green Hill and on several nearby buttes in secs. 29 and 30, T. 52 N., R. 66 W. It is exposed in a narrow band along the western margin of the quadrangle in secs. 26 and 35, T. 52 N., R. 67 W., and in secs. 2, 11, 13, and 14, T. 51 N., R. 67 W. The formation is about 60 feet thick in this area.

Sandstone beds occur generally in the lower and upper parts of the formation. The remainder is composed of nonresistant beds of gray siltstone, yellow bentonitic clay, dark-red silty claystone, and black carbonaceous clay. The sandstone beds in the upper part are thin bedded, very fine grained, platy, and the interstices between detrital quartz grains are filled with calcite. In the northern part of the quadrangle the lower part of the formation is composed of a light-gray, fine-grained, thin-bedded, locally crossbedded, massive sandstone that contains abundant fragments of carbonized wood. This massive sandstone grades southward into thin, platy sandstone interbedded with gray, black, and red clay.

The contact between the Newcastle and the overlying Mowry shale is sharp, with the siliceous shale of the Mowry resting on silty or sandy beds comprising the upper part of the Newcastle.

The fauna of the Newcastle is representative of a shallow marine or brackish-water environment. Crowley (1951, p. 85) reports a Newcastle microfauna similar to that in the Skull Creek shale. Mollusks collected by W. W. Rubey from various localities in the Black Hills were identified by J. B. Reeside, Jr., as *Corbula subtrigonalis* Meek and Hayden, *Viviparus* sp., and unidentifiable species of the genera *Protocardia*, *Thracia*, *Tellina*, and *Mactra*. Other Newcastle fossils collected by Rubey and identified by Reeside included *Halymenites major* Lesquereux, and some remains of a conifer. Barnett (1915, p. 101) reported unidentified fossil invertebrates from the sandstone underlying the Mowry shale in the SE¼ sec. 22, T. 52 N., R. 67 W., just west of the Carlile quadrangle.

The following sections that were measured in the Carlile quadrangle give lithologic details of the Newcastle sandstone.

Partial section of Newcastle sandstone at Oil Butte, NW¼ sec. 35, T. 52 N., R. 67 W., Crook County, Wyo.

	Feet
Newcastle sandstone:	
8. Sandstone, buff, fine-grained, calcareous, forms westward-dipping ledge	2.0
7. Covered	18.0
6. Claystone, dark-gray, sandy, carbonaceous	5.0
5. Partly covered; mostly light-gray very fine grained clayey sandstone; forms slope	3.8
4. Clay, bentonitic	.5
3. Peat and carbonaceous clay	6.0
2. Partly covered; mostly gray friable fine-grained poorly bedded, sandstone; contains fragments of carbonized wood; forms slope	12.0
Measured thickness of Newcastle sandstone (rounded)	47
Skull Creek shale:	
1. Shale, dark-gray, brittle, forms slope	10+

Section of Newcastle sandstone near center sec. 2, T. 51 N., R. 67 W., Crook County, Wyo.

Mowry shale.	
Newcastle sandstone:	
8. Covered, lower part probably same as 7	12.0
7. Sandstone, light-gray, fine-grained, thin-bedded, platy; weathers to tan; some beds calcareous; forms westward-dipping ledge	1.0
6. Clay and siltstone, yellow, bluish-gray, black; lower 5½ ft dark-gray swelling clay that grades upward into 3 ft of clayey and silty peat; remainder of interval is interlaminated gray siltstone and bluish-gray claystone	19.5
5. Clay, gray, tan, light-green, bentonitic; swells on weathered surface	3.9
4. Claystone, black, carbonaceous; fissile in upper and lower 4 in	2.4

Section of Newcastle sandstone near center sec. 2, T. 51 N., R. 67 W., Crook County, Wyo.—Continued

	Feet
Newcastle sandstone—Continued	
3. Siltstone, and silty claystone, gray; siltstone containing limonite or weathered siderite(?) nodules in lower 2 ft; finely divided carbonaceous material and clay increase upward; ribs of limonite stand out on weathered surface	5.0
2. Sandstone, gray, very fine grained, silty, massive; obscure bedding; contains irregular stringers of dark-gray clay; weathers to rounded ledge	3.6
1. Covered, probably sandstone in upper part; contact with Skull Creek shale not exposed	9.0
Total thickness of Newcastle sandstone (rounded)	56

MOWRY SHALE

The Mowry shale is the uppermost formation of the Lower Cretaceous series. It is predominantly a dark-gray siliceous shale containing several thin bentonite beds and one relatively thick and persistent bentonite layer at the top, known as the Clay Spur bentonite bed. Rubey (1929) discussed the lithologic details and the origin of the Mowry, and Robinson and others (written communication, 1957) summarize the regional characteristics of the formation in northeastern Wyoming. Knechtel and Patterson (1955) described the bentonite deposits of the Mowry.

The Mowry shale is exposed in the southwestern part of the Carlile quadrangle. It forms a low, rounded, northwestward-trending escarpment that commonly is covered with pine trees. The Mowry weathers to brittle, silver-gray chips that contrast sharply with the somber dark colors of the Skull Creek shale below and the Belle Fourche shale above. In the Carlile area the Mowry is about 180 feet thick.

On fresh exposure, the Mowry is dark gray. It is relatively hard, because of a high percentage of silica (Rubey, 1931, p. 157, 169). In the NW¼ sec. 25, T. 51 N., R. 67 W., the upper part of the formation, including the Clay Spur bentonite bed, is well exposed. The Clay Spur bed ranges from 3 to 6 feet in thickness in this immediate area and consists of greenish-yellow highly dilatant clay with very little if any detrital impurities. The clay is waxy when damp, and when saturated with water it has a gelatinous consistency and is several times its original volume. Outcrops of the Clay Spur bed weather to a popcornlike clay crust. A thickness of 6 inches to 2 feet of siliceous shale overlies the bentonite and is in sharp contact with the overlying Belle Fourche shale.

Fish scales are abundant throughout the Mowry. Radiolaria of the suborder *Nasselaria* (and *Spumellaria?*) were found by Rubey

(1929, p. 154). Cobban (1951, p. 2179) reported impressions of the ammonites *Metengonoceras* and *Gastroplites* (now known to be *Neogastroplites*) collected by A. J. Collier from the Mowry in the northwestern Black Hills.

UPPER CRETACEOUS SERIES

BELLE FOURCHE SHALE

The basal formation of the Upper Cretaceous series in the Black Hills area is the Belle Fourche shale. Named by Collier (1922, p. 83) from exposures along the Belle Fourche River near Wind Creek, Crook County, Wyo., the Belle Fourche shale is a soft, dark-gray to bluish-black shale with numerous concretions and a few thin bentonite beds.

The Belle Fourche is exposed in the southwestern corner of the Carlile quadrangle in parts of secs. 23, 25, and 26, T. 51 N., R. 67 W. It is about 700 feet thick in this area. It is a nonresistant formation and underlies broad undulating flats dissected locally by gullies. Distinguishing features of the Belle Fourche shale are its black color and abundant concretions.

The lower part of the formation is characterized by abundant ferruginous concretions, some sideritic. These are flattened ellipsoidal bodies, having the long dimensions parallel to the bedding. The larger of these are 3 feet across. At least two bentonite beds, less than 1 foot thick, occur in the lower few feet of the formation. The upper 300 to 400 feet contains numerous yellowish-brown spherical limestone concretions 2 to 5 feet in diameter. The "gray-red" bentonite bed of Bramlette and Rubey (in Moore, 1949, p. 27), which is a persistent marker near the top of the formation, was not found in this area.

Marine invertebrates common in the Belle Fourche are listed by Cobban (1951, p. 2182). Cobban and Reeside (1952, p. 1017) report the zone of *Acanthoceras*(?) *amphibolum* Morrow from the middle part of the Belle Fourche, and the zone of *Acanthoceras*(?) sp. A, now named *A. athabascense* Warren and Stelck, according to Reeside (written communication, 1957), from the uppermost part of the formation. Fossils collected by W. W. Rubey (identified by J. B. Reeside, Jr.) from various localities along the northwestern flank of the Black Hills are listed by Robinson and others (written communication, 1957).

GREENHORN FORMATION

The Greenhorn formation around the periphery of the northwestern Black Hills consists of a varied thickness of calcareous mudstone, thin platy limestone, marl, and limestone concretions. The lithic characteristics change along the outcrop to the extent that three general lithologic types may be recognized: a limestone facies, a concretionary facies, and a chalk marl facies (Robinson and others, (written communication, 1957). On the north flank of the Black Hills, Cobban (1951, p. 2183–2185) recognized 4 stratigraphic subdivisions of the Greenhorn, each with a characteristic lithology and 3 having distinctive fauna. The Greenhorn is somewhat more resistant than the enclosing shales and it commonly forms a low hogback that shows the degree of tilting of the beds at the outer margin in the Black Hills uplift.

The Greenhorn formation is exposed in the southwest corner of the quadrangle, in sec. 26, T. 51 N., R. 67 W., where the rocks of the formation strike N. 24° W., and dip 11° to the southwest. The formation is between 70 and 80 feet thick here.

The concretionary facies of the Greenhorn crops out in this area. Lying on the black shale of the Belle Fourche is a layer of tan septarian limestone concretions about 4 feet thick. This is overlain by about 9 feet of tan-weathering dark-gray shale. A 4-foot interval of thin-bedded, platy limestone overlies the shale. The remainder of the formation is composed chiefly of gray shale with a few thin beds of sandy limestone and at least one layer of septarian limestone concretions.

A varied fauna collected from the Greenhorn at localities far to the north of the Carlile quadrangle is listed by Cobban (1951, p. 2184–2185). He noted that the pelecypod *Inoceramus* aff. *I. fragilis* Hall and Meek and the ammonite genera *Dunveganoceras*, *Mantelliceras*, and *Metoicoceras* are the characteristic forms in the lower part of the formation, while *Inoceramus labiatus* (Schlotheim) is abundant in the upper part. Robinson and others (written communication, 1957) list a number of marine invertebrates from several localities immediately west of the Carlile quadrangle.

CARLILE SHALE, LOWER UNNAMED MEMBER

The Carlile shale, a dark-gray shale, consists of three members: a lower unnamed member; the Turner sandy member; and the Sage Breaks member. Only the lower unnamed member remains within the Carlile quadrangle.

Cobban (1951, p. 2187–2190) and Robinson and others (written communication, 1957) present faunal lists, lithologic descriptions, and correlations of each member as it occurs in the northwestern Black Hills.

A thin veneer of the lower unnamed member is exposed on the southwestward-dipping hogback formed by the Greenhorn formation in the extreme southwest corner of the quadrangle (sec. 26, T. 51 N., R. 67 W.). The thickness of the member in this area is from 40 to 60 feet.

The lower member of the Carlile shale is a soft dark-gray shale that conformably overlies the Greenhorn formation. It erodes easily and forms a narrow shallow valley between the more resistant beds in the Greenhorn formation and the Turner sandy member. Near Belle Fourche, S. Dak., Cobban (1951, p. 2187) noticed that this member could be subdivided into two lithologic units separated by a layer of limestone concretions. This apparently is not a regional characteristic. In the vicinity of the Carlile quadrangle, the lower member seems to be predominantly dark shale with only a few ferruginous concretions in the upper part.

PLEISTOCENE AND RECENT SERIES

STREAM TERRACE DEPOSITS

Thin unconsolidated deposits of silt, sand, and gravel are preserved at various altitudes on the bluffs overlooking the Belle Fourche River. These deposits, which occur as isolated patches less than 1 square mile in extent, mantle terraces that were cut into the older rocks at an earlier stage of the erosion cycle. Four distinct levels of terrace deposits were noted; they are at altitudes of 400, 220, 130, and 100 feet above the present river channel. The thicknesses of the deposits range from about 1 foot to more than 30 feet.

The gravel is composed of pebbles of sandstone, limestone, chalcedony, quartzite, quartz, and scattered pebbles of phonolite porphyry. The sand is fine to coarse grained and consists predominantly of quartz. Silt is abundant in the terraces near Keyhole Dam and in the southeastern corner of the quadrangle. Much of the silt near the ground surface may be wind blown; however, no landforms or sedimentary features characteristic of wind-deposited material were found.

The higher and older terrace deposits in the Carlile area are thought to be equivalent to the higher stream terrace deposits of Pleistocene age that were mapped by Knechtel and Patterson (1955) along the Belle Fourche River in northern Crook County, Wyo.

ALLUVIUM

Alluvial deposits of gravel, sand, and silt occur in the valley of the Belle Fourche River and extend for considerable distances up the canyons cut by tributary streams. A broad veneer of silt and sand covers the flood plain of Deer Creek in the southwestern part of the quadrangle, and the shallow valley of Cabin Creek along the northern boundary of the quadrangle is partly filled with alluvium.

Low benches in the Belle Fourche valley are capped with stream deposits. They are considerably higher than the present river flood plain and should, perhaps, be regarded as low terraces.

LANDSLIDE DEBRIS

Several large masses of landslide debris occur along the base of the cliffs that rise above the valley of the Belle Fourche River. Their distribution and position indicates that they are related to the present erosion cycle. The largest landslide is in the vicinity of the Carlile mine in sec. 26, T. 52 N., R. 66 W. It is about three-quarters of a mile long and almost one fourth of a mile wide. Another large landslide is on the north shore of Keyhole Reservoir, where the Belle Fourche River has cut its channel across the Pine Ridge anticline.

Most of these masses of slumped rock are arcuate on the inside edge, the surfaces are hummocky, and the shattered rocks either dip steeply toward the cliff or are scattered in an unoriented fashion.

Apparently the landsliding was caused by the Belle Fourche River undercutting vertical cliffs of the Lakota and Fall River formations. The soft clays of the Morrison formation and Redwater shale member of the Sundance formation facilitated this undercutting and furnished relatively frictionless slopes for downward movement. Failure of the overlying sediments probably occurred in areas of closely spaced joints.

STRUCTURE

The Carlile quadrangle is on the western edge of the Black Hills uplift, and the basic structural feature of the area is the gentle westward and southwestward dip of the sedimentary rocks away from the center of the Black Hills uplift, some miles to the east. The boundary between the Black Hills uplift and the Powder River basin is generally considered to be the Black Hills monocline, a portion of which passes through the southwestern corner of the quadrangle. Superimposed upon the regional dip are many subordinate anticlines, synclines, domes, basins, and terraces, which locally modify or mask the regional structural features. The larger of these, as the Oil Butte and Pine Ridge anticlines, are alined parallel to the Black Hills monocline. Many of the smaller structural features have random orientation. The total structural relief in the Carlile quadrangle is about 1,800 feet.

East of the anticline is an area of shallow synclines, broad anticlinal folds, and smaller domes and depressions chiefly in the northeastern and southeastern parts of the area. The structural features are shown by structure contours drawn on the base of the Fall River formation (pl. 34).

FOLDS

BLACK HILLS MONOCLINE

The steeply dipping Black Hills monocline marks the western limit of the Black Hills uplift, and separates rocks that dip gently outward from the center of the uplift from rocks that dip gently westward toward the interior of the Powder River Basin. The monocline trends north-northwest from south of Newcastle, Wyo., nearly to the Wyoming-Montana boundary, a distance of about 90 miles.

A short segment of the monocline may be seen in the southwest corner of the Carlile quadrangle where beds of Newcastle sandstone, Mowry shale, Belle Fourche shale, Greenhorn formation, and Carlile shale dip west-southwest at 10° to 12°. These dips, although appreciably steeper than the regional dips on either side of the monocline, are in rather sharp contrast to dips elsewhere along the monocline, which commonly are 25° to 30° and locally are nearly vertical.

It is difficult to delineate the eastern limit of the monocline in the Carlile quadrangle because it merges into the west flanks of the Oil Butte and Pine Ridge anticlines. It appears reasonably certain, however, that the outcrop of Newcastle sandstone in sec. 14, T. 51 N., R. 67 W., is included in the monoclinal fold rather than in the anticline. The dip of the beds in this outcrop is about 10° WSW., in contrast to dips of about 7° of beds exposed to the east and southeast along the anticlinal limb. The eastern limit of the monocline, therefore, probably is somewhere in the Skull Creek shale east of the Newcastle outcrop. The crest of the monocline trends northwestward and probably passes out of the quadrangle in the vicinity of the boundary between T. 51 N. and T. 52 N., R. 67 W.

OIL BUTTE ANTICLINE

The Oil Butte anticline is the northernmost of two folds superimposed upon the crest of the Black Hills monocline in the western part of the quadrangle. It is a doubly-plunging, asymmetrical anticline, whose axis trends north-northwestward. The highest point of the structure is in sec. 25, T. 52 N., R. 67 W. The eastern limb dips more steeply than does the western; maximum dips on the eastern limb average about 27°, those on the western, about 7° to 10°.

The southern end of the anticline is connected with the northern end of the Pine Ridge anticline by a narrow anticline or, assuming both anticlines to be parts of a single more complex structural feature, by a structural saddle in sec. 1, T. 51 N., R. 67 W. The configuration of the connecting feature can be seen by the structure contours (pl. 34).

The structural closure on the Oil Butte anticline, from the saddle to the crest is about 300 feet; the total closure, including both anticlines, is about 480 feet.

Most of the anticline is covered by the sandstone unit of the Fall River formation, although canyons eroded into the flanks, particularly by the heads of the Spring Creek and Cyclone Creek (in the extreme northwestern corner of the quadrangle) drainages, expose older formations down to and including the Morrison.

PINE RIDGE ANTICLINE

The Pine Ridge anticline lies south of the Oil Butte anticline and is connected to it by the structural saddle mentioned above. The Pine Ridge anticline also is a doubly plunging, asymmetrical fold whose axis trends north-northwestward. Its structurally highest point is in sec. 19, T. 51 N., R. 66 W. The average maximum dip on the eastern side of the fold is about 18°; that on the western side is about 7°.

The structural closure on the anticline, from saddle to crest, is 200 feet; the total closure, relative to the combined structural features, is about 380 feet.

The Pine Ridge anticline is more deeply dissected than the Oil Butte anticline. Rocks of the Fall River formation comprise the bulk of the exposures on the northern half; and the Lakota and Morrison formations and the Redwater shale member of the Sundance formation are exposed in the southern part, where the Belle Fourche River has breached the anticline, and deep southward-facing canyon walls expose sheer cliffs of sandstone of the Lakota formation.

Several features common to both anticline strongly suggest that both are related to a single compressive force that was exerted from a west-southwestward to east-northeastward direction. Projections of the crest lines of the northern half of the Oil Butte anticline and the southern half of the Pine Ridge anticlines are practically a straight line. Deviations of the crest lines occur in the vicinity of the structural saddle. In addition, both anticlines are asymmetrical to approximately the same degree. Probably in the area of the structural saddle either a lessening of the compressive force occurred or else the rocks in this area were more resistant to the force. Perhaps this resistance caused a component of the force to be transmitted slightly northward, which resulted in the bulging of the southeastern end of the Oil Butte anticline.

DAKOTA DIVIDE ANTICLINE

The Dakota Divide anticline is a smaller doubly plunging asymmetrical fold, whose axis trends northwestward near the top of Dakota Divide in the east-central part of the quadrangle. It is separated from the Pine Ridge-Oil Butte anticline by the Eggie Creek syncline. In plan its limbs, particularly the southwestern limb, are rather irregular, and its plunge to the northwest is more abrupt than to the southeast. These features are well shown by the structure contours (pl. 34). The closure on the Dakota Divide anticline is about 80 feet.

SYNCLINES

There are two principal synclines in the quadrangle. The larger is a southward-plunging syncline, whose axis trends along, or just northeast of, Eggie Creek and which is here called the Eggie Creek syncline. The trough of this depression passes out of the quadrangle just east of the center of the southern boundary. The northern part of the syncline splits into two segments. One segment trends westward and heads against the saddle between the Pine Ridge and Oil Butte anticlines; the other is expressed in the Spring Creek drainage in sec. 31, T. 52 N., R. 66 W. The syncline separates an area on the west that includes the south end of the Oil Butte anticline and the Pine Ridge anticline from an area to the east that includes the Dakota Divide anticline and the terraced area along the Belle Fourche River to the south, as shown by the structural features on plate 34.

Another broad, northward-plunging synclinal area is in secs. 13 and 24, T. 52 N., R. 67 W., and separates the north end of the Oil Butte anticline from the gently westward-dipping area to the east.

Several smaller depressed areas are shown by the structure contours (pl. 34). One, near the southeastern corner of the quadrangle, is either the west end of a small eastward-plunging syncline, or the west and central parts of a closed depression. Another is the bowl-shaped depression on Thorn Divide.

The structural features in the remainder of the quadrangle, particularly in the northeastern part, may be considered as an area of predominantly gentle westward dips with superimposed low domes, shallow depressions, and structural terraces. On Thorn Divide and at the Carlile mine, uranium deposits are associated with locally modified structural terraces.

FAULTS AND JOINTS

Stresses were relieved throughout the area almost entirely by folding as only a few faults were found within the quadrangle. All faults are small, nearly vertical, and cannot be traced for any great distance.

The largest fault is at the north end of the Pine Ridge anticline in secs. 1 and 12, T. 51 N., R. 67 W. It roughly parallels the northwestward-trending axis of the anticline. The fault is inferred to be about 3,500 feet long, and the maximum displacement (30–35 feet) is near the northwestern end where the upper unit of the Fall River formation in the north or downthrown block is in contact with the mudstone unit of the Fall River in the south block. The displacement along the fault decreases toward the southeast.

A small northeastward-trending fault, about 1,500 feet long, occurs just west of the fault described above, mainly in sec. 11, T. 51

N., R. 67 W. Its maximum displacement of about 20 feet is at the northeastern end; the fault dies out to the southwest. The southeastern side is downthrown, as shown by displaced beds of the Fall River formation.

Two parallel faults that trend north-northeastward were traced slightly less than 2,000 feet on the western side of the Oil Butte anticline, in sec. 23, T. 52 N., R. 67 W. The displacement along these faults is shown on the cross section *B–B′* (pl. 34). The block between the faults has been downthrown as much as 15 feet relative to the block on the west and a maximum of 30 feet relative to the block on the east. Maximum displacements are at the north ends of the faults, and the faults die out toward the south ends. No other faulting was noted in the quadrangle.

Vertical joints are conspicuous in the sandstone unit of the Fall River formation, but they are not traceable through the rocks above or below. These joints locally are spaced from 10 to 30 feet apart; more commonly they are at intervals of several hundreds of feet. There are two sets of joints; the most prominent set strikes N. 55°–75° W.; the subordinate set strikes N. 20°–N. 25° W.

LANDSLIDES

At several of localities throughout the quadrangle landsliding has taken place. The landslides are most prevalent along the valley of the Belle Fourche where downcutting by the river has exposed the Morrison formation and, less commonly, the Redwater shale member of the Sundance. In these areas large blocks of sandstone from the Lakota and Fall River formations have slid down across the weak clays of the Morrison. In a few places, notably on the eastern side of the Oil Butte anticline and along the western side of the Pine Ridge anticline, blocks of sandstone of the Fall River formation have slid down over the slopes of the underlying mudstone unit.

The largest slides are those at the southern end of the Pine Ridge anticline and along the Belle Fourche River east of Thorn Divide, in sec. 26, T. 52 N., R. 66 W. At both localities, failures in claystone beds of the Morrison have allowed large masses of the overlying sandstone to slide a few hundred feet vertically.

The slide in sec. 26 is noteworthy in that a large section of the Lakota and Fall River formations has slid downward, intact, with a maximum vertical displacement of about 300 feet (see p. 672, 673).

STRUCTURAL HISTORY

The structural history of the northern Black Hills region has been outlined by Darton (1909, p. 76–77) and by Noble (1952, p. 31–37). Local unconformities in the pre-Cretaceous rocks give evidence of early periods of deformation, but the major upwarp began in latest Cretaceous or earliest Tertiary time and was completed before deposition of Oligocene sediments. This deformation accounts for the major structural features seen in the Black Hills today. Intrusions of igneous material accompanied the uplift of the region. Uplift has continued since Oligocene time, as shown by the wide vertical distribution of thin remnants of White River formation of Oligocene age.

SEDIMENTARY PETROGRAPHY OF THE INYAN KARA GROUP

Petrographic studies of samples from the Lakota and Fall River formations were made to present descriptive data that may have some significance with regard to the uranium deposits that occur in these formations in the northern Black Hills. In addition, it was believed desirable to augment field observations by determining whether or not differences in composition and texture exist between rocks of similar grain size in each formation. Another useful function of these studies is to supply data that could contribute to a regional study to determine the source of the sediments.

Only the finer grained units of the Lakota formation were analyzed so that comparisons of sorting coefficients could be made with samples of similar grain size from the Fall River formation.

Mechanical analysis of size, heavy mineral separation, examination of mineral-grain slides and thin sections with a petrographic microscope and standard laboratory methods of preparation and measurement were used in the study.

MECHANICAL ANALYSIS

Samples were placed in a mechanical shaker and were agitated for 15 minutes each and separated by Tyler screens of the following sizes: 0.295 mm, 0.208 mm, 0.147 mm, 0.104 mm, 0.074 mm, 0.053 mm, and 0.044 mm.

The median diameters and sorting coefficients were derived from the cumulative frequency curves, which were plotted from the data obtained from the weighed size fractions (figs. 59 and 60). Histograms also were drawn to show the size frequency distribution.

A well-sorted sediment, as defined by Trask (1932, p. 71–72), has a sorting coefficient of less than 2.5. By this definition, all the samples shown in figures 59 and 60 are well sorted; however, the average sorting coefficient of Lakota samples is larger (they are not as well sorted) than that of samples from the Fall River formation. While the gross field characteristics clearly show that the Lakota is poorly sorted and the Fall River well sorted, it is interesting to note that this difference still exists in rocks of nearly the same grain size from the two formations.

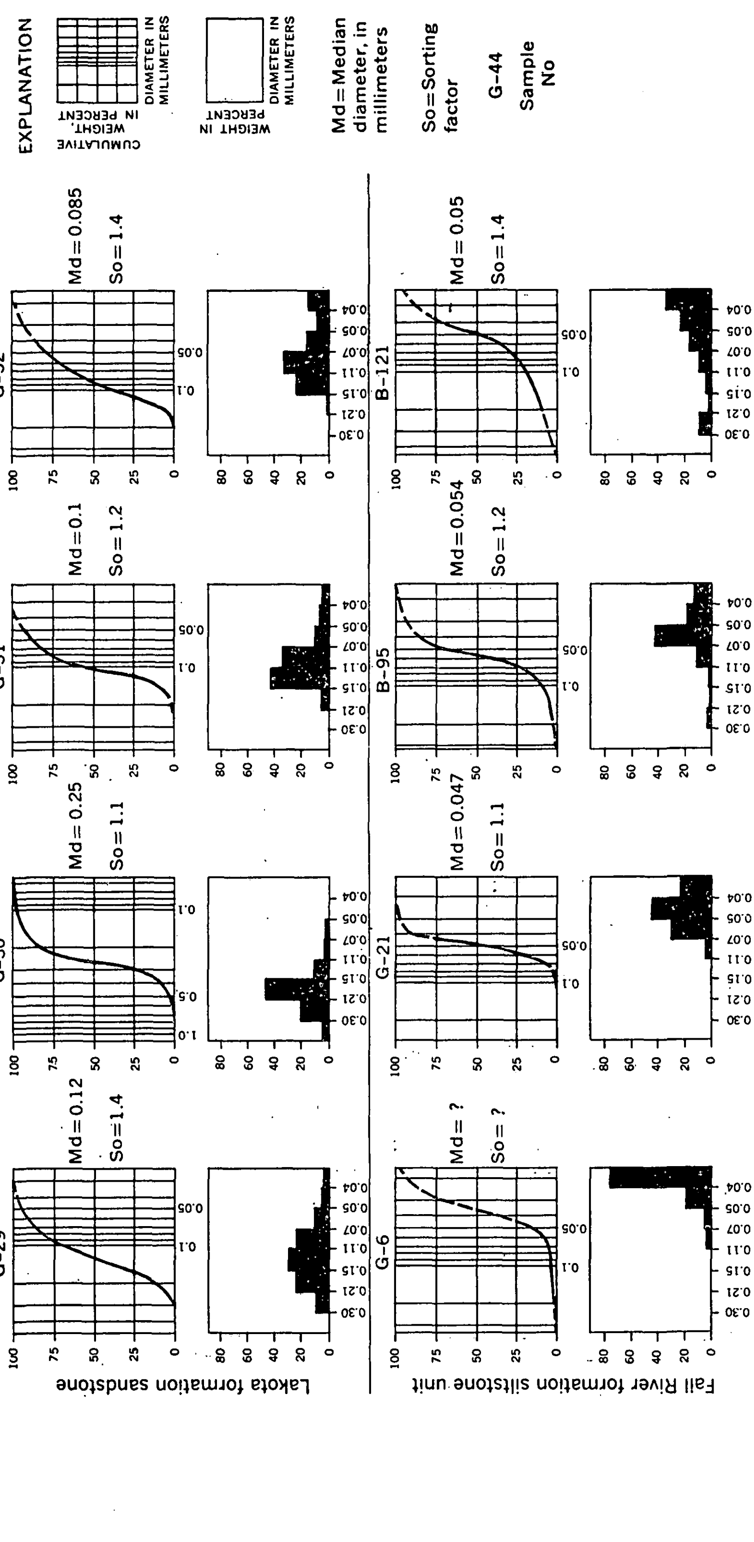


FIGURE 59.—Cumulative frequency curves and histograms of samples from the Lakota and Fall River formations, Carlile quadrangle, Wyoming.

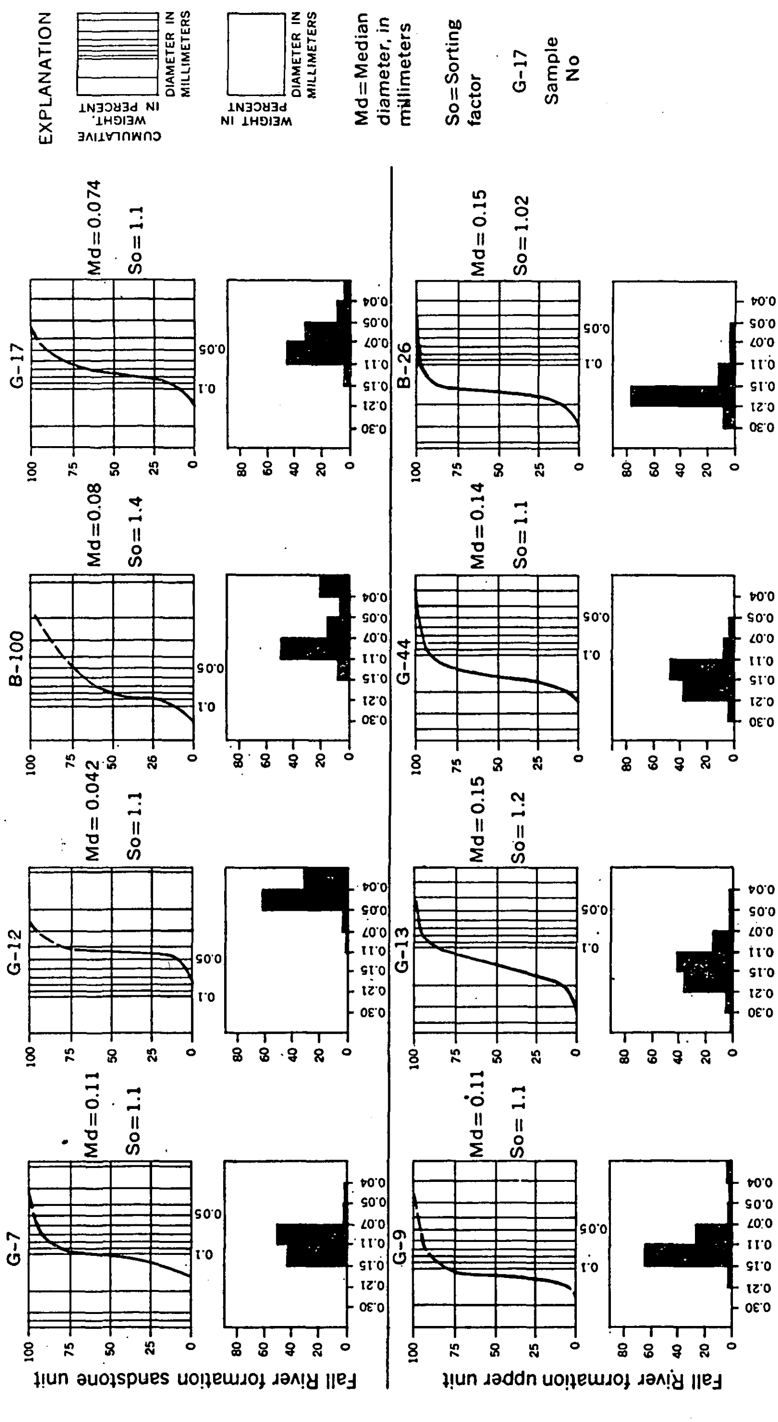


FIGURE 60.—Cumulative frequency curves and histograms of samples from the Fall River formation, Carlile quadrangle, Wyoming.

The median diameters of the sand grains range from 0.042 mm to 0.25 mm, which, according to Wentworth's grade scale, classifies the rocks as ranging from siltstone to fine-grained sandstone.

The median diameter and sorting coefficient for sample G-6 (fig. 59) cannot be determined by normal statistical methods because lack of data precludes projection of the cumulative frequency curve beyond the first quartile.

HEAVY MINERAL SEPARATION

Separation of heavy minerals as made from nine samples of sandstones from the Lakota and Fall River formations.

In general, the sandstones of the Lakota and Fall River contain similar small suites of heavy minerals, but differences exist in the mineral species that are minor constituents of the heavy mineral fraction. The heavy minerals probably were derived from a preexisting sedimentary or metasedimentary terrane. The distribution and relative abundance of the heavy minerals in the samples studied are shown in the following table. Heavy minerals identified in the Lakota samples are predominantly zircon and tourmaline, with minor amounts of anatase, brookite, garnet, rutile, and staurolite.

Distribution of heavy minerals in the Lakota and Fall River formations, Carlile quadrangle, Wyoming

[VA, very abundant, more than 60 percent; A, abundant, 41–60 percent; C, common, 6–40 percent; R, rare, 1–5 percent; VR, very rare, less than 1 percent]

Sample No.	Anatase	Brookite	Chlorite	Chloritoid	Epidote	Garnet	Rutile	Sillimanite	Staurolite	Tourmaline	Zircon
Lakota formation (sandstone)											
G-29	--------	VR	--------	--------	--------	VR	R	--------	R	C	VA
G-30	--------	--------	--------	--------	--------	R	R	--------	C	C	A
G-31	VR	--------	--------	--------	--------	VR	C	--------	R	C	VA
G-32	--------	--------	--------	--------	--------	VR	C	--------	R	C	VA
Fall River formation (siltstone unit)											
G-6	--------	--------	VR	R	--------	R	C	--------	R	C	A
Fall River formation (sandstone unit)											
G-17	--------	R	VR	C	--------	R	C	--------	VR	A	C
B-100	--------	--------	VR	C	--------	R	C	--------	VR	C	A
B-122	--------	--------	--------	R	--------	VR	C	--------	VR	C	VA
Fall River formation (upper unit)											
G-44	VR	--------	VR	R	VR	R	R	VR	C	VA	C

The Fall River samples contain a similar assemblage and, in addition, a few percent of chlorite, chloritoid, epidote, and sillimanite. An opaque mineral, probably hydrous iron oxide, is abundant in all samples but is not listed in the table. Two varieties of tourmaline were identified in nearly all samples: dravite, which occurs as light-brown to nearly colorless grains containing dark inclusions, and indicolite, which occurs at bluish-green grains.

Despite a general similarity, significant differences were observed between heavy mineral assemblages in Lakota samples and those in Fall River samples. Chloritoid occurs throughout the sandstone beds of the Fall River to within 2 feet above the contact of the Lakota and Fall River; no chloritoid was seen in the Lakota samples. The presence of chloritoid and other minerals in the Fall River suggests either a change in source or a wider source than for the Lakota. In general, zircon and tourmaline grains in the Lakota show a higher degree of rounding than those in the Fall River, indicating a greater distance of travel from the source, a more intense reworking of material, or derivation from older sedimentary rocks.

MICROSCOPIC EXAMINATION

LAKOTA FORMATION

Measurements in thin sections show that detrital grains in sandstone units of the Lakota formation range from silt to granule size. The grains consist predominantly of quartz, chert, feldspars, and white mica, the relative proportions of which vary as a function of the average grain size. The rocks consisting chiefly of granule-size grains contain as much as 95 percent chert and 5 percent quartz, whereas the very fine-grained samples consist of 95 percent quartz and 5 percent chert. Only minor amounts, less than 1 percent, of feldspars and white mica were detected, and these minerals were limited to fine-grained beds near the top of the Lakota.

In all thin sections examined, detrital quartz had three types of extinction—sharp, undulatory, and flamboyant—indicating grains of several different origins. Some grains, which show sutured contacts, probably were derived from metaquartzite. Inclusions of tourmaline, zircon, and rutile, and linear trains of bubbles occur commonly and appear not to be limited to a single type of quartz. The characteristics of grain boundaries vary considerably. Some are conspicuously corroded; others are characterized by authigenic outgrowths of quartz in optical continuity with the detrital grains.

Chert grains are generally composed of a mosaic of cryptocrystalline quartz. Some, however, show a radial fibrous structure, and others contain rhombocasts of a colorless to light-yellow isotropic mineral tentatively identified as collophane. A few of the grains show relict oolitic texture and contain silicified fossil fragments. The sand grains are generally subangular to subround, although grains of granule size are well rounded. Interstitial cement is composed of either hydrous iron oxide or clay minerals. Porosity of the sandstone beds, calculated from point counts, ranges from 15 to 25 percent.

The polished pebbles and cobbles that occur in the mudstone unit of the Lakota formation have been discussed previously and have some interesting microscopic characteristics. Chert is the predominant rock type, but other pebbles are composed of orthoquartzite, metaquartzite, spherulitic chalcedony, silicified muddy sandstone and siltstone, and rounded fragments of silicified wood. Pebbles of vein quartz are rare. Many of the chert pebbles show relict oolitic texture and contain silicified fossil remains. The orthoquartzite pebbles show well-defined overgrowths of authigenic quartz in optical continuity with the detrital grains. Metaquartzite pebbles show sutured contacts between grains. Camera lucida drawings of some typical quartzite pebbles are shown in figure 61.

Though the pebbles and cobbles are all well rounded, smooth, and commonly highly polished, the degree of polish seems to be a function of composition. The dense chert variety is polished; the quartzite varieties are smooth but not highly polished. Some surfaces show percussion marks and microstriations.

FALL RIVER FORMATION

The sandstone units of the Fall River formation are similar in composition to fine-grained sandstone units of the Lakota. Point-count analyses were made on thin sections of the siltstone unit, sandstone unit, and upper unit of the Fall River. Thin sections of the mudstone unit were not prepared because the rock consists of a submicroscopic matrix of clay minerals and minor admixtures of silt- and sand-size particles. Averages of point-count analyses for each of the units show that the rocks consist predominantly of quartz grains, ranging from a low of 60 percent in the siltstone unit to a high of 82 percent in the upper unit. Interstitial clay minerals comprise a minimum of 13 percent of the upper unit and a maximum of 35 percent of the siltstone unit. Each of the three units contain from 2 to 3 percent chert, 1 percent feldspar, and about 1 percent white mica. From the foregoing it can be concluded that the relative abundance of quartz grains and clay is merely a function of the average grain size of the rock and that the minor constituents remain the same regardless of grain size. Finely divided carbonaceous material is abundant in thin sections of the siltstone unit and commonly occurs in samples of the sandstone and upper units.

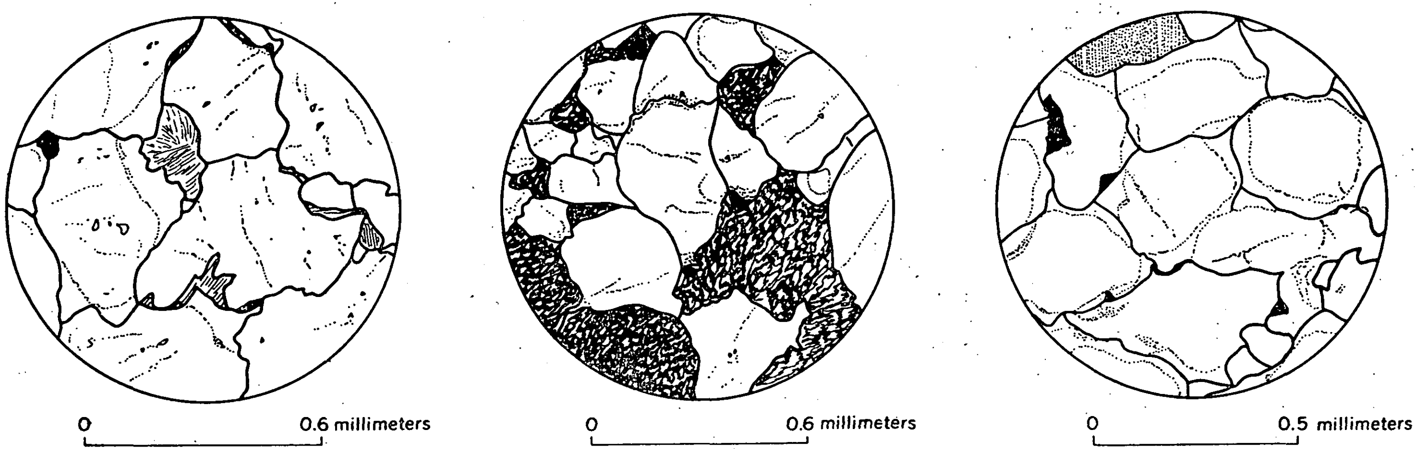


FIGURE 61.—Camera lucida drawings of polished pebbles from the Lakota formation, Carlile quadrangle, Wyoming. *A*. Polished pebble of metaquartzite. Quartz grains show sutured contacts, and white mica (patterned) fills interstices. Opaque material is concentrated along grain boundaries. *B*. Polished pebble of orthoquartzite. Quartz and chert (patterned) grains show some sutered boundaries. Concentrations of opaque material are along some grain boundaries. *C*. Polished pebble of orthoquartzite. Well-sorted subrounded quartz and (stippled) grains are tightly cemented by clear authigenic quartz overgrowths. Concentrations of opaque material are along some grain boundaries.

As in the Lakota, the quartz grains in the Fall River show sharp, undulatory, and flamboyant extinction, indicating varied origins. A few grains in the sandstone and upper units show outgrowths of authigenic quartz in optical continuity with the detrital grains. Corrosion of quartz grain boundaries is marked in the carbonate-cemented lower 2 feet of the sandstone unit.

Chert grains are composed of cryptocrystalline quartz. Twinned plagioclase, microcline, and orthoclase grains are slightly altered. Nearly all of the sand grains are subangular to subround, although some angular lath-shaped quartz grains, possibly derived from a metamorphic terrane, are conspicuous in some samples. Hydrous iron oxide coats many grains and stains much of the matrix in all thin sections. Porosity, computed from point-count analyses, ranges from 2 to 5 percent in the siltstone unit, from 15 to 20 percent in the sandstone unit, and from 21 to 26 percent in the upper unit.

ECONOMIC GEOLOGY

Concentrated locally in the sedimentary rocks of the northern Black Hills are commercially important accumulations of uranium, petroleum, bentonite, and coal. Discovery of minable deposits of uranium in the Carlile quadrangle and at several localities to the north generated interest in conducting detailed geologic studies to evaluate properly the potential of the area for uranium. Of less economic importance than uranium in the Carlile area are bentonite and petroleum; however, at other localities around the periphery of the Black Hills, small oil fields and bentonite strip mines are in full-scale operation. Coal mining, once a thriving activity in the Black Hills, is now dormant.

URANIUM

Uranium ore has been produced from several localities in the northern Black Hills, and many other areas of anomalous radioactivity are known. In 1957 all the commercial deposits and most of the known anomalies are in the sandstone and siltstone beds of the Lakota and Fall River formations; a few areas of anomalous radioactivity occur in other formations, and visible uranium minerals have been noted in the Newcastle sandstone near Strawberry Hill, north of Hulett, Wyo.

The uranium deposits form irregular, tabular masses that average about 4 feet in thickness and have lateral dimensions that may be measured in tens, and in some deposits, hundreds of feet. In gross aspect, the ore deposits have no preferred orientation or trend.

The deposits may be divided into two general types—those that occur above the local water table and consist of a carnotite-tyuyamunite type of mineral assemblage, and those that occur below the water table and are characterized by a uraninite-coffinite assemblage. A feature common to all deposits of both types is the association of uranium minerals with finely divided carbonaceous material. Locally both carbonaceous material and uranium minerals are concentrated in sandy or silty seams that generally apear to be alined along bedding planes and planes of cross stratification; these concentrations constitute the richest parts of the ore bodies. Uranium deposits of similar occurrence in the southern Black Hills have been described by Bell and Bales (1955).

CARLILE MINE

The Carlile mine was the largest single producer of uranium in the Black Hills area of Wyoming and South Dakota until the summer of 1955. The mine is on the eastern margin of the quadrangle (pl. 34), along the west side of the valley of the Belle Fourche River in the W½ sec. 26, T. 52 N., R. 66 W. The property is about 5½ miles by road southeast of Carlile and can be reached most directly by driving south from Carlile on U.S. Highway 14, a distance of 1.6 miles, then east across Thorn Divide on graded dirt roads a distance of 3.8 miles. The dirt roads generally are passable except during and immediately after heavy rains.

The first discovery of uranium deposits in sedimentary rocks in the northern Black Hills was at the Carlile mine. The discovery was made on May 20, 1952, by T. M. Rizzi, geologist, Homestake Mining Co., using airborne scintillation-detection equipment. A ground party, which checked the anomalous area the following day, found good exposures of carnotite-bearing sandstone. Claims were staked by the company on about 80 acres of Government-owned land. The first uranium ore was shipped from the mine in January 1953, and the mine was operated intermittently until 1955, at which time the ore bodies were mined out. The company did additional exploratory drilling during the summer of 1955, but mining was not resumed.

The mine workings consist of about 700 feet of drifts, a stripped area of about 1.2 acres, and an opencut 180 feet wide by 650 feet long.

GEOLOGY

STRATIGRAPHY

Rocks mapped in detail in the mine area comprise a total thickness of about 325 feet of sandstone, siltstone, claystone, and limestone of the Morrison, Lakota, and Fall River formations. These formations and their general lithologic characteristics throughout the quadrangle have been described on pages 25–95 and their distribution in the mine area is shown on plates 36 and 37.

The uranium deposits occur in the mudstone unit of the Lakota formation, in the sandstone lens that is designated as the upper sandstone subunit on the detailed maps of the mine area. The lens can be traced from the mine less than 1 mile to the south, about 1½ miles to the north, and 1 mile to the southwest. Beyond the mine area the lens merges with the massive sandstone unit below.

The sandstone lens ranges in thickness from less than 20 to about 40 feet. At most places the rock is a gray to tan, medium-grained, thick-bedded, quartzose, fairly well sorted sandstone, containing seams of carbonized wood and carbonaceous siltstone ranging in thickness from ¼ inch to 4 inches. The lens is very thinly cross-laminated to thinly crossbedded on a medium scale at low angles; carbonaceous seams are arranged along planes of cross-stratification. Woody material in small particles is disseminated throughout the sandstone.

The sandstone lens is separated from the lower massive sandstone unit of the Lakota by a layer of claystone and siltstone, which has been designated the lower claystone subunit on the detailed maps (pls. 36 and 37). It consists of beds of very dark gray to light-gray or white claystone and siltstone that grade into one another laterally and vertically. Locally the entire subunit, which in the mine area ranges from 20 to about 55 feet thick, is somewhat sandy, and in the lower part sand grains may become very abundant. (See subunit 5 of the stratigraphic section, p. 671.) Elsewhere, however, this lower part of the lower claystone subunit is represented by gray or gray-green claystone.

Interbedded carbonaceous and noncarbonaceous silty claystone separates the ore-bearing sandstone lens from the base of the Fall River formation; this sequence of claystone beds has been designated the upper claystone subunit on the maps of the mine and mine area. The subunit consists of a gray to black, clayey siltstone and silty claystone, generally containing disseminated finely divided woody fragments. The thickness of the subunit ranges from less than 20 feet to nearly 50 feet.

The three subunits, which separate the lower massive sandstone of the Lakota from the Fall River, constitute the unit mapped elsewhere in the quadrangle as the mudstone unit of the Lakota formation.

The following section was measured in the W½ sec. 26, T. 52 N., R. 66 W., along the road that passes up the valley wall on the east side of the long, narrow, central promonotory that contains the ore bodies 1, 2, and 3 (pl. 37).

Section 6 (pl. 35) measured in W½ sec. 26, T. 52 N., R. 66 W.

	Feet
Top of hill.	
Fall River formation (part):	
Upper unit (part):	
27. Siltstone, gray, unindurated	0.2
26. Layer of carbonized wood fragments	.5
Sandstone unit:	
25. Sandstone, tan, very fine grained, micaceous, locally calcareous, laminated; contains finely divided carbonaceous material; several lenses of fissile silt and carbonaceous material 3 to 8 in thick in lower 3 ft	16.0
24. Sandstone, brownish, fine-grained, micaceous; calcareous at base, very thin- to very thick-bedded; commonly contains spherical, calcareous concretions as much as 1 ft in diameter; finely divided carbonaceous material disseminated throughout; forms cliff	21.5
Mudstone unit:	
23. Siltstone, gray, slightly calcareous, laminated; contains a few sandy, platy to flaggy limestone beds; becomes sandy in upper 3 ft	42.5
Siltstone unit:	
22. Siltstone, sandy, dull-gray, thin-bedded, and laminated silty claystone; slightly calcareous; upper contact gradational into unit 23	3.5
21. Siltstone, sandy, gray to tan, micaceous, locally calcareous, thin- to very thick bedded, wavy-bedded; contains gray clayey seams between siltstone beds; cross stratified on medium scale; tiny fragments of plant material disseminated throughout; vertical borings and worm(?) trails common	30.5
20. Siltstone, banded light- to dark-gray; sandy in part; laminated; quite sandy in upper 6 in	2.0
19. Siltstone, tan to brown, sandy, ferruginous; base probably is base of Fall River formation	2.0
Total measured Fall River formation (rounded)	119.0
Disconformity.	
Lakota formation (part):	
Mudstone unit:	
Upper claystone subunit:	
18. Siltstone, gray; clayey in lower 3 ft; contains some woody fragments	9.5
17. Claystone, very dark gray; contains woody fragments	2.0
16. Claystone, gray, silty, thin-bedded; breaks into small, slabby fragments	2.0
15. Claystone, black, silty; ferruginous zone 6 to 8 in thick at top; coaly	1.5
14. Covered interval	5.5
13. Siltstone, gray; ferruginous zone 6 in thick at top; thin-bedded; breaks into small, slabby fragments; contains finely divided plant material	7.0

Section 6 (pl. 35) measured in W½ sec. 26, T. 52 N., R. 66 W.—Continued

	Feet
Lakota formation (part)—Continued	
Mudstone unit—Continued	
Upper sandstone subunit:	
12. Sandstone, gray to tan, medium- to fine-grained; grades upward into light-gray siltstone	2.5
11. Sandstone, gray, medium-grained; conglomeratic, containing granules of chert in lower 2 ft; silty and fine-grained in upper 3 ft; thick-bedded; low-angle, lenticular cross-stratification on medium scale; very thinly cross-laminated to thinly crossbedded; contains thin seams of carbonaceous silt along planes of cross-stratification; tan on weathered surface; contains much plant material both disseminated and concentrated in seams and stringers; contains ore at mine	20.5
Lower claystone subunit:	
10. Claystone, light-gray, sandy; grades to siltstone in top 4 to 6 in	1.5
9. Claystone, very dark gray, sandy	2.0
8. Siltstone, white, cherty, clayey, hard, brittle, very thin- to thin-bedded; contains bed of carbonaceous claystone, 1-ft thick, 1.5 ft above base	6.0
7. Claystone, dark-gray, gradational into unit 8	1.0
6. Claystone, dark-gray; contains sand grains up to granule size	1.5
5. Siltstone, gray to brown; sandy, clayey; very weakly cemented; conglomeratic with fragments of small pebble size size; contains a few thin beds of less sandy siltstone	22.0
Sandstone unit (part):	
4. Sandstone, light-gray, calcareous, well-cemented; weathers purplish brown	.5
3. Sandstone, light-gray to tan, medium to very coarse grained, poorly sorted; locally slightly clayey; very weakly cemented; contains bed of greenish-gray, shaly claystone, 6-in thick, 1.5 ft above base	29.5
2. Slumped interval; lobe of landslide block containing sandstone, siltstone, and claystone; carnotite-type mineralization in sandstone	10.5
1. Sandstone, light-gray, coarse-grained, firmly cemented, thick-bedded to very thick bedded; conglomeratic, with abundant chert granules and pebbles; medium-scale, low-angle cross stratification	5.0
Total measured Lakota formation	130.0
Approximate distance to base of Lakota formation	3.0
Approximate thickness of Lakota formation	133.0

The base of the lowest sandstone unit of the Lakota formation (unit 1) is not exposed along the line of section, but, about 175 feet to the southwest and about 3 feet lower in elevation, the base of a thick-bedded conglomeratic unit is exposed in sharp contact with a dark-grayish-brown, noncalcareous claystone similar to that described previously under the discussion of the Morrison formation. This dark claystone has a thickness of 7 to 8 feet, below which it grades almost imperceptibly through about 3 feet into the light-greenish-gray calcareous claystone typical of the Morrison formation.

STRUCTURE

The Carlile mine is in an area where the regional dip of the beds is interrupted by small anticlines, synclines, domes, depressions, and terraces. The most pronounced structural features near the mine are the Dakota Divide anticline, whose crest is about 2 miles to the southwest, and the circular depression on Thorn Divide, about one mile west of the mine (pl. 34). The mine is on a structural terrace, and the beds, for at least half a mile in all directions, dip gently to the west or southwest at less than 100 feet per mile.

Large-scale mapping has shown that the ore-bearing sandstone lens is slightly higher in altitude at the mine than in immediately adjacent areas (pl. 36 and 37). This structure probably is a gentle dome with a closure of about 10 feet; its apex cannot be located exactly because of the narrowness of the promontory, the landslide to the east, and the lack of exposures to the south. The dome may be the result of tectonic forces, or it may be a primary sedimentary structure, such as a local thickening of underlying strata or deposition on an irregular surface.

The most pronounced structural feature in the immediate vicinity is a landslide block that has dropped from the east side of the central promontory, containing ore bodies 1, 2, and 3 (pl. 37), into the valley of the Belle Fourche River. A cross section through this structure and its relation to the nearly flat lying rocks on the west are shown on plate 37.

A hole (pl. 37) was drilled through Lakota beds at depths approximately consistent with projections of the beds along the dips measured in the opencut. This indicates that vertical displacement along the plane of movement is approximately 300 feet. Vertical displacement of the eastern part of the block, measured from exposures at the east edge of the opencut, is roughly half that amount, or about 150 feet. The block has moved downward, nearly intact and with little internal disturbance, and has been tilted toward the adjacent cliff.

Reiche has described landslide blocks in the Mesaverde formation and Mancos shale in northeastern Arizona, where landslide blocks exceeding 1,700 feet in length are displaced vertically as much as 220 feet along planes of failure in the Mancos shale (Reiche, 1937, p. 542). He has suggested the name "Toreva-block" for this type of slide. An analogous situation may exist at the Carlile mine, wherein a block composed of Fall River, Lakota, and Morrison formations, and perhaps Redwater shale member of the Sundance formation slid along a plane of failure in the underlying clay and shale of the Morrison and Sundance formations.

Another explanation for the landslide block is that it is the outermost block of a series that overlies a collapsed area, whose center lies east or northeast of the block. Reconnaissance mapping in the adjacent quadrangle to the east shows faulting or sliding of a similar nature, which might be the eastern margin of such a collapsed area (C. S. Robinson, oral communication, 1956).

Many faults of small magnitude were mapped in the underground workings that give access to ore body 3 (pl. 38). These faults have a nearly north-south alinement, are essentially vertical, and generally have displacements of less than 6 inches. The faults are approximately parallel to the plane along which the landslide moved, and they probably are related to the landslide. At several places ore in the underground workings is displaced several inches by these small faults (pl. 38) indicating that they are postmineralization faults. The fracture surfaces are barren of uranium minerals and iron oxides, either or both of which would be expected in some degree if the faults were formed before emplacement of the ore.

The sandstone unit of the Fall River formation is cut by two sets of vertical joints. One set strikes about N. 25° E., and the other strikes about N. 25° W. These joints cannot be traced downward into the underlying sandstone units.

Sedimentary structural features consist chiefly of medium-scale, low-angle cross-stratification and are most predominant in the upper sandstone subunit of the Lakota formation. Alinement of the sets of cross strata indicates that locally, at least, the streams that deposited the sandstone flowed across this area from the west or southwest.

ORE DEPOSITS

The ore deposits at the Carlile mine consisted of four ore bodies in the upper sandstone subunit of the Lakota formation. The original outlines of these bodies, as determined by drilling, are shown on plate 37. The mine workings comprise about 700 feet of drifts (pl. 38) accessible through two adits, a stripped area of about 1.2 acres south of the adits (pl. 37), and an opencut, 180 feet wide by 650 feet long, located several hundred feet east of and about 150 feet lower in altitude than the adits (pl. 37).

The ore minerals carnotite and tyuyamunite occur as fine-grained aggregates that fill interstices and coat sand grains and fragments of carbonized wood. The grade of ore remaining in the mine in 1955 ranged from 0.10 percent to 1.93 percent uranium and from less than 0.1 percent to 3.37 percent V_2O_5.

Although visible uranium minerals at the Carlile mine are found only in the upper sandstone subunit, a small area of anomalous radioactivity was found in the sandstone unit of the Lakota formation at a point 1,600 feet northwest of the stripped area on the west side of the canyon, less than 5 feet above the canyon floor. The anomalous radioactivity was 0.72 milliröntgens per hour in contrast to a background of 0.025 milliröntgens per hour but no uranium minerals were detected. A chip sample of the otucrop here contained 0.057 percent equivalent uranium but only 0.015 percent uranium.

Several additional areas of anomalous radioactivity are present in the upper sandstone subunit in the area adjacent to the mine workings. These have been prospected by bulldozer cuts (pl. 36), but the extent of ore, if any, at these localities is unknown.

CHARACTERISTICS AND GRADE

Discontinuous lenses and pods containing concentrations of uranium minerals comprised the four large ore bodies of the Carlile deposit (pl. 37). Sandstone containing more than 0.10 percent uranium is considered ore. These concentrations are associated with carbonaceous and clayey seams that are alined along planes of cross-stratification in the upper sandstone subunit of the Lakota formation.

Closely spaced drilling and chemical analyses of samples of drill core by the Homestake Mining Co. delineated the limits of ore, except for ore in the landslide block. The original outlines of the ore bodies so determined are shown on plate 37. The ore bodies were irregular in outline, had no preferred orientation or trend, and rarely exceeded 3 feet in thickness. Ore body 1 was 275 feet long and from 50 to 105 feet wide. Ore body 2, which is of low grade, is 110 feet long and from 25 to 30 feet wide. Ore body 3, which was mined from the underground workings, was 150 feet long and from 25 to 60 feet wide. Ore body 4, in the landslide block, is 320 feet long and has been mined down the dip of the beds for a distance of 60 feet. Most of the ore shown on plate 37 has been mined out. An undetermined amount of ore-grade material still remains in ore body 4, but any further deepening of the opencut by mining the sandstone of the Lakota formation downdip would result in considerable caving. Some ore is left in the underground workings (ore body 3), but it is of doubtful value because the shattered host rock makes mining difficult and expensive (J. O. Harder, chief geologist, Homestake Mining Co., written communication, 1955).

Samples were taken from the underground workings (pl. 38 and fig. 62), the landslide ore body, the remainder of ore body 1 and the prospect pits (fig. 8). Results of analyses for uranium and V_2O_5 in these samples are shown in the following table. Samples B-1 through B-51 were taken from the underground workings; B-61 through B-68 were taken from the opencut; B-74 and B-75 are from ore body 1; B-76 through D-1 were taken from the bulldozer cuts shown on plate 36.

The grade of mineralized rock remaining in the underground workings in 1955, as determined from 45 samples (B-1 through B-51), ranges from trace amounts to 1.93 percent uranium and from less than 0.1 percent V_2O_5 to 3.37 percent V_2O_5. Two samples from the landslide ore body, B-61 and B-62, contained more than 0.10 percent uranium. Samples from 4 of the 5 prospect pits beyond the main ore bodies contained uranium in amounts well above ore grade. The amount of ore in the vicinity of these pits is not known; however, the areas of anomalous radioactivity are small, and it is doubtful that any sizable tonnage of ore is present.

Samples B-74 and B-75, from the remnants of ore body 1, showed uranium in amounts below ore grade. Ore body 1 was sampled in June 1953 by W. A. Braddock of the U.S. Geological Survey, and the analytical results of these samples with regard to uranium content, uranium to vanadium ratios, and uranium to equivalent uranium equilibria are not unlike the computations made from the analytical data shown in the following table.

The highest uranium and vanadium concentrations are associated with higher than normal concentrations of clay and carbonized wood as thick seams and groups of coalescent thin seams in the sandstone. (fig. 62). Samples B-4, B-5, and B-10, which contain 0.016, 0.014, and 0.014 percent uranium respectively, and less than 0.1 percent V_2O_5, are practically free of carbonized wood and clay. Samples B-1, containing 0.32 percent uranium and 0.22 percent V_2O_5, and B-8, containing 0.94 percent uranium and 1.16 percent V_2O_5, are from carbonaceous and clayey intervals.

Table 1 shows that in most of the samples of ore grade, the uranium occurs in slightly larger quantities than is suggested by the measured radioactivity (equivalent uranium). From a total of 60 samples, 46 contained more uranium than was indicated by the equivalent uranium determinations. Of the 46 samples only 8 contained less than 0.1 percent uranium. The excess uranium over equivalent uranium ranged from 3 to 84 percent, with the exception of sample B-5 which contained 250 percent more uranium than was shown by the equivalent uranium analysis. Fourteen samples showed equivalent uranium in excess of uranium in amounts ranging from 7 to 100 percent. In 12 of these 14 samples, the uranium content was less than 0.1 percent.

551308—61——6

TABLE 1.—*Chemical analyses for U and V_2O_5 and radioactivity analyses for U*

[Analysts: D. L. Schafer, Mary Finch, J. E. Wilson, James Wahlberg, and C. G. Angelo]

Serial No.	Field No.	Thickness of interval represented by sample (feet)	eU [1] (percent)	U (percent)	V_2O_5 (percent)
235430	B-1	1.0	0.31	0.32	0.22
235516	B-4	.5	.021	.016	<.1
235517	B-5	.5	.004	.014	<.1
235431	B-8	.9	.80	.94	1.16
235432	B-10	.6	.018	.014	.1
235518	B-11	1.1	.66	.76	.75
235519	B-13	.5	1.4	1.93	1.08
235433	B-14	1.0	.14	.18	.53
235520	B-15	.8	.26	.30	.58
235521	B-16	.5	.59	.88	2.48
235522	B-17	1.7	.12	.10	<.1
235523	B-18	.8	.16	.19	.66
235524	B-19	.5	.25	.33	.51
235525	B-20	1.0	.032	.026	<.1
235434	B-21	.9	.42	.56	1.23
235526	B-22	.4	.50	.81	3.37
235527	B-23	2.1	.50	.74	1.56
235435	B-24	1.5	.57	.74	.90
235528	B-25	.8	.74	1.20	1.89
235529	B-26	1.0	.068	.060	.95
235530	B-27	.9	.36	.44	1.00
235531	B-28	1.3	.019	.025	<.1
235532	B-29	2.0	.004	.006	<.1
235533	B-30	2.3	.002	Trace	<.1
235534	B-31	1.6	.048	.062	<.1
235535	B-32	.5	.15	.17	.31
235536	B-33	1.8	1.1	1.44	1.89
235537	B-34	1.9	.081	.076	.22
235538	B-35	2.3	.26	.32	.70
235539	B-36	2.5	.42	.58	1.32
235540	B-37	1.0	.20	.13	.55
235541	B-38	1.0	.40	.51	.98
235542	B-39	1.5	.13	.15	.20
235543	B-40	1.7	.37	.47	.39
235544	B-41	.9	.27	.42	2.22
235545	B-42	1.1	.19	.22	.98
235546	B-43	.6	.24	.45	1.74
235547	B-44	2.5	.20	.31	.90
235548	B-45	2.0	.13	.19	.53
235549	B-46	1.3	.21	.31	1.14
235550	B-47	1.0	.10	.13	.35
235551	B-48	1.4	.069	.11	.11
235552	B-49	1.5	.16	.23	.18
235553	B-50	.5	.051	.066	.11
235554	B-51	.7	.095	.099	.20
235555	B-61	1.5	.11	.13	.15
235556	B-62	2.2	.23	.34	.26
235436	B-63	2.0	.030	.018	.62
235557	B-64	2.0	.011	.008	<.1
235437	B-66	1.5	.010	.008	<.1
235558	B-67	2.3	.047	.067	.11
235559	B-68	1.5	.012	.008	<.1
235439	B-74	2.0	.048	.032	<.1
235562	B-75	2.0	.010	.005	.41
235440	B-76	.3	1.5	1.92	1.54
235441	B-77	.5	.62	.80	.70
235442	B-78	2.5	.031	.039	.22
235443	B-79	2.0	.34	.53	.86
235451	D-1	5.0	.31	.38	.18

[1] eU (equivalent uranium) is the theoretical amount of uranium in equilibrium with its disintegration products that would produce the measured radioactivity.

The ratios of V_2O_5 to U_3O_8 in all samples containing 0.1 percent or more V_2O_5 range from 0.4:1 to 67:1. The average V_2O_5 to U_3O_8 ratio is about 1.4:1. The five samples having the most extreme V_2O_5 to U_3O_8 ratios, ranging from 5:1 to 67:1, were samples containing less than 0.1 percent uranium. The vanadium is fixed in oxides and uranyl-vanadates; no vanadium silicates were found in any of the samples studied.

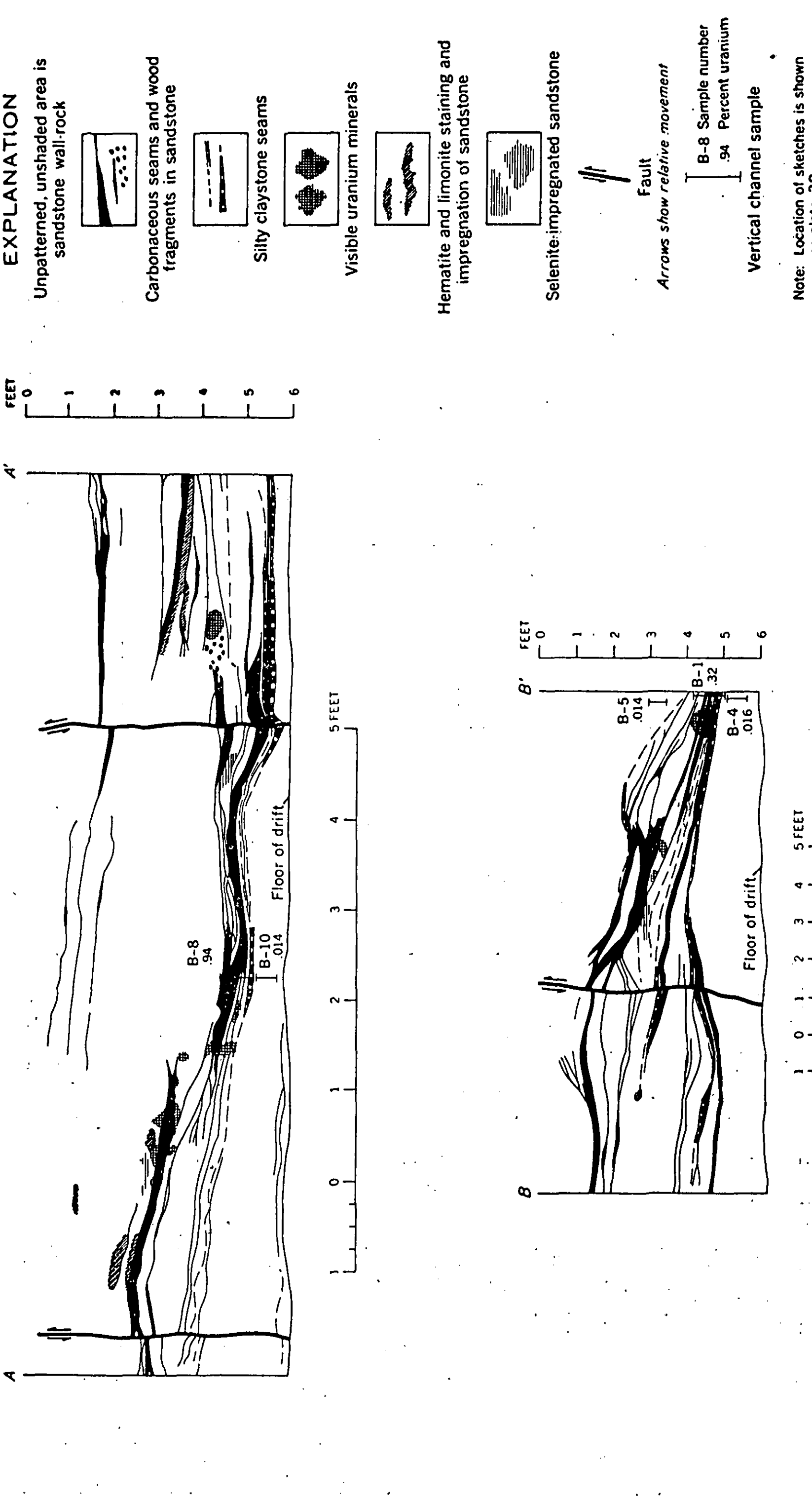


FIGURE 62.—Sketches of parts of walls of underground workings showing characteristics of carbonaceous and siltstone seams and their relationship to the uranium mineralization.

Table 2 shows the content of uranium, phosphorous pentoxide, arsenic, zinc, and selenium in five selected samples from the underground workings of the mine. The samples were selected in order to show the association of uranium and certain other elements that were in the host rock or were deposited with uranium from the mineralized solutions. Sample B-29 were chosen because of its very low uranium content relative to other samples in the ore zone; the other four samples are of ore grade. In addition to these samples, 71 nonradioactive samples were analyzed for the same constituents although only 17 arsenic analyses were made (table 3, p. 680–690). The uranium content of these nonmineralized samples ranged from less than 0.0001 to 0.0029 percent.

TABLE 2.—*Analyses of selected samples from the Carlile mine*

[Analysts: C. G. Angelo, J. P. Schuch, Claude Huffman, J. S. Wahlberg, and G. T. Burrow. Phosphorus pentoxide, arsenic and zinc were analyzed by colorimetric method; selenium was analyzed by colorimetric and volumetric method]

Serial No.	Field No. (See fig. 11)	U (percent)	P_2O_5 (percent)	As (percent)	Zn (percent)	Se (percent)
252315	B-13	1.93	0.07	0.0225	0.0094	0.0590
252314	B-11	.76	.16	.0110	.0015	.0470
252316	B-27	.44	.05	.0085	.0009	.0730
252318	B-37	.13	.10	.0040	.0006	.0200
252317	B-29	.006	.05	.0005	.0001	.0075

As can be seen from table 2, the concentration of phosphorus pentoxide in the samples is erratic and holds little relation to uranium content. This random distribution also holds in the nonmineralized rocks in which phosphorus pentoxide ranges from less than 0.05 percent to 0.39 percent. The maximum content for Lakota samples is 0.08 percent.

The concentration of arsenic, on the other hand, is closely related to the uranium content in mineralized samples. Comparison of arsenic and uranium content in mineralized samples (table 2) with unmineralized samples (table 3) shows that arsenic is concentrated in the ore samples, but to a somewhat lesser degree than uranium. This can be more clearly illustrated by considering ratios of arsenic to uranium. In the ore samples (table 2) the ratios of arsenic to uranium range from 1:32 to 1:96, whereas in the unmineralized samples (table 3), the ratios range from 1:1 to 8:1.

Zinc varies directly with uranium in the mineralized samples (table 2), but zinc is more abundant in some samples of claystone from the Morrison and shale from the Skull Creek that are very low in uranium (table 3). No consistent relationship of zinc with uranium can be noted in the unmineralized samples in table 3. From this it is assumed that zinc was present in the rocks before uranium was deposited and that it was redistributed within the mineralized rocks, rather than added to them by the uranium-bearing solutions.

Selenium is relatively abundant in mineralized samples (table 2). Selenium content throughout the nonmineralized rocks ranges from less than 0.00005 to 0.0015 percent. The minimum concentration in the mineralized samples is 0.0075 percent, well above the maximum in nonmineralized samples. Selenium has been concentrated several hundredfold in the mineralized rocks, although its concentration is not consistent relative to uranium concentration.

Semiquantitative spectrographic analyses of 71 samples from the Morrison, Lakota and Fall River formations, the Skull Creek shale, and the Newcastle sandstone, and 10 ore samples from the Carlile mine are listed in table 3. These were made in an effort to determine whether or not any relationships exist between minor elements and uranium minerals or anomalous radioactivity. No such relationships are apparent. The relatively high titanium content (0.3 to 0.7 percent) in many of the samples cannot be accounted for in the titaniferous heavy minerals. It is probable that the bulk of the titanium is present in the clay fraction, as explained by Rankama and Sahama (1950, p. 563).

MINERALOGY

The principal ore minerals (identified by E. J. Young) of the Carlile deposit are carnotite and tyuyamunite. Bodine (1954, p. 21–28) reported metarossite, coffinite(?), doloresite(?), and rauvite(?), but none of these were found during the present investigation. Coffinite, doloresite, and rauvite were extremely fine grained and were only tentatively identified by Bodine from X-ray data. Evans and Mrose (1956, p. 1693) reported two new black vanadium minerals from the Carlile area, known as minerals "A" and "B." Crystals of hewettite were seen by the authors and by C. S. Robinson (oral communication, 1957) in ore specimens from the Carlile mine. The Carlile mine is the type locality for a new vanadium oxide called häggite by Evans (written communication, 1957).[1] No data other than crystal structure and formula ($V_2O_3 . V_2O_4 . 3H_2O$) are available at this writing.

The uranium minerals occur as yellow, fine-grained aggregates that coat sand grains and fragments of carbonized wood and fill interstices between sand grains. Where carbonaceous seams are relatively thick, or where several seams coalesce, uranium minerals are more abundant (fig. 62). Much of the ore is impregnated with a mixture of cryptocrystalline calcite and gypsum. Hematite and limonite are closely associated with the uranium minerals. A few small lenses of sandstone are impregnated with hematite, but elsewhere lesser amounts of iron oxides merely stain the sandstone yellow and brown.

[1] Evans, H. T., Jr., and Mrose, M. E., 1957, The crystal structures of three new vanadium oxide minerals: U.S. Geol. Survey Trace Elements Invesetigations Report 684, p. 5, 6.

TABLE 3.—*Radiometric, chemical, and semiquantitative spectrographic analyses of 71 samples and semiquantitative spectrographic analyses of 10 ore samples from Carlile quandrangle, Crook County, Wyoming*

[All values are in percent unless otherwise noted. M, major constituent, greater than 10 percent; O, looked for but not detected. The concentrations of the elements are reported to the nearest numbers in the series 7, 3, 1.5, 0.7, 0.3, 0.15 and so on down to the limit of detection for each element. These numbers represent midpoints of group data on the geometric scale. Comparisons of this type of semiquantitative results with those obtained by quantitative methods show that the assigned group includes the value about 60 percent of the time. Elements looked for in all samples but not detected in spectrographic analyses: P, Ag, As, Au, Bi, Cd, Dy, Er, Eu, Gd, Hf, Hg, Ho, In, Ir, Li, Lu, Os, Pd, Pr, Pt, Re, Rh, Ru, Sb, Sm, Ta, Tb, Te, Th, Tl, Tm, U, W, Zn. Elements not looked for: Cs, F, Rb. Analysts: C. G. Angelo, H. H. Lipp, J. P. Schuch, J. S. Wahlberg, G. T. Burrow, J. C. Hamilton, J. Haffty, C. Annell, and N. M. Conklin]

Serial No.	Field No.	Rock types	Radiometric	Chemical analysis					Semiquantitative spectrographic analysis						
			eU	U	P_2O_5	Zn (ppm)	Se (ppm)	As (ppm)	Si	Al	Fe	Mg	Ca	Na	K
Morrison formation															
248739	G-28	Claystone	0.005	0.0029	<0.05	150	15	-------	M	M	3	3	0.3	0.3	3
248764	B-6-56	Sandstone	.001	.0002	.11	4	<.5	-------	M	3	.3	-------	M	-------	1.5
248765	B-7-56	Claystone	<.001	.0002	.39	69	<.5	-------	M	3	.3	.3	M	1.5	3
248766	B-8-56	do	.002	.0003	.27	83	<.5	-------	M	M	3	1.5	3	1.5	7
248767	B-9-56	do	.002	.0006	.21	117	1	-------	M	M	3	1.5	.15	.7	7
248768	B-10-56	Limestone	.001	.0003	<.05	24	<.5	-------	3.	1.5	.7	.7	M	.3	1.5
Lakota formation															
248712	G-1	Claystone	0.002	0.0008	<0.05	19	<.5	8	M	7	3	1.5	0.7	0.15	1.5
248713	G-2	Sandstone	.001	.0002	<.05	24	<.5	>5	M	1.5	3	.7	.15	0	0
248714	G-3	Claystone	.001	.0003	<.05	2	<.5	6	M	M	3	.7	.3	.3	1.5
248715	G-4	Sandy claystone	.001	.0004	<.05	18	.5	5	M	M	3	.7	.07	.7	3
248740	G-29	Sandstone	<.001	.0006	<.05	12	3	-------	M	1.5	1.5	.07	.03	.3	1.5
248741	G-30	do	<.001	.0004	<.05	<1	.5	-------	M	1.5	.3	.07	.07	0	0
248742	G-31	do	<.001	.0003	<.05	<1	.5	-------	M	1.5	.7	.015	.03	.07	0
248743	G-32	Siltstone	.003	.0028	<.05	<1	1	-------	M	1.5	.07	.07	.3	.07	0
248744	G-33	Sandstone	.003	.0019	<.05	2	1	-------	M	7	.15	.15	.03	.07	0
248745	G-34	Siltstone	.001	.0008	<.05	4	<.5	-------	M	7	.15	.07	.03	0	0
248746	G-35	Sandstone	<.001	.0004	<.05	<1	<.5	-------	M	1.5	.3	.07	.03	0	0
248747	G-36	Claystone	.001	.0004	<.05	22	.5	-------	M	M	1.5	.7	.07	.3	3
248748	G-37	do	.001	.0002	<.05	21	.5	-------	M	M	.7	.7	.7	.3	1.5
248749	G-38	do	.001	.0004	.08	40	1	-------	M	M	3	.7	.03	.7	1.5
248758	G-47	Sandstone	.001	.0002	<.05	3	.5	-------	M	1.5	.7	.07	.07	0	0

248769	B-11-56	do	<.001	.0002	<.05	<1	<.5		M	3	3	.03	3	.15	0
248770	B-12-56	Mudstone	<.001	.0001	<.05	5	<.5		M	7	1.5	.15	.07	0	0
248771	B-13-56	Sandstone	.001	.0001	<.05	<1	.5		M	1.5	.3	.07	.07	0	0
248772	B-14-56	Mudstone	<.001	.0001	<.05	31	<.5		M	M	3	.7	1.5	.15	1.5
248773	B-15-56	Claystone	.001	.0002	<.05	29	<.5		M	7	3	.7	.3	.3	1.5
248774	B-16-56	Sandstone	<.001	.0003	<.05	14	.5		M	7	3	.15	.07	.07	0
248775	B-17-56	do	<.001	.0001	<.05	6	<.5		M	3	.3	.03	.07	0	0
	B-18-56	Claystone	<.001	.0005	<.05	9	2		M	7	.7	.07	.15	.15	0
Fall River formation															
248716	G-5	Siltstone	0.001	0.0006	<0.05	>1	0.5	15	M	1.5	3	0.15	0.07	0.15	0.7
248717	G-6	do	.001	.0006	.05	27	.5	>5	M	M	1.5	.7	.3	.3	3
248718	G-7	Sandstone	<.001	.0002	<.05	>1	<.5	16	M	1.5	1.5	.15	.15	.15	0
248719	G-8	do	<.001	.0003	.07	10	<.5	>5	M	1.5	1.5	.3	.15	.3	.7
248720	G-9	do	<.001	.0006	<.05	>1	<.5	15	M	1.5	1.5	.15	.07	.3	.7
248721	G-10	Carbonized wood	.001	.0005	<.05	22	<.5	6	M	M	1.5	.7	.3	.7	3
248722	G-11	Claystone	.002	.0005	.10	62	.5	10	M	M	3	1.5	.15	.7	3
248723	G-12	Sandstone	.001	.0002	<.05	25	<.5		M	1.5	.7	.3	.15	.7	1.5
248724	G-13	do	<.001	.0001	<.05	10	<.5		M	1.5	.7	.07	.07	.07	0
248725	G-14	do	<.001	.0004	.15	74	.5		M	7	3	.7	.15	.7	1.5
248726	G-15	Siltstone	.001	.0005	.12	95	<.5		M	M	3	1.5	.3	.7	3
248727	G-16	do	<.001	.0004	.09	77	<.5		M	M	3	1.5	.15	.7	3
248728	G-17	Sandstone	<.001	.0002	.08	59	.5		M	1.5	1.5	.07	.07	.15	0
248729	G-18	Siltstone	.001	.0007	.28	60	.5		M	M	3	.7	.07	.7	3
248730	G-19	Sandstone	<.001	.0003	.09	31	.5		M	7	3	.3	.3	.7	1.5
248731	G-20	Siltstone	<.001	.0004	.05	53	<.5		M	7	3	.7	.03	.7	1.5
248732	G-21	Sandstone	.002	.0001	<.05	16	<.5		M	1.5	.3	.07	.03	.15	0
248733	G-22	Siltstone	.001	.0004	.08	30	<.5		M	7	1.5	.3	.03	.7	1.5
248734	G-23	Sandstone	.001	.0001	<.05	3	<.5		M	1.5	.7	.07	.03	.3	0
248750	G-40	Siltstone	.001	.0004	.08	44	<.5		M	M	3	.7	.07	.7	3
248751	G-41	do	.002	.0004	<.05	30	.5		M	M	1.5	.7	.3	.7	3
248752	G-42	do	<.001	.0003	.30	59	<.5		M	3	M	.7	.7	.7	1.5
248753	G-43	do	<.001	.0002	<.05	26	.5		M	3	1.5	.3	.15	.3	0
248777	B-19-56	Sandstone	<.001	.0001	<.05	3	.5	>5	M	.7	.15	.03	.07	.07	0
248778	B-21-56	Carbonized wood	<.001	.0001	<.05	7	4	>5	M	1.5	.7	.03	.07	0	0
248779	B-22-56	Claystone	.001	.0004	<.05	42	1	>5	M	M	3	.7	.15	.7	3
248780	B-23-56	do	.001	>.0001	.17	53	.5	12	M	M	3	.7	.15	.7	3
248781	B-24-56	Sandstone	<.001	>.0001	.21	114	.5	13	M	3	7	.3	.15	.7	3
248782	B-25-56	Siltstone	.002	.0001	.11	70	.5	>5	M	M	3	.7	.7	.7	3

TABLE 3.—*Radiometric, chemical, and semiquantitative spectrographic analyses of 71 samples and semiquantitative spectrographic analyses of 10 ore samples from Carlile quadrangle, Crook County, Wyoming*—Continued

[All values are in percent unless otherwise noted. M, major constituent, greater than 10 percent; O, looked for but not detected. The concentrations of the elements are reported to the nearest numbers in the series 7, 3, 1.5, 0.7, 0.3, 0.15 and so on down to the limit of detection for each element. These numbers represent midpoints of group data on the geometric scale. Comparisons of this type of semiquantitative results with those obtained by quantitative methods show that the assigned group includes the value about 60 percent of the time. Elements looked for in all samples but not detected in spectrographic analyses: P, Ag, As, Au, Bi, Cd, Dy, Er, Eu, Gd, Hf, Hg, Ho, In, Ir, Li, Lu, Os, Pd, Pr, Pt, Re, Rh, Ru, Sb, Sm, Ta, Tb, Te, Th, Tl, Tm, U, W, Zn. Elements not looked for: Cs, F, Rb. Analysts: C. G. Angelo, H. H. Lipp, J. P. Schuch, J. S. Wahlberg, G. T. Burrow, J. C. Hamilton, J. Haffty, C. Annell, and N. M. Conklin]

Serial No.	Field No.	Rock types	Radiometric	Chemical analysis					Semiquantitative spectrographic analysis						
			eU	U	P_2O_5	Zn (ppm)	Se (ppm)	As (ppm)	Si	Al	Fe	Mg	Ca	Na	K
Skull creek shale															
248754	G-45a	Fissile claystone	0.002	0.0010	0.21	139	1	--------	M	M	3	1.5	0.3	0.7	3
248755	G-45b	Siltstone	.002	.0005	.18	113	.5	--------	M	7	3	1.5	.3	.7	3
248756	G-45c	Fissile claystone	.001	.0005	.15	115	.5	--------	M	M	3	1.5	1.5	.7	3
248757	G-46	do	.002	.0010	.13	110	<.5	--------	M	M	3	1.5	.7	.3	3
Newcastle sandstone															
248735	G-24	Sandstone	0.002	0.0005	0.06	99	1	--------	M	M	3	0.7	0.7	0.3	3
248736	G-25	do	.001	.0003	<.05	4	<.5	--------	M	3	.7	.15	.3	0	0
248737	G-26	Carbonized wood	.002	.0024	.06	10	2	--------	M	7	.7	.3	.7	.07	0
248738	G-27	Sandstone	.001	.0003	<.05	<1	<.5	--------	M	.7	.7	.07	M	.07	0
248759	B-1-56	do	<.001	.0004	<.05	10	.5	--------	M	3	.7	.15	1.5	.15	0
248760	B-2-56	Silty claystone	<.001	.0005	<.05	13	.5	--------	M	M	1.5	.3	.3	.3	0
248761	B-3-56	Bentonitic clay	.002	.0009	<.05	85	.5	--------	M	M	7	3	3	3	1.5
248762	B-4-56	Silt and clay	.002	.0008	<.05	40	.5	--------	M	M	1.5	.7	.7	.3	1.5
248763	B-5-56	Sandstone	<.001	.0004	<.05	8	<.5	--------	M	1.5	.7	.15	7	.07	0

Selected ore samples from Lakota sandstone at Carlile mine

252314	B-11								M	1.5	0.7	0.015	3.0	0.07	0
252315	B-13								M	1.5	3	.03	M	.3	0
145795	B-14								M	.3	1.5	.015	.03	0	0
252316	B-27								M	3	3	.07	.3	.07	0
145796	B-33								M	.7	1.5	.07	1.5	.03	0
145797	B-36								M	.3	1.5	.03	.15	.03	0
252318	B-37								M	1.5	.7	.07	.7	.15	0
145798	B-51								M	.7	1.5	.03	.7	.015	0
145799	B-61								M	.3	1.5	.015	.03	.015	0
145800	B-63								M	.3	1.5	.015	.015	.015	0

TABLE 3.—*Radiometric, chemical, and semiquantitative spectrographic analyses of 71 samples and semiquantitative spectrographic analyses of 10 ore samples from Carlile quadrangle, Crook County, Wyoming*—Continued

[All values are in percent unless otherwise noted. M, major constituent, greater than 10 percent; O, looked for but not detected. The concentrations of the elements are reported to the nearest numbers in the series 7, 3, 1.5, 0.7, 0.3, 0.15 and so on down the to limit of detection for each element. These numbers represent midpoints of group data on the geometric scale. Comparisons of this type of semiquantitative results with those obtained by quantitative methods show that the assigned group includes the value about 60 percent of the time. Elements looked for in all samples but not detected in spectrographic analyses: P, Ag, As, Au, Bi, Cd, Dy, Er, Eu, Gd, Hf, Hg, Ho, In, Ir, Li, Lu, Os, Pd, Pr, Pt, Re, Rh, Ru, Sb, Sm, Ta, Tb, Te, Th, Tl, Tm, U, W, Zn. Elements not looked for: Cs, F, Rb. Analysts: C. G. Angelo, H. H. Lipp, J. P. Schuch, J. S. Wahlberg, G. T. Burrow, J. C. Hamilton, J. Haffty, C. Annell, and N. M. Conklin]

Serial No.	Field No.	Rock types	Semiquantitative spectrographic analysis											
			Ti	Mn	B	Ba	Be	Ce	Co	Cr	Cu	Ga	Ge	La
Morrison formation														
248739	G-28	Claystone	0.3	0.03	0.015	0.015	0.0003	0	0.003	0.003	0.015	0.003	0	0
248764	B-6-56	Sandstone	.15	.07	Trace	.15	0	0	0	.0015	.0015	0	0	0
248765	B-7-56	Claystone	.15	.07	Trace	.15	0	0	0	.003	.0015	0	0	0
248766	B-8-56	do	.3	.03	.007	.03	.00015	0	.0015	.007	.003	.003	0	.003
248767	B-9-56	do	.3	.015	.007	.03	.00015	0	.007	.003	.007	.0015	0	0
248768	B-10-56	Limestone	.07	.15	0	.03	0	<.05	0	.0015	.0007	0	0	0
Lakota formation														
248712	G-1	Claystone	0.3	0.015	0.007	0.03	0	0.015	0.0007	0.003	0.007	0.0015	0	0.007
248713	G-2	Sandstone	.15	.015	Trace	.03	0	0	.0007	.0007	.003	Trace	0	0
248714	G-3	Claystone	.3	.007	Trace	.03	0	0	0	.003	.007	.003	0	.003
248715	G-4	Sandy claystone	.7	.015	.007	.03	.00015	.015	.0007	.007	.007	.003	0	.007
248740	G-29	Sandstone	.07	.003	Trace	.015	0	0	0	.0015	.0015	0	0	0
248741	G-30	do	.07	.0007	Trace	.015	0	0	0	.0015	.0007	0	0	.003
248742	G-31	do	.15	.0007	Trace	.003	0	0	0	.0007	.0007	0	0	.003
248743	G-32	Siltstone	.7	.0015	.007	.007	0	0	0	.003	.007	0	0	.003
248744	G-33	Sandstone	.7	.0007	Trace	.007	0	0	0	.003	.003	.0007	0	0
248745	G-34	Siltstone	.7	.0007	Trace	.015	0	0	0	.003	.003	.0003	0	.003
248746	G-35	Sandstone	.3	.0015	Trace	.015	0	0	0	.0015	.0015	0	0	0
248747	G-36	Claystone	.3	.003	.007	.03	0	0	0	.015	.003	.003	0	.007
248748	G-37	do	.3	.003	.007	.03	0	0	0	.007	.003	.0015	0	.003
248749	G-38	do	.7	.015	.007	.07	0	Trace	.0007	.015	.007	.0015	0	.007
248758	G-47	Sandstone	.07	.0007	.007	.15	0	.03	0	.0015	.0015	0	0	.015

248769	B-11-56	do	.15	.003	.003	.07	0	.015	0	.0015	.0015	0	0	.015
248770	B-12-56	Mudstone	.3	.0015	.003	.03	0	.015	0	.003	.007	.0007	0	.007
248771	B-13-56	Sandstone	.15	.0003	Trace	.03	0	0	0	.0015	.0015	0	0	0
248772	B-14-56	Mudstone	.3	.007	.003	.03	0	0	Trace	.003	.007	.0015	0	0
248773	B-15-56	Claystone	.3	.007	.007	.03	0	.015	.0007	.007	.007	.0015	0	.007
248774	B-16-56	Sandstone	.3	.007	.003	.015	0	0	0	.003	.007	.0007	0	0
248775	B-17-56	do	.3	.007	.003	.007	0	0	0	.0015	.0015	0	0	0
	B-18-56	Claystone	.3	.007	.007	.015	.00015	0	Trace	.007	.007	.0007	.003	.003
Fall River formation														
248716	G-5	Siltstone	0.7	0.007	0.007	0.03	0	Trace	0	0.003	0.007	Trace	0	0.003
248717	G-6	do	.7	.015	.007	.03	0	0.015	.0007	.007	.007	0.0015	0	.007
248718	G-7	Sandstone	.3	.015	Trace	.03	0	Trace	0	.0015	.0015	0	0	.003
248719	G-8	do	.7	.15	.007	.03	0	Trace	.0007	.003	.003	Trace	0	.003
248720	G-9	do	.15	.03	Trace	.03	0	0	0	.0015	.0015	Trace	0	0
248721	G-10	Carbonized wood	.7	.007	.0015	.03	.00015	.015	.0007	.015	.007	.003	.0015	.007
248722	G-11	Claystone	.7	.03	.007	.03	.0003	.015	.0015	.007	.007	.003	0	.007
248723	G-12	Sandstone	.3	.03	.007	.03	0	Trace	.0007	.003	.0015	.0003	0	.007
248724	G-13	do	.3	.03	.007	.03	0	.015	0	.0015	.0015	0	0	0
248725	G-14	do	.3	.015	Trace	.07	.00015	Trace	.0015	.007	.003	.0015	0	.003
248726	G-15	Siltstone	.3	.007	.007	.07	.00015	.015	.0015	.007	.007	.003	0	.007
248727	G-16	do	.7	.15	.007	.03	.00015	.015	.003	.007	.007	.003	0	.007
248728	G-17	Sandstone	.3	.015	Trace	.015	0	0	.0015	.0015	.003	0	0	0
248729	G-18	Siltstone	.7	.03	.007	.07	0	.015	.0007	.007	.007	.0015	0	.007
248730	G-19	Sandstone	.7	.03	.007	.03	0	.015	.0007	.007	.007	.0007	0	.007
248731	G-20	Siltstone	.7	.03	.007	.07	0	.015	.0015	.007	.007	.0007	0	.007
248732	G-21	Sandstone	.3	.03	Trace	.03	0	0	.0007	.0015	.0015	0	0	0
248733	G-22	Siltstone	.3	.015	.007	.03	.00015	Trace	.0015	.007	.003	.0007	0	.007
248734	G-23	Sandstone	.3	.003	.007	.015	0	0	0	.0015	.0015	0	0	0
248750	G-40	Siltstone	.7	.07	.007	.03	0	Trace	.0015	.007	.007	.0015	0	.007
248751	G-41	do	.7	.03	.007	.03	0	Trace	.0015	.007	.007	.0015	0	.007
248752	G-42	do	.3	1.5	Trace	.03	0	0	.0015	.003	.007	.0015	0	.003
248753	G-43	do	.3	.07	Trace	.07	0	0	.0015	.0015	.003	.0003	0	.003
248777	B-19-56	Sandstone	.15	.015	.003	.007	0	0	0	.0007	.0007	0	0	0
248778	B-21-56	Carbonized wood	.07	.0007	.003	.007	0	0	Trace	.0007	.0015	0	.0015	0
248779	B-22-56	Claystone	.3	.007	.003	.03	.00015	.015	.0007	.015	.007	.003	0	.007
248780	B-23-56	do	.3	.015	.007	.03	.00015	.015	.0015	.007	.007	.0015	0	.007
248781	B-24-56	Sandstone	.3	.03	.007	.03	Trace	.015	.0015	.007	.007	.0007	0	.007
248782	B-25-56	Siltstone	.7	.015	.003	.07	.00015	.015	.0015	.007	.007	.0015	0	.007

TABLE 3.—*Radiometric, chemical, and semiquantitative spectrograph analyses of 71 samples and semiquantitative spectrographic analyses of 10 ore samples from Carlile quadrangle, Crook County, Wyoming*—Continued

[All values are in percent unless otherwise noted. M, major constituent, greater than 10 percent; O, looked for but not detected. The concentrations of the elements are reported to the nearest numbers in the series 7, 3, 1.5, 0.7, 0.3, 0.15 and so on down the to limit of detection for each element. These numbers represent midpoints of group data on the geometric scale. Comparisons of this type of semiquantitative results with those obtained by quantitative Methods show that the assigned group includes the value about 60 percent of the time. Elements looked for in all samples but not detected in spectrographic analyses: P, Ag, As, Au, Bi, Cd, Dy, Er, Eu, Gd, Hf, Hg, Ho, In, Ir, Li, Lu, Os, Pd, Pr, Pt, Re, Rh, Ru, Sb, Sm, Ta, Tb, Te, Th, Tl, Tm, U, W, Zn. Elements not looked for: Cs, F, Rb. Analysts: C. G. Angelo, H. H. Lipp, J. P. Schuch, J.S. Wahlberg, G. T. Burrow, J. C. Hamilton, J. Haffty, C. Annell, and N. M. Conklin]

Serial No.	Field No.	Rock types	Semiquantitative spectrographic analysis											
			Ti	Mn	B	Ba	Be	Ce	Co	Cr	Cu	Ga	Ge	La
Skull Creek shale														
248754	G-45a	Fissile claystone	0.3	0.015	0.007	0.03	0.00015	Trace	0.0015	0.015	0.007	0.003	0	0.007
248755	G-45b	Siltstone	.3	.03	.007	.03	.00015	0	.0015	.007	.007	.0015	0	.003
248756	G-45c	Fissile claystone	.3	.03	.007	.03	.00015	0	.0015	.007	.007	.003	0	.003
248757	G-46	do	.3	.015	.007	.03	.00015	0	.0015	.007	.007	.003	0	.003
Newcastle sandstone														
248735	G-24	Sandstone	0.3	0.03	0.015	0.03	0.0003	Trace	0.003	0.007	0.007	0.003	0	0.015
248736	G-25	do	.3	.0015	.007	.03	0	0	0	.0015	.003	.0003	0	.003
248737	G-26	Carbonized wood	.3	.0007	.007	.003	.0015	.03	0	.003	.003	.0015	0	.015
248738	G-27	Sandstone	.15	.03	Trace	.007	0	0	0	.0007	.0015	0	0	.000
248759	B-1-56	do	.3	.03	.007	.015	0	Trace	0	.003	.0015	.0007	0	007
248760	B-2-56	Silty claystone	.3	.003	.015	.015	.00015	0	0	.007	.003	.003	0	0
248761	B-3-56	Bentonitic clay	.07	.07	Trace	.03	0	Trace	0	.0007	.0007	.003	0	.007
248762	B-4-56	Silt and clay	.3	.003	.007	.03	.0003	.03	0	.003	.0015	.0015	.0015	.015
248763	B-5-56	Sandstone	.15	.03	.003	.03	0	0	.0007	.0015	.0015	0	0	0

Selected ore samples from Lakota sandstone at Carlile mine

252314	B-11		0.07	0.003	Trace	0.015	0	0	<.005	0.0007	0.0015	0	0	0.003
252315	B-13		.07	.007	0	.07	Trace	0	<.005	.0015	.003	0	0	.003
145795	B-14		.015	.015	.015	.015	0	0	0	.0007	.007	0	0	0
252316	B-27		.3	.003	Trace	.015	0	0	<.005	.0015	.0015	0	0	.003
145796	B-33		.015	.015	.015	.03	0	0	0	.0015	.007	0	0	0
145797	B-36		.03	.015	.015	.015	0	0	0	.0015	.007	0	0	0
252318	B-37		.15	.003	Trace	.015	0	0	.0007	.0015	.0015	0	0	Trace
145798	B-51		.03	.015	.015	.015	0	0	.0015	.0015	.003	0	0	0
145799	B-61		.03	.015	.015	.015	0	0	0	.0015	.003	0	0	0
145800	B-63		.015	.015	.015	.015	0	0	0	.0015	.003	0	0	0

TABLE 3.—*Radiometric, chemical, and semiquantitative spectrographic analyses of 71 samples and semiquantitative spectrographic analyses of 10 ore samples from Carlile quadrangle, Crook County, Wyoming*—Continued

[All values are in percent unless otherwise noted. M, major constituent, greater than 10 percent; O, looked for but not detected. The concentrations of the elements are reported to the nearest numbers in the series 7, 3, 1.5, 0.7, 0.3, 0.15 and so on down to the limit of detection for each element. These numbers represent midpoints of group data on the geometric scale. Comparisons of this type of semiquantitative results with those obtained by quantitative methods show that the assigned group includes the value about 60 percent of the time. Elements looked for in all samples but not detected in spectrographic analyses: P, Ag, As, Au, Bi, Cd, Dy, Er, Eu, Gd, Hf, Hg, Ho, In, Ir, Li, Lu, Os, Pd, Pr, Pt, Re, Rh, Ru, Sb, Sm, Ta, Tb, Te, Th, Tl, Tm, U, W, Zn. Elements not looked for: Cs, F, Rb. Analysts: G. C. Angelo, H. H. Lipp, J. P. Schuch, J. S. Wahlberg, G. T. Burrow, J. C. Hamilton, J. Hafty, C. Annell, and N. M. Conklin]

Serial No.	Field No.	Rock types	Semiquantitative spectrographic analysis											
			Mo	Nb	Nd	Ni	Pb	Sc	Sn	Sr	V	Y	Yb	Zr
			Morrison formation											
248739	G-28	Claystone	0.0015	0.0015	0	0.003	0.0015	0.003	0	0.003	0.007	0.003	0.0007	0.03
248764	B-6-56	Sandstone	0	Trace	0	.0003	Trace	0	0	.015	.003	.0015	.00015	.015
248765	B-7-56	Claystone	0	Trace	0	.0003	0	0	0	.015	.003	.0015	.00015	.015
248766	B-8-56	do	0	.0015	0	.003	.0015	.0015	0	.015	.007	.003	.0003	.015
248767	B-9-56	do	0	.0015	0	.007	.003	.0015	0	.007	.007	.003	.0003	.015
248768	B-10-56	Limestone	0	0	0	0	0	0	0	.03	.003	.0015	0	.003
			Lakota formation											
248712	G-1	Claystone	0	0.0015	Trace	0.0007	0.0015	0.0015	0	0.007	0.007	0.007	0.0007	0.03
248713	G-2	Sandstone	0	Trace	0	.0015	0	.0007	0	.0015	.007	0	.00015	.03
248714	G-3	Claystone	0	Trace	0	.0007	.003	.0015	0	.007	.007	.007	.0007	.03
248715	G-4	Sandy claystone	0	.0015	Trace	.0015	.003	.003	0	.007	.015	.007	.0007	.03
248740	G-29	Sandstone	.0007	Trace	0	0	0	0	0	.003	0	.0015	.00015	.03
248741	G-30	do	0	Trace	0	0	0	0	0	.0015	0	.0015	.00015	.007
238742	G-31	do	.0007	Trace	0	0	0	0	0	.0007	0	.0015	.00015	.03
248743	G-32	Siltstone	.0015	.003	Trace	0	0	.0015	0	.0015	.003	.015	.0015	.07
248744	G-33	Sandstone	.0015	.003	0	0	.0015	.0007	0	.0015	.007	.015	.0015	.03
248745	G-34	Siltstone	.0015	.003	0	0	0	.0007	0	.0015	.007	.007	.0007	.07
248746	G-35	Sandstone	0	.0015	0	0	0	0	0	.0015	0	.003	.0007	.15
248747	G-36	Claystone	0	.0015	Trace	.0007	.0015	.003	0	.015	.015	.003	.0007	.015
248748	G-37	do	0	.0015	0	.0007	.0015	.015	0	.007	.007	.0015	.0003	.03
248749	G-38	do	0	.003	Trace	.0015	.0015	0	0	.007	.015	.007	.0007	.03
248758	G-47	Sandstone	0	Trace	Trace	.0003	.0015	0	0	.007	.0015	.0015	.00015	.007

248769	B-11-56	do	.0007	Trace	0	0	0	Trace	0	.007	.0015	.0015	.00015	.03
248770	B-12-56	Mudstone	.0007	.0015	Trace	.0003	.003	.0015	0	.03	.003	.0015	.00015	.03
248771	B-13-56	Sandstone	0	Trace	0	0	0	0	0	.0007	.003	0	Trace	.015
248772	B-14-56	Mudstone	0	Trace	0	.0007	.0015	.0015	0	.015	.007	.0015	.0003	.015
248773	B-15-56	Claystone	0	.0015	Trace	.0007	.0015	.0015	0	.007	.007	.007	.0007	.03
248774	B-16-56	Sandstone	.0007	.0015	0	0	.0015	.0015	0	.0015	.007	.003	.0003	.03
248775	B-17-56	do	0	.0015	0	0	0	.0007	0	0	.0015	.003	.0007	.07
	B-18-56	Claystone	0	.0015	Trace	.0015	.0015	.0015	0	.003	.007	.007	.0007	.03
		Fall River formation												
248716	G-5	Siltstone	0	0.0015	0	0	0.0015	0.0015	0	0.003	0.007	0.007	0.0007	0.15
248717	G-6	do	0	.0015	Trace	.0015	.003	.003	0	.015	.015	.007	.0007	.07
248718	G-7	Sandstone	0	.0015	0	.0007	0	0	0	.0015	.007	.0015	.0003	.03
248719	G-8	do	0	.0015	0	.0007	0	.0007	0	.003	.007	.007	.0007	.07
248720	G-9	do	0	0	0	.0007	0	0	0	.0015	.007	.0015	.00015	.007
248721	G-10	Carbonized wood	.0015	.0015	Trace	.003	.0015	.003	0	.007	.015	.007	.0007	.07
248722	G-11	Claystone	.0007	.0015	.015	.003	.0015	.003	0	.007	.015	.007	.0007	.03
248723	G-12	Sandstone	0	.0015	0	.0007	0	.007	0	.003	.007	.003	.0007	.07
248724	G-13	do	0	.0015	0	0	0	0	0	.0003	.003	.003	.0003	.15
248725	G-14	do	0	.0015	Trace	.003	.0015	.0015	0	.007	.015	.003	.0007	.07
248726	G-15	Siltstone	0	.0015	Trace	.003	.0015	.0015	0	.015	.015	.007	.0007	.03
248727	G-16	do	0	.0015	.015	.007	.0015	.003	0	.015	.015	.007	.0007	.03
248728	G-17	Sandstone	0	Trace	0	.0015	0	.003	0	.0007	.003	.003	.0003	.03
248729	G-18	Siltstone	0	.0015	Trace	.0015	.0015	.0015	0	.007	.015	.007	.0007	.03
248730	G-19	Sandstone	0	.0015	Trace	.0007	.0015	.0015	0	.015	.007	.007	.0007	.07
248731	G-20	Siltstone	0	.0015	Trace	.0015	.0015	.0015	0	.003	.015	.007	.0007	.07
248732	G-21	Sandstone	.0007	Trace	0	0	0	0	0	.0003	.0015	.003	.0003	.07
248733	G-22	Siltstone	.0007	.0015	Trace	.0015	.003	.0015	0	.003	.007	.007	.0007	.07
248734	G-23	Sandstone	0	.0015	0	0	0	0	0	.0015	.0015	.0015	.0003	.07
248750	G-40	Siltstone	0	.003	Trace	.003	.0015	.003	0	.007	.0015	.007	.0007	.03
248751	G-41	do	0	.003	Trace	.003	.0015	.0015	0	.007	.0015	.007	.0007	.03
248752	G-42	do	.0015	.0015	0	.003	.0015	.0015	0	.003	.007	.007	.0007	.03
248753	G-43	do	0	.0015	0	.0015	0	.0007	0	.0015	.003	.003	.0003	.03
248777	B-19-56	Sandstone	0	Trace	0	0	0	0	0	Trace	.0015	0	Trace	.007
248778	B-21-56	Carbonized wood	.0007	Trace	0	.003	0	0	0	0	.007	Trace	Trace	.003
248779	B-22-56	Claystone	0	.0015	Trace	.003	.007	.003	0	.0015	.015	.007	.0007	.015
248780	B-23-56	do	0	.0015	Trace	.003	.003	.003	0	.0015	.015	.007	.0007	.03
248781	B-24-56	Sandstone	.0007	Trace	Trace	.0015	.0015	.0015	0	.003	.007	.007	.0007	.015
248782	B-25-56	Siltstone	0	.0015	Trace	.003	.0015	.003	0	.0015	.015	.007	.0007	.03

TABLE 3.—*Radiometric, chemical, and semiquantitative spectrographic analyses of 71 samples and semiquantitative spectrographic analyses of 10 ore samples from Carlile quadrangle, Crook County, Wyoming*—Continued

[All values are in percent unless otherwise noted. M, major constituent, greater than 10 percent; O, looked for but not detected. The concentrations of the elements are reported to the nearest numbers in the series 7, 3, 1.5, 0.7, 0.3, 0.15 and so on down to the limit of detection for each element. These numbers represent midpoints of group data on the geometric scale. Comparisons of this type of semiquantitative results with those obtained by quantitative methods show that the assigned group includes the value about 60 percent of the time. Elements looked for in all samples but not detected in spectrographic analyses: P, Ag, As, Au, Bi, Cd, Dy, Er, Eu, Gd, Hf, Hg, Ho, In, Ir, Li, Lu, Os, Pd, Pr, Pt, Re, Rh, Ru, Sb, Sm, Ta, Tb, Te, Th, Tl, Tm, U, W, Zn. Elements not looked for: Cs, F, Rb. Analysts: G. C. Angelo, H. H. Lipp, J. P. Schuch, J. S Wahlberg, G. T. Burrow, J. C. Hamilton, J. Hafty, C. Annell, and N. M. Conklin]

Serial No.	Field No.	Rock types	Semiquantitative spectrographic analysis											
			Mo	Nb	Nd	Ni	Pb	Sc	Sn	Sr	V	Y	Yb	Zr
						Skull Creek shale								
248754	G-45a	Fissile claystone	0	0.0015	Trace	0.003	0.003	0.003	0	0.007	0.0015	0.007	0.0007	0.03
248755	G-45b	Siltstone	.0007	.0015	Trace	.003	.003	.0015	0	.015	.007	.007	.0007	.015
248756	G-45c	Fissile claystone	0	.0015	0	.003	.003	.003	0	.015	.0015	.007	.0007	.03
248757	G-46	do	.0007	.0015	0	.003	.003	.0015	0	.015	.0015	.003	.0007	.015
						Newcastle sandstone								
248735	G-24	Sandstone	0.0007	0.003	Trace	0.003	0.003	0.0015	0	0.007	0.015	0.007	0.0007	0.03
248736	G-25	do	0	.003	0	0	0	.0007	0	.0007	.003	.003	.0007	.07
248737	G-26	Carbonized wood	0	.003	Trace	.0015	.003	.0015	0	.007	.007	.007	.0007	.03
248738	G-27	Sandstone	0	Trace	0	0	0	0	0	.015	.003	.0015	.015	.03
248759	B-1-56	do	0	.0015	Trace	.0003	.0015	.0007	0	.003	.003	.003	.0003	.03
248760	B-2-56	Silty claystone	0	.003	0	.0007	.003	.003	0	.003	.007	.003	.0007	.03
248761	B-3-56	Bentonitic clay	0	.003	0	.0007	.003	.0007	.0015	.07	.0015	.007	.0007	.015
248762	B-4-56	Silt and clay	.0007	.003	.015	.0007	.003	.0015	0	.007	.007	.007	.0007	.03
248763	B-5-56	Sandstone	0	.0015	0	.0003	0	Trace	0	.015	.0015	.003	.0003	.03
						Selected ore samples from Lakota sandstone at Carlile mine								
252314	B-11		0	0	0	0.0007	0.0007	0	0	0.007	0.15	0.003	<.002	0.015
252315	B-13		0	0	0	.003	.0015	.0007	0	.03	.15	.0015	<.002	.015
145795	B-14		0	0	0	.0015	0	0	0	.003	.15	0	0	.0015
252316	B-27		.0015	.0015	0	.0007	.0015	.0007	0	.003	.3	.003	<.002	.015
145796	B-33		0	0	0	.0015	0	0	0	.007	.3	0	0	.0015
145797	B-36		0	0	0	.0015	0	0	0	.007	.3	0	0	.0015
252318	B-37		0	0	0	.0007	0	Trace	0	.003	.15	.0015	<.002	.015
145798	B-51		0	0	0	.003	0	0	0	.007	.15	.003	0	.003
145799	B-61		0	0	0	.003	.0015	0	0	.007	.15	.003	0	.015
145800	B-63		0	0	0	.0015	.0015	0	0	.003	.15	0	0	.003

The heavier concentration of iron oxides usually are distributed sporadically outward in all directions from accumulations of uranium minerals. In the vicinity of ore body 1 (pl. 37) the sandstone is stained a pinkish red on weathered surfaces by iron oxides.

Figure 63 shows the distribution of ore minerals and their relations with quartz grains and interstitial calcite and gypsum. Closely associated with the yellow uranium minerals is an unidentified black mineral that generally appears to have formed earlier than the carnotite and tyuyamunite. Most of the ore minerals coat sand grains or fill embayments in the quartz; however, isolated clusters of uranium minerals are common in the microcrystalline gypsum and calcite intergranular matrix (fig. 63).

The foregoing relations suggest two possibilities with regard to paragenesis. Either the interstitial cement formed before the uranium-vanadium minerals and was locally replaced by them, or the calcite and gypsum were deposited essentially contemporaneously with the uranium minerals. Etching of the quartz grains was probably accomplished by the ore solutions at an early stage, before deposition of the ore minerals, for the quartz grains in unmineralized sandstone from the same unit of the Lakota formation are not corroded. Although the microcrystalline gypsum and calcite cement is closely related to the ore minerals, it is quite evident that either a later redistribution of the gypsum occurred or else additional calcium sulfate was introduced. Selenite crystals as much as 3 inches in maximum dimension line fractures that are clearly postmineralization, and parts of the walls of the underground workings are coated with selenite.

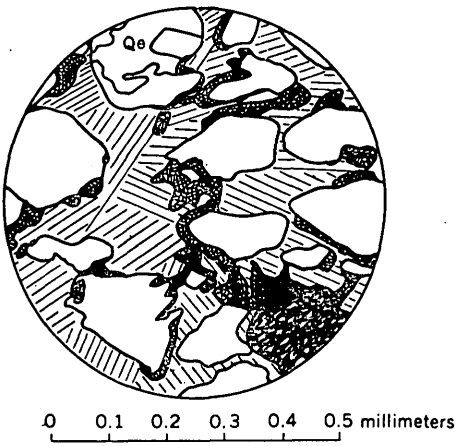


FIGURE 63.—Camera lucida drawing of uranium ore from the Carlile mine, Crook County, Wyo. Unpatterned grains are quartz; *Qe* is quartzite grain; diagonal line pattern is mixture of cryptocrystalline gypsum and calcite; mottled grain is chalcedony; mosaic patterned areas are aggregates of carnotite and tyuyamunite; black areas are opaque black vanadium(?) mineral. Quartz grains are etched and corroded and uranium and vanadium(?) minerals fill embayments and also coat the detrital grains; in most places vanadium(?) appears to have been deposited prior to the uranium minerals.

ORIGIN

The ultimate source of the uranium-bearing solutions from which the ore minerals at the Carlile mine were deposited is not known, but certain assumptions can be made with regard to the origin of the deposits.

The authors believe that uranium and vanadium minerals were deposited from aqueous solutions as primary oxides in a reducing environment. These primary minerals were later oxidized in place to form the present mineral assemblage. There is no evidence to indicate that the primary minerals were decomposed at some remote point, brought in to the present site by solutions, and redeposited.

At the Carlile mine groundwater probably transported the uranium and vanadium from the unkown source to the site of the ore bodies. As pointed out by Gruner and others (1953, p. 50–51) and by Breger and Deul (1956, p. 506–507), the uranyl ion is very mobile and can be transported by aqueous solutions under acidic or alkaline conditions, owing to its stability in acid solution and its ability to form uranyl complexes in alkaline solution. Vanadium probably was present in these ground water solutions in quinqivalent form. The ore-bearing sandstone subunit of the Lakota is permeable and is enclosed between two relatively impermeable clayey subunits of the mudstone sequence, a condition that could permit lateral movement of large volumes of water carrying dissolved uranium and vanadium salts.

The close association of uranium minerals with seams of carbonized plant material clearly indicates that organic matter played a major role in precipitating uranium from ground-water solutions. Experiments by Moore (1954), Breger and others (1955), and by other workers have demonstrated the ability of organic matter in various states of decomposition to release uranium from its soluble complexes and to cause its precipitation. According to Breger and Deul (1956), who recently summarized the present state of knowledge dealing with effectiveness of organic material in concentrating uranium, organic matter extracts uranium, probably as uranyl ion, from aqueous solutions and then by some mechanism transforms it to an organouranium complex, perhaps a uranyl humate, which is insoluble except under extremely acid conditions.

The discovery of coffinite(?) in the Carlile deposit by Bodine (1954) lends credence to the assumption that uranium was deposited initially in the low-valent state, having been reduced from U(VI) in the uranyl ion. The vanadium minerals "A" and "B" of Evans and Mrose (1956), which contain trivalent and quadrivalent vanadium, are thought to represent a gradation from a primary V(III) oxide to a partially oxidized V(IV) species. Recent studies by Pommer

(1956) indicate that vanadium can be reduced from solution with relative ease by organic material, including wood and lignite. By what mechanism the uranyl ion is reduced to the quadrivalent state is not clear, but the local occurrence of pyrite, along with carbonaceous material, indicates a preexisting reducing environment. Although some workers (Frederickson, 1948) have suggested that uranium minerals having high-valent uranium might have formed by adsorption of uranyl ion by graphite and thus not require reduction to a low-valent state and precipitation of primary oxide minerals, more recent studies have shown that oxidized ores, at least those on the Colorado Plateaus, were most certainly derived from quadrivalent uranium complexes (Garrels and Christ, written communication, 1956; Gruner, 1956, p. 508).

Garrels (1953, 1955) and Garrels and Christ (written communication, 1956) have presented thermodynamic and chemical data for vanadium and uranium oxides and have outlined the chemical behavior of uranium minerals during oxidation as applied to the uranium and vanadium ores of the Colorado Plateaus. The mineral assemblage of the Carlile ores and their lithologic similarity to the ores in the plateaus indicate that the processes of oxidation outlined by Garrels and Christ (written communication, 1956) may be applied with certainty to oxidized ores in the northern Black Hills in general and in particular to the Carlile deposits.

The primary mineral assemblage probably consisted of U(IV) compounds, probably uraninite and coffinite, and V(III) compounds, perhaps montroseite and other oxides. A lowering of the ground water table allowed the primary minerals, stable under a reducing environment, to come into contact with moist air or aerated water, and an oxidizing environment prevailed. Low-valent uranium was oxidized to U(VI), perhaps, as suggested by Garrels and Christ (written communication, 1956), to amorphous UO_3; low-valent vanadium was oxidized to V(IV), as indicated by the presence of doloresite(?) ($3V_2O_4 \cdot 4H_2O$), and V(V). In the presence of potassium and calcium, carnotite and tyuyamunite were formed. The excess of V(V) over that needed to produce the uranyl vanadates is reflected by the presence of the calcium vanadates metarossite and hewettite. Rauvite, which may represent an intermediate stage in the formation of the uranyl vanadates (Garrels and Christ, written communication, 1956), also occurs in the mineral assemblage at the Carlile mine. It has been suggested by Garrels (1953) that the present varied mineral assemblage in secondary uranium deposits may be due to the superimposition of varied degrees of oxidation.

The foregoing oxidation sequence is similar to that described by Weeks, Coleman, and Thompson (1959) for the vanadiferous uranium ores of the Colorado Plateau.

During the time of oxidation iron sulfides would have been oxidized to limonite and possibly hematite. Partly oxidized grains of pyrite can be seen in thin-sections of the ore.

Direct evidence for a hydrothermal source of the uranium-bearing solutions is lacking. The nearest exposed intrusive is Devils Tower, about 9 miles to the north. Evidence for other sources, such as beds of volcanic ash or migrating petroliferous solutions, is equally obscure.

Briefly summarizing, the original solutions contained U(VI) and V(V). In the presence of carbonaceous material and perhaps an additional reducing mechanism, the U(VI) was reduced to U(IV), the V(V) to V(III), resulting in the formation of low-valent minerals, probably coffinite, uraninite, and montroseite. Subsequent contact with moist air caused oxidation of the low-valent uranium to U(VI), and the low-valent vanadium to V(IV) and V(V) in which state these combined with potassium and calcium to form the present ore minerals carnotite and tyuyamunite.

The concentration of zinc in the ore samples (table 2) is not believed significant. Table 3 shows the erratic distribution of zinc in the rocks sampled. There seems to be no consistent relation of zinc concentrations with any other element.

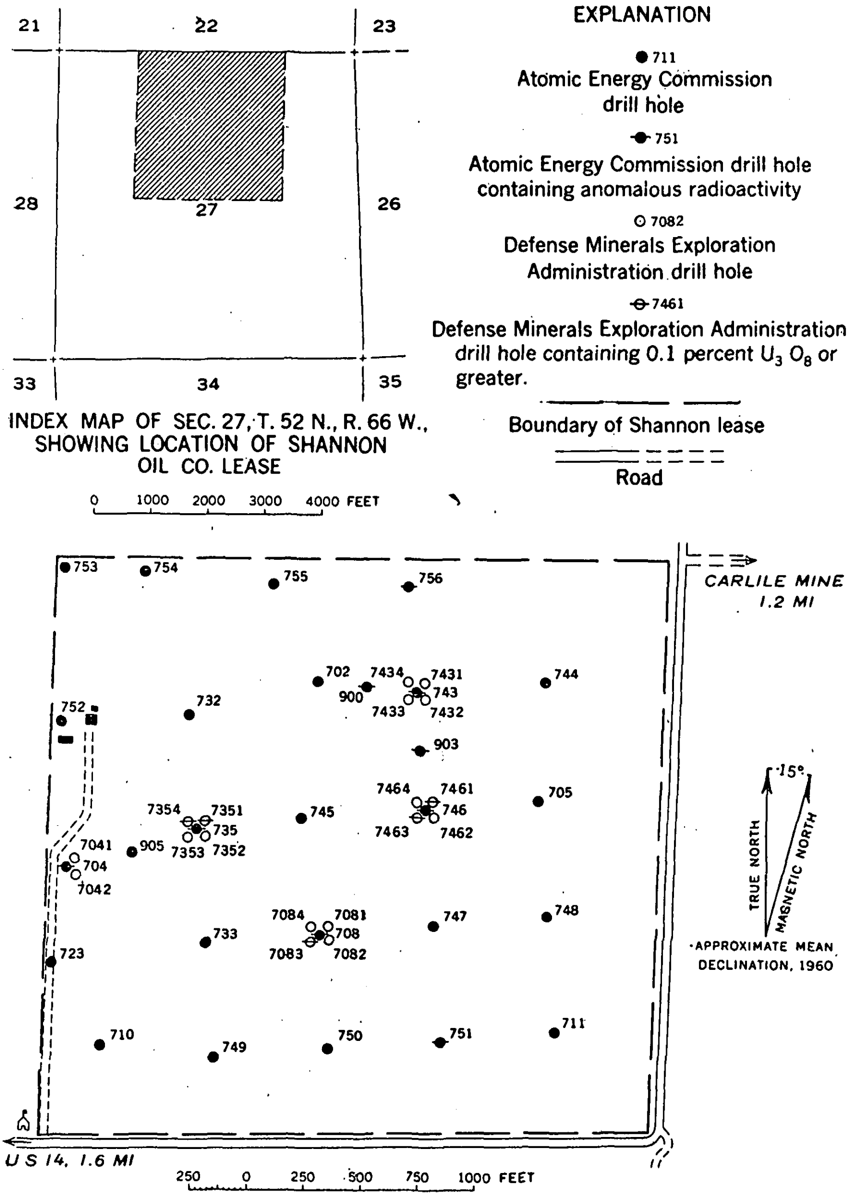
The concentration of selenium in ore samples can be explained by the substitution of selenium for sulfur in pyrite deposited from the ore solutions. This is discussed by Coleman and Delevaux (1957, p. 499–527).

Arsenic can also be present in pyrite, and considerable quantities may be concentrated in land plants (Rankama and Sahama, 1950, p. 739, 742). Thus, arsenic could have been in the carbonaceous material before emplacement of the ore.

OTHER DEPOSITS

THORN DIVIDE

In 1954, the Atomic Energy Commission drilled 27 holes on the Shannon Oil Co. lease in sec. 27, T. 52 N., R. 66 W., as part of an exploration program on Thorn Divide. The Shannon Oil Co., in 1955, received approval from Defense Minerals Exploration Administration, under contract Idm–E870, for a drilling program which provided for holes offset around mineralized holes drilled previously by the Atomic Energy Commission. After completion of 18 holes totalling 4,453 feet, the contract was terminated by the Shannon Oil Co. The positions of the drill holes are shown in figure 64, and the assay data for the five holes drilled under Defense minerals Exploration Administration contract that contained more than 0.1 percent uranium are listed in table 4.



Published by permission of the Shannon Oil Company
and the Defense Minerals Exploration Administration

FIGURE 64.—Map of lease, of the Shannon Oil Co., showing location of drill holes.

All the 18 holes drilled under the Defense Minerals Exploration Administration contract were started in the upper unit of the Fall River formation, and 12 were drilled into the Morrison formation at an average depth of 263 feet. In five of these holes, two zones of black uranium mineral concentrations were detected in the Lakota

TABLE 4.—*Chemical analyses of samples from five drill holes on Thorn Divide, Crook County, Wyo.*

[Chemical assays by The Brown Laboratory, 2263 Broadway, Grand Junction, Colo. Holes drilled by the Shannon Oil Co. under Defense Minerals Exploration Administration contract and published by permission of the Shannon Oil Co. and the Defense Minerals Exploration Administration. Drill hole localities shown on figure 64]

Hole No.	Interval (feet)	U_3O_8 (percent)	V_2O_5 (percent)
7083	176–177	0.29	0.79
	178–179	.28	.28
7351	267–268	.18	----------
7354	271	.10	.03
7461	185–186	.23	.67
	186–187	.15	.21
	189–190	.23	.30
7463	183–184	.1	.18
	184–185	.29	.63
	186–187	.38	.33
	187–188	.40	.72
	190–191	1.07	1.03
	191–192	.28	.67

formation—one in the upper sandstone subunit at an average depth of 186 feet, and another in the sandstone unit at an average depth of 269 feet. The uranium mineral in these ore holes was associted with laminations of carbonaceous material and streaks of pyrite in very fine- to coarse-grained sandstone. The only visible uranium mineral was black, sooty, and weathered yellow.

The structure contours (pl. 34) show that the mineralized holes lie near a structural depression that has about 35 feet of closure.

The drilling program on Thorn Divide revealed a significant tonnage of uranium minerals, which were too deep to be mined economically in 1955; however, the limits of uranium concentrations were not defined closely enough to preclude additional tonnage, which, if large enough, could make mining of the deposits economically feasible.

OTHER MINERALIZED AREAS

A small area of anomalous radioactivity in oil-stained sandstone of the upper unit of the Fall River formation in SE¼ sec. 35, T. 52 N., R. 67 W., had a maximum reading of 0.4 milliröntgens per hour as compared with a background of 0.015 mr/hr. A sample of this sandstone contained 0.12 percent equivalent uranium and 0.007 percent uranium. Analysts, C. G. Angelo, equivalent uranium; H. H. Lipp, uranium.

Two other areas of anomalous radioactivity, one in SW¼ sec. 26, T. 52 N., R. 66 W., and another in NE¼ sec. 35, T. 52 N., R. 66 W., were in the upper sandstone subunit of the Lakota formation. A yellow uranium mineral associated with fine divided carbonaceous material was visible at both localities. The maximum reading at the anomaly in sec. 26 was 1.2 mr/hr calculated from a background count of 0.014 mr/hr, and a sample of the sandstone contained 0.14

percent equivalent uranium, 0.18 percent uranium, and 0.23 percent V_2O_5. (Analysts C. G. Angelo, equivalent uranium; H. H. Lipp, uranium; J. S. Wahlberg, V_2O_5). The anomaly in sec. 35 had a maximum reading of 0.06 mr/hr calculated from a background count of 0.01 mr/hr. The anomaly in sec. 26 extends for about 275 feet around the end of a narrow promontory capped by the siltstone unit of the Fall River formation. The lower 3 feet of the upper sandstone subunit of the Lakota is mineralized. Several holes have been drilled from the top of the promontory to explore this anomaly, but the results of this drilling are not known.

The anomaly in sec. 35 is in the lower 4 to 6 feet of the upper sandstone subunit of the Lakota and extends for about 450 feet along the outcrop. It is not known whether or not this anomaly has been explored by drilling.

ORE CONTROLS

Sedimentary and structural features probably controlled the emplacement of ore bodies in the Carlile area; the sedimentary features include favorable lithologic characteristics and characteristics that exert local controls on ground water passage; the structural features probably influence regional ground-water movement, although its role is not completely understood.

The composition of the host rock was an important factor in fixing uranium and vanadium. At the Carlile mine organic matter concentrated in seams of clay and silt apparently was the precipitant of the uranium from ground-water solutions. The local occurrence of pyrite, as in the deposit on Thorn Divide, indicates that a reducing environment prevailed and that in this environment uranium minerals occur. Areas that lacked sufficient carbonaceous material or the proper reducing environment, although otherwise favorable, are not mineralized to any great extent.

The manner in which lithologic character locally controlled the flow of ground water was a second important feature. The fine- to medium-grained, fairly well sorted sandstone of the ore-bearing lens apparently was permeable enough to permit the flow of moderately large amounts of ground water. By contrast, the massive conglomeratic sandstone of the lower sandstone unit is much more permeable and allowed a much greater flow of water per unit area. Reduction in the rate of flow within the sandstone lens may have been caused by the less permeable clay and silt seams that contain the carbonaceous material.

The irregularities in the shape and thickness of the ore-bearing lens may have been still another influence on the rate of flow of the ground water. Local damming probably occurred near the thinner parts of the lens. The lower contact of the lens with the underying mudstone, where it can be seen, is uneven, owing to either deposition upon an irregular surface or differential compaction of the mudstone during sedimentation. There is no evidence that the unevenness of the contact surface was caused by tectonic forces, nor were any clearly defined channels found. This irregular surface may have caused local reductions in the rate of flow near the bottom of the lens.

The control that tectonic structural features may have exerted on the emplacement of uranium deposits is not clearly defined. At the Carlile mine the deposits coincide with a small dome, as has been mentioned previously. Even though this minor feature coincides with the ore deposits, the authors do not think that it has any genetic or spatial significance with regard to the uranium occurrence. Elsewhere in the Carlile quadrangle, there are similar small domes, yet no uranium deposits have been found associated with them.

Conversely, the deposit on Thorn Divide has a tenuous relationship to the depression shown by the structure contours (pl. 34). The deposit does not coincide with the structural low, which has considerably more closure than the dome at the Carlile mine, but it is situated in such a way as to give the impression that the structure may have influenced the direction or rate of flow of ground water in the immediate area.

No evidence was found to indicate that landsliding, as seen at the Carlile mine, influenced uranium accumulation. Uranium minerals are limited to the upper sandstone subunit of the Lakota both in the undisturbed rocks and in the landslide block. Although the plane along which the landslide moved is in reality a zone of fracture that would provide an easy avenue for movement of any solutions after the landslide, there is no evidence of any such movement of solution except for scattered small blocks of upper sandstone that are mineralized. These blocks, however, could have been broken from the undisturbed rocks and incorporated into the shattered material along the inside edge of the down-ward-moving mass. It seems reasonable to conclude that downward movement of the displaced block occurred after the uranium was deposited.

The strong joint system in the sandstone unit of the Fall River formation does not continue downward into the Lakota formation, and it is doubtful that the joints could have functioned as channels for solutions moving downward to the ore-bearing unit.

While it seems reasonably clear that joints, landsliding, and small local domes have not influenced the concentration of uranium minerals, the regional structural features, discounting the minor local modifications, may be significant in this respect. The Carlile and Thorn Divide deposits both lie on structural terraces that are parts of an uneven surface between two pronounced anticlines, whose crests are about 9 miles apart. The western anticline is the Pine Ridge–Oil Butte structure, the eastern one passes through Sunny Divide, about 5 miles east of the Carlile mine. These two anticlines may have channeled uranium-bearing solutions into the intervening flat area, and uranium was precipitated locally where lithologic and hydraulic factors were favorable.

In summary, it appears that in this area the factors controlling the precipitation and accumulation of uranium were the lithologic and sedimentary features of the host rock insofar as they were responsible for the necessary organic material and proper reducing environment and caused variations in the rate of flow of ground water either by changes in permeability or thickness irregularities in sedimentation, and the structural features insofar as they controlled the regional and local flow of ground water within favorable host rocks.

PETROLEUM

On the anticlines near the western margin of the quadrangle there are several oil seeps, and outcrops of oil-stained sandstone and siltstone of the Fall River formation are abundant, especially on the western limb of the Oil Butte anticline. These features influenced early exploration, and 15 wells were drilled on the Oil Butte and Pine Ridge anticlines, according to Barnett (1915) in his description of the Moorcroft oil field. Five of these holes were drilled no deeper than 125 feet, and the deepest hole reached 1,650 feet. No oil was produced from any of these holes.

Since Barnett's report, a few additional wells have been drilled for oil on the Oil Butte–Pine Ridge anticlines, but none of them have been productive. The oldest formation reached in this later drilling was the Deadwood formation of Cambrian age. Mapel and others (1957) give brief descriptions and locations of these holes.

A seep known as the Bird Oil Spring, in the SE¼ sec. 2, T. 51 N., R. 67 W., issues small quantities of water mixed with petroleum that forms a black, viscous scum on top. Many small birds that visit this spring become immobilized in the black ooze and die slowly of starvation. The spring issues from the lower part of the mudstone unit of the Fall River formation and lies along a small normal fault that trends to the northeast. Another oil seep, smaller than the Bird Oil Spring, is located near the center of sec. 1, T. 51 N., R. 67 W. Small quantities of oil and water trickle from the lower 2 feet of the sandstone unit of the Fall River formation.

Although no oil has been produced from the wells drilled in the Carlile quadrangle, a few barrels per day were pumped until 1936 from seven wells in the Moorcroft field (NW¼ sec. 34, T. 52 N., R. 67 W., immediately west of the quadrangle) according to Espach and Nichols (1941, p. 64). Recent drilling in this field has resulted in renewed production from the Muddy sandstone member of the Thermopolis shale (Newcastle sandstone) at depths of about 680 feet. Drilling in section 31 of the same township has led to the discovery of the West Moorcroft field, in which oil is produced from the Muddy sandstone member (Newcastle sandstone) at depths of 3,564–3,600 feet.

Southeast of the Carlile quadrangle several shallow wells in the Barton oil field (secs. 27 and 35, T. 50 N., R. 65 W.) are producing oil from the Fall River formation at depths of about 70 feet and from the Lakota formation at depths of about 120 feet. In 1958 and 1959 there was considerable exploration in the area immediately west and southwest of the Carlile quadrangle, resulting in a number of successful wells that tapped pools in minor structures and stratigraphic traps in the Fall River formation.

In view of these recent discoveries, small structures such as the Dakota Divide anticline, and the previously tested Oil Butte and Pine Ridge anticlines, should not be ruled out as completely lacking in oil-producing possibilities.

BENTONITE

The northern Black Hills is the most important bentonite-producing area in the United States. Seams and thin beds of bentonite are abundant in most of the Lower Cretaceous marine formations. Heathman (1939, p. 8–10) presents a general discussion of the bentonite deposits in Crook and Weston Counties, Wyo. The mineralogy, distribution, thickness, physical properties, and results of tests of all the major bentonite beds in the various Cretaceous formations in the northern Black Hills are given by Knechtel and Patterson (1955).

In the Carlile quadrangle bentonite occurs in minable quantities in the Mowry shale and the Newcastle sandstone. The persistent Clay Spur bentonite bed of the Mowry is exposed for only a short distance in the NW¼ sec. 25, T. 51 N., R. 67 W., where it has been mined from a shallow opencut for almost a quarter of a mile along the outcrop. This mine was inactive at the time of the investigation.

At least one bentonite bed in the Newcastle sandstone appears pure enough and is of sufficient thickness to be minable. This bed, which probably is the same as bed A of Knechtel and Patterson (1955), is 3 feet thick in SW¼ sec. 2, T. 51 N., R. 67 W. Although claims have been staked, no bentonite has been mined from the Newcastle sandstone in the Carlile area.

REFERENCES CITED

Barnett, V. H., 1915, The Moorcroft oil field, Crook County, Wyoming: U.S. Geol. Survey Bull. 581–C, p. 83–104.

Bell, Henry, and Bales, W. E., 1955, Uranium deposits in Fall River County, South Dakota: U.S. Geol. Survey Bull. 1009–G, p. 211–233.

Bodine, M. W., Jr., 1954, Mineralogy of the Carlile deposit, Crook County, Wyoming, *in* Annual report for June 30, 1953 to April 1, 1954, Part 1: U.S. Atomic Energy Comm. RME–3096 (Pt. I), p. 16–37, issued by U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge.

Breger, I. A., and Deul, Maurice, 1956, The organic geochemistry of uranium, *in* Page, L. R., Stocking, H. E., and Smith, H. B., Contributions to the geology of uranium and thorium by the United States Geological Survey and Atomic Energy Commission for the United Nations International Conference on peaceful uses of atomic energy, Geneva, Switzerland, 1955: U.S. Geol. Survey Prof. Paper 300, p. 505–510.

Breger, I A., Deul, Maurice, and Rubinstein, Samuel, 1955, Geochemistry and mineralogy of a uraniferous lignite: Econ. Geology, v. 50, p. 206–226.

Cobban, W. A., 1951, Colorado shale of central and northwestern Montana and equivalent rocks of the Black Hills: Am. Assoc. Petroleum Geologists Bull., v. 35, p. 2170–2198.

Cobban, W. A., and Reeside, J. B., Jr., 1952, Correlation of the Cretaceous formations of the western interior of the United States: Geol. Soc. America Bull., v. 63, p. 1011–1044.

Coleman, R. G., and Deleraux, Maryse, 1957, Occurrence of selenium in sulfides from some sedimentary rocks of the western United States: Econ. Geology, v. 52, no. 5, p. 499–527.

Collier, A. J., 1922, The Osage oil field, Weston County, Wyoming: U.S. Geol. Survey Bull. 736–D, p. 71–110.

Crowley, A. J., 1951, Possible Lower Cretaceous uplifting of Black Hills, Wyoming and South Dakota: Am. Assoc. Petroleum Geologists Bull., v. 35, p. 83–90.

Darton, N. H., 1899, Jurassic formations of the Black Hills of South Dakota: Geol. Soc. America Bull., v. 10, p. 383–396.

——— 1901, Preliminary description of the geology and water resources of the southern half of the Black Hills and adjoining regions in South Dakota and Wyoming: U.S. Geol. Survey 21st Ann. Rept., pt. 4, p. 489–599.

——— 1905, Description of the Sundance quadrangle, Wyoming–South Dakota: U.S. Geol. Survey Geol. Atlas, folio 127.

——— 1909, Geology and water resources of the northern portion of the Black Hills and adjoining regions in South Dakota and Wyoming: U.S. Geol. Survey Prof. Paper 65.

Darton, N. H., and O'Harra, C. C., 1905, Description of the Aladdin quadrangle, Wyoming–South Dakota–Montana: U.S. Geol. Survey Geol. Atlas, folio 128.

——— 1907, Description of the Devils Tower quadrangle, Wyoming: U.S. Geol. Survey Geol. Atlas, folio 150.

Espach, R. H., and Nichols, H. D., 1941, Petroleum and natural-gas fields in Wyoming: U.S. Bur. Mines Bull. 418, p. 63–65.

Evans, H. T, Jr., and Mrose, Mary E., 1956, Crystal chemical studies of low-valence vanadium oxide minerals from the Colorado Plateau (abs.): Geol. Soc. America Bull., v. 67, no. 12, pt. 2, p. 1693.

Frederickson, A. F., 1948, Some mechanics for the fixation of uranium in certain sediments: Science, v. 108, p. 184–185.

Garrels, R. M., 1953, Some thermodynamic relations among the vanadium oxides and their relation to the oxidation state of the uranium ores of the Colorado Plateaus: Am. Mineralogist, v. 38, p. 1251–1265.

——— 1955, Some thermodynamic relations among the uranium oxides and their relation to the oxidation states of the uranium ores of the Colorado Plateaus: Am. Mineralogist, v. 40, p. 1004–1021.

Gruner, J. W., 1956, Concentration of uranium in sediments by multiple migration-accretion: Econ. Geology, v. 51, p. 495–520.

Gruner, J. W., Gardiner, Lynn, and Smith, D. K., Jr., 1953, Annual report for July 1, 1952 to March 31, 1953: U.S. Atomic Energy Comm. RME–3044, issued by the U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge.

Hancock, E. T., 1920, The Mule Creek oil field, Wyoming: U.S. Geol. Survey Bull. 716–C, p. 35–53.

Heathman, J. H., 1939, Bentonite in Wyoming: Wyoming Geol. Survey Bull. 28, 20 p.

Imlay, R. W., 1947, Marine Jurassic of the Black Hills area, South Dakota and Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 31, p. 227–273.

Knechtel, M. M., and Patterson, S. H., 1955, Bentonite deposits of the northern Black Hills district, Montana, Wyoming, and South Dakota: U.S. Geol. Survey Mineral Inv. Field Studies Map MF 36.

Mapel, W. J., Robinson, C. S., and Theobald, P. K., Jr., (1959), Geologic and structure contour map of the northern and western flanks of the Black Hills in Wyoming, Montana, and South Dakota: U.S. Geol. Survey Oil and Gas Inv. Map OM 191.

McKee, E. D., and Weir, G. W., 1953, Terminology for stratification and cross-stratification in sedimentary rocks: Geol. Soc. America Bull., v. 64, p. 381–390.

Moore, G. W., 1954, Extraction of uranium from aqueous solution by coal and other materials: Econ. Geology, v. 49, p. 652–648.

Moore, R. C., 1949, Meaning of facies, *in* Longwell, C. R., Sedimentary facies in geologic history: Geol. Soc. America Mem. 39, p. 1–39.

Noble, J. A., 1952, Structural features of the Black Hills and adjacent areas developed since Precambrian time *in* Billings Geol. Soc. Guidebook, Third Ann. Field Conf., Black Hills-Williston basin; Billings Geol. Soc., Billings, Mont., p. 31–37.

Pommer, A. M., 1956, Oxidation potential and state of some vanadian ores and the relation of woody material to their deposition: U.S. Geol. Survey open file report.

Rankama, Kalervo, and Sahama, T. G., 1950, Geochemistry: Chicago, Ill., Chicago Univ. Press, 912 p.

Reeside, J. B., Jr., 1944, Map showing thickness and general character of the Cretaceous deposits in the western interior of the United States: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 10.

Reeside, J. B., Jr., 1952, Summary of the stratigraphy of the Morrison formation, *in* Yen, T. C., Molluscan fauna of the Morrison formation: U.S. Geol. Survey Prof. Paper 233–B, p. 22–26.

Reiche, Parry, 1937, The Toreva-block, a distinctive landslide type: Jour. Geology, v. 45, p. 538–548.

Richards, P. W., 1955, Geology of the Bighorn Canyon–Hardin area, Montana and Wyoming: U.S. Geol. Survey Bull. 1026.

Rubey, W. W., 1929, Origin of the siliceous Mowry shale of the Black Hills region: U.S. Geol. Survey Prof. Paper 154, p. 153–170.

Rubey, W. W., 1931, Lithologic studies of fine-grained upper Cretaceous sedimentary rocks of the Black Hills region: U.S. Geol. Survey Prof. Paper 165–A, p. 1–54.

Russell, W. L., 1928, The origin of artesian pressure: Econ. Geology, v. 23, p. 132–157.

Stokes, W. L., 1952, Lower Cretaceous in Colorado Plateau: Am. Assoc. Petroleum Geologists Bull., v. 36, p. 1766–1776.

Summerford, H. E., Schieck, E. E., and Hiestand, T. C., 1949, Newcastle sandstone, upper Cretaceous, Wyoming: Wyoming Geol. Assoc. Guidebook, Powder River basin, p. 69–79.

——— 1950, Oil and gas accumulation controlled by sedimentary facies in upper Newcastle sandstone, Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 34, p. 1850–1865.

Trask, P. D., 1932, Origin and environment of source sediments of petroleum: Houston, Tex., Gulf Publishing Co., p. 71–72.

U.S. Department of Commerce, 1951, Climatological data for the United States by sections: U.S. Dept. Commerce, Weather Bureau, Ann. Summary, v. 38, p. 220–228.

Waagé, K. M., 1955, Dakota group in northern Front Range foothills, Colorado: U.S. Geol. Survey Prof. Paper 274–B, p. 15–51.

——— 1959, Stratigraphy of the Inyan Kara group in the Black Hills: U.S. Geol. Survey Bull. 1081–B, p. 11–90.

Ward, L. F., 1894, The Cretaceous rim of the Black Hills: Jour. Geology, v. 2, p. 250–266.

——— 1899, The Cretaceous formation of the Black Hills as indicated by the fossil plants: U.S. Geol. Survey 19th Ann. Rept., pt. 2, p. 521–946.

Weeks, A. D., Coleman, R. G., and Thompson, M. E., 1959, Summary of the mineralogy of the Colorado Plateau uranium ores *in* Garrels, R. M., and Larsen, E. S., 3d, Geochemistry and mineralogy of the Colorado Plateau uranium ores: U.S. Geol. Survey Prof. Paper 320, p. 65–81.

Yen, Teng-Chien, 1952, Molluscan fauna of the Morrison formation: U.S. Geol. Survey Prof. Paper 233–B, p. 21–51.

INDEX

O