Geology of the Clifton Quadrangle Wyoming and South Dakota

GEOLOGICAL SURVEY BULLETIN 1063-H

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

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By NORMAN P. CUPPELS

GEOLOGY AND URANIUM DEPOSITS OF THE SOUTHERN BLACK HILLS

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UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1963

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

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[Plates are in pocket]

GEOLOGY OF THE CLIFTON QUADRANGLE, WYOMING AND SOUTH DAKOTA

By NORMAN P. CUPPELS

ABSTRACT

The Clifton quadrangle includes about 55 square miles of the southwestern flank of the Black Hills in parts of Weston County, Wyo., and Custer County, S. Dak. The geology of this quadrangle was mapped as part of a program to investigate the environment and controls of uranium deposition in the southern Black Hills. All the uranium produced in the southern Black Hills has been mined from terrestrial rocks of the Inyan Kara Group of Early Cretacious age, and for this reason these rocks have been mapped in greater detail than adjoining rocks. Approximately 2,900 feet of sedimentary rocks which range in age from Permian to Tertiary(?) crop out within the quadrangle. Fifteen formations, 6 members, and 13 lithologic units are represented. Fluvatile and lacustrine rocks of the Inyan Kara Group constitute approximately 375 feet of the stratigraphic section. Post-Inyan Kara rocks include 1,425 feet of dark marine shales and a thick-bedded lenticular sandstone. Pre-Inyan Kara rocks consist of a series of marine and nonmarine beds totaling 1,100 feet in thickness.

The Inyan Kara Group ranges in thickness from 320 feet in the northwestern part of the quadrange to 400 feet in the southern part. Most of the variation in thickness is within the Lakota Formation; the Fall River Formation is uniformly 140 to 160 feet thick. These 2 formations have been subdivided into 8 mappable lithologic units. A uranium-bearing rim-forming sandstone in the middle part of the Fall River Formation is as much as 80 feet thick and changes to thin-bedded sandstone and siltstone at five places within the quadrangle. The thick-bedded facies of this sandstone may be parts of a continuous meandering channel or they may be erosionally truncated segments of different channel tributary to a larger drainage system. At most places this sandstone is light brown to light gray, but in the southern part of the quadrangle the color changes abruptly to sulfur yellow.

Parts of four regional structural elements of the Black Hills are included within the quadrangle: the Fanny Peak monocline, the Dewey structural terrace, the Black Hills monocline, and the structural terrace that forms the Limestone Plateau of the western Black Hills. The rocks involved have a structural relief of 3,800 feet.

Structural, stratigraphic, and geochemical considerations suggest that the most favorable locality for uranium exploration is on the Dewey terrace in the west-central part of the quadrangle. The same locality is also considered favorable for petroleum exploration because of stratigraphic and structural traps in the oil-bearing Newcastle Sandstone. The Spearfish Formation contains 590 million tons of thick-bedded gypsum at depths of less than 127 feet that is not considered minable because of transportation costs.

INTRODUCTION

The Clifton quadrangle includes about 55 square miles of the southwestern flank of the Black Hills in parts of Weston County, Wyo., and Custer County, S. Dak. (fig. 57). The quadrangle is astride the boundary between the Powder River Basin and the Black Hills uplift. West of the quadrangle, featureless prairie extends 150 miles across the Powder River Basin to the Bighorn Mountains. Within, and for 60 miles east of the quadrangle, erosion of sedimentary rocks in the Black Hills uplift has produced a series of concentric hogbacks and cuestas, steep-walled canyons, a peripheral valley known locally as the Racetrack—or the Red Valley, and a plateau underlain by Paleozoic limestones that extends eastward to the Precambrian core.

The Black Hills are a product of the uplift and erosion of an elongate dome in the Precambrian basement. The physiographic expression of the uplift is a doubly plunging northwest-trending anticline which projects 4,000 feet above the Great Plains of western South Dakota and eastern Wyoming. This anticline is expressed in surface rocks over an area 125 miles long and 50 miles wide. Igneous and metamorphic rocks of the Precambrian basement exposed in the central part of the Black Hills are surrounded by 12,000 to 13,000 feet of upturned sedimentary rocks ranging in age from Cambrian to Tertiary. Differential resistance to erosion of the several rock types has sharply defined the uplift and produced several geomorphic provinces within the Black Hills. Terrain underlain by Precambrian rocks is characterized by low, rolling hills and monoliths of granite. The Deadwood formation of Cambrian age and gently dipping beds of limestone in the Englewood, Whitewood, and Pahasapa formations of younger Paleozoic age form a plateau in the west-central part of the uplift. The most conspicuous feature of the periphery of the uplift is the hogback formed by resistant sandstones of the Lower Cretaceous Inyan Kara Group of rocks. The hogback is accentuated in many places by deep erosion of red beds of Permian and Triassic age underlying the Red Valley which encircles the uplift.

According to Darton (1925), every period of the Paleozoic and Mesozoic Eras except the Silurian and Devonian is represented in the stratigraphic column of the Black Hills. In addition to the Silurian and Devonian hiatus, major gaps in the column occur in the

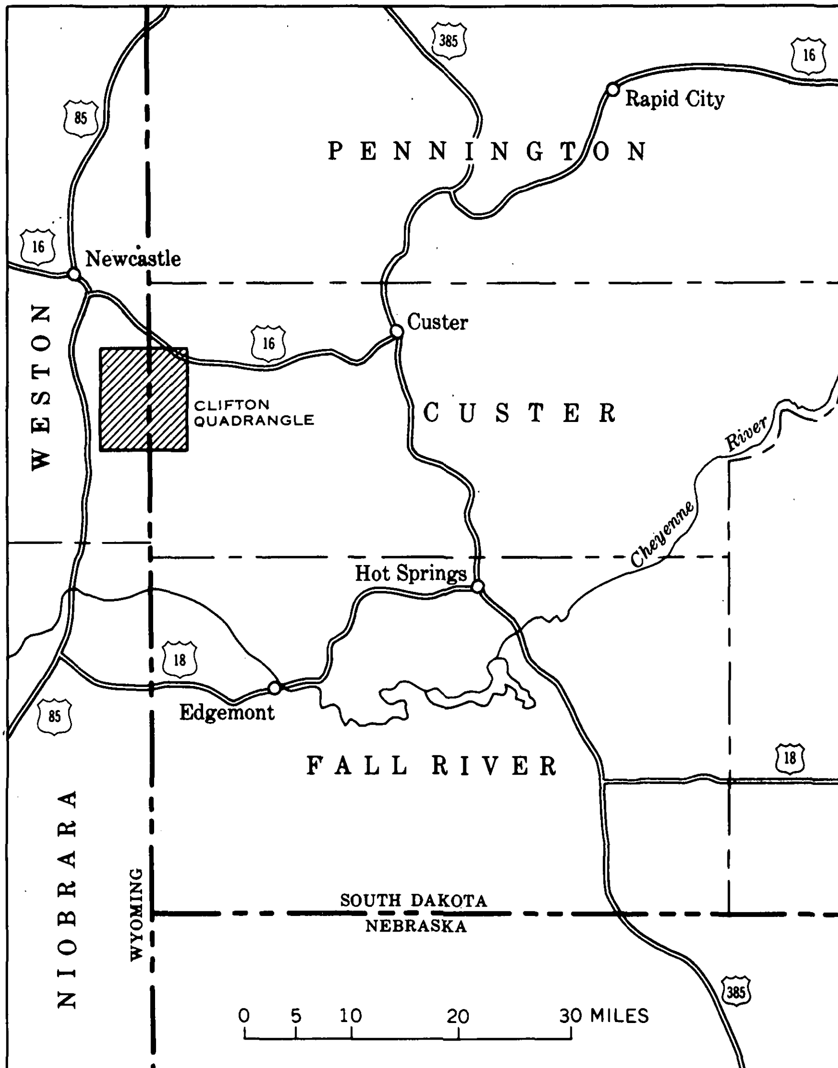

FIGURE 57.—Index map showing the location of the Clifton quadrangle, Weston County, Wyo., and Custer County, S. Dak.

Lower and Middle Cambrian, Upper Mississippian, and Lower and Middle Jurassic rocks. Although most rocks in the column were deposited in a marine environment, these hiatuses, as well as terrestrial rocks of Triassic, Jurassic, and Cretaceous age, mark withdrawals of the sea which first invaded the area during the Ordovician Period. The hiatuses probably mark intervals when the area was above sea level but in a topographic low. Final withdrawal of the sea occurred in Late Cretaceous time and was probably concomitant with early movement associated with the Black Hills uplift. There has been considerable erosional truncation of Upper Cretaceous rocks; however, it is probable that the youngest Cretaceous rocks (the Hell Creek Formation) extended across the area now occupied by the Black Hills.

The distribution of post-Cretaceous rocks, which are all nonmarine near the Black Hills, reflects tectonic movements and can be used as an aid in dating the uplift. West of the Black Hills, Paleocene rocks overlie cretaceous rocks with little or no interruption of the stratigraphic sequence; however, north, east, and south of the Black Hills, Paleocene and Oligocene rocks unconformably overlie Cretaceous rocks, and within the uplift, Oligocene rocks rest on erosion surfaces carved on rocks as old as Precambrian. No Eocene rocks are found east of the uplift. The absence of Eocene deposits within and east of the Black Hills indicates that the Eocene Epoch was a time of active uplift and erosion. Erosion had lowered the land surface sufficiently to permit aggradation in the stream valleys by Oligocene time.

The geology of the Clifton quadrangle was mapped in 1956 and 1957 as part of a program in the southern Black Hills which was established in 1952 to investigate the environment and controls of uranium deposition. Under the program, thirteen 7½-minute quadrangles have been mapped at a scale of 1:7,200; the geologic environment of specific uranium deposits has been investigated in considerable detail at the Gould and Runge mines in Fall River County, S. Dak., and studies have been made at more than 15 uranium mines elsewhere within the mapped area. All the uranium produced in the southern Black Hills has been mined from terrestrial rocks of the Inyan Kara Group, and for this reason these rocks have been mapped more thoroughly than any of the associated rocks. Lithologic units within the Inyan Kara Group have been mapped and correlated from Hot Springs, S. Dak., to Government Canyon, 15 miles north of Hulett, Wyo., (Mapel and Gott, 1959).

Prior to the present investigation, the geology of the Newcastle area had been mapped, in whole or in part, by several geologists. Darton (1904) described the rocks of the Clifton quadrangle as part of an investigation which included most of the Black Hills. The structure and stratigraphy of rocks younger than the Fall River Formation of Early Cretaceous age in eastern Weston County, Wyo., were described by Dobbin and Horn (1949). Brobst (1961) mapped the Dewey quadrangle, which is due south of the Clifton quadrangle, in 1956. Brobst and Epstein mapped the Fanny Peak quadrangle, north of the Clifton quadrangle, in 1957.

The author is indebted to G. B. Gott for many helpful suggestions in the field and in the office and to F. R. Conwell and J. Gliozzi,

who rendered willing and able assistance in the fieldwork. This investigation was made on behalf of the U.S. Atomic Energy Commission.

GENERAL GEOLOGY

A section of about 2,900 feet of consolidated sedimentary rocks is included within the Clifton quadrangle; it comprises 15 formations, 6 members, and 13 lithologic units ranging in age from Permian to Cretaceous (pls. 23 and 24). These rocks are covered locally by Recent alluvium, colluvium, and landslide debris and by high gravel terraces which may be Tertiary(?) in age. Erosion of the consolidated rocks in a semiarid environment has produced steep-walled landforms, such as canyons, escarpments, mesas, buttes, cuestas, and hogbacks. A north-trending cuesta made up of Inyan Kara rocks which extends across the central part of the quadrangle and which composes the Elk Mountains is the most conspicuous landform in the area.

The eastern edge of the cuesta is a cliff, 400 to 600 feet high, which is here called the Elk Mountains escarpment (fig. 58). The cuesta extends westward from the escarpment to the Dewey Terrace. It ends abruptly in the northern part of the quadrangle, where the escarpment has been eroded back to Ferguson Canyon. In contrast with the relatively gently dipping beds underlying the cuesta, rocks exposed in Ferguson Canyon dip at high angles westward. Partial erosion of these rocks has resulted in a hogback which forms the west wall of the canyon. For nearly a mile south of the hogback, the cuesta is covered with landslide debris. The cuesta is underlain by a thick-bedded granule sandstone of the Lakota Formation which dips west and southwest at about 10°. Erosional remnants of siltstone, mudstone, and thin sandstones of the upper part of the Lakota conceal the sandstone at many places on the dip slope. The relatively incompetent beds of the Morrison and Sundance Formations of Jurassic age which underlie the Lakota capping are truncated in the escarpment along the eastern edge of the cuesta. Except for the Hulett Sandstone Member of the Sundance, the truncated edges of these formations are covered by slump blocks and colluvium at most places along the escarpment. The Minnekahta Limestone of Permian age and red beds of the Spearfish Formation of Permian and Triassic age underlie an interior lowland known as the Red Valley, which extends eastward from the escarpment to the quadrangle boundary. This lowland has a gently undulating grass-covered surface of low relief which is interrupted locally by steep-sided erosion gullies. Beds of gypsum in the lower part of the Spearfish cap many of the low hills and ridges of the lowland.

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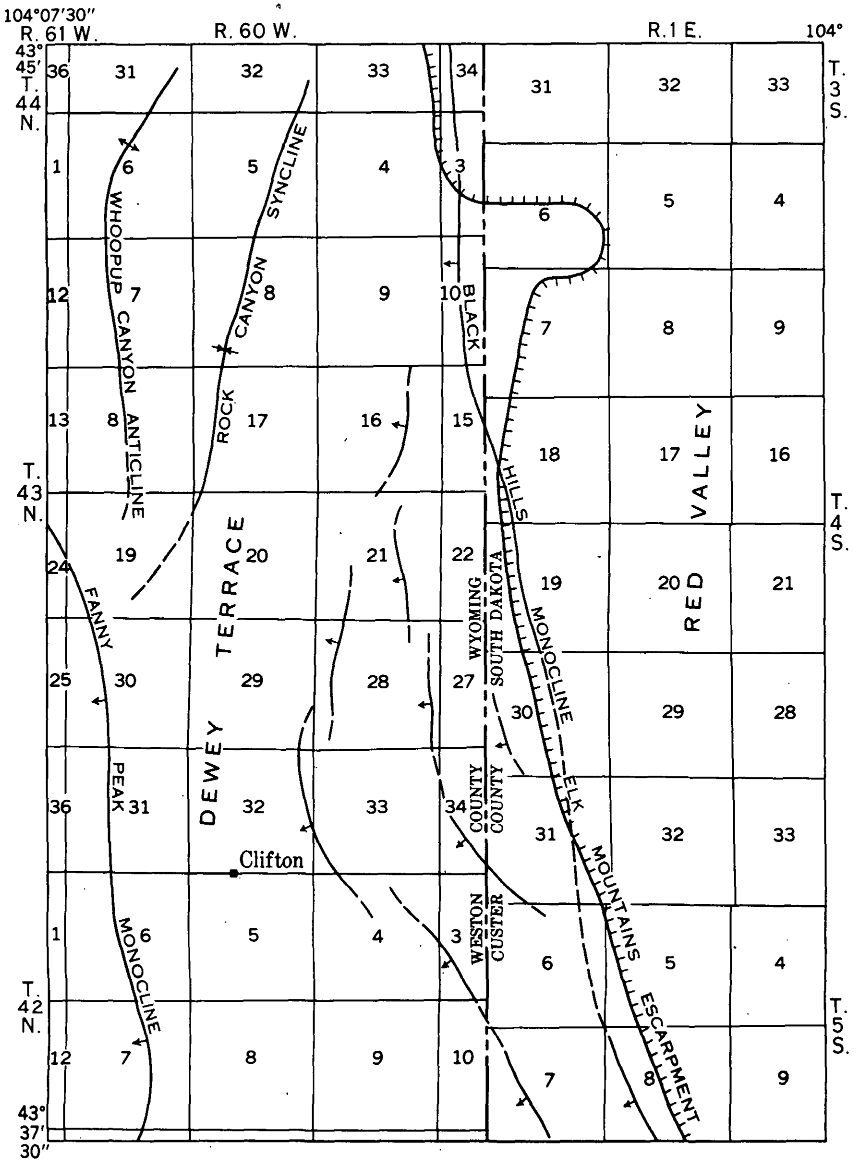

FIGURE 58.—Map showing structural and physiographic features in the Clifton quadrangle, Wyoming. Single arrows point in the direction of steeper dips at the upper break in slope of the monoclines.

West of the cuesta, the Fall River Formation has been truncated by erosion along the steeply dipping rocks of the Black Hills monocline. Because of the relatively steep dips, the Fall River outcrop pattern is relatively narrow in comparison with the outcrop pattern of the Lakota Formation. The Dewey terrace, bounded by the Black Hills monocline on the east and the Fanny Peak monocline on the west, ranges in width from 1 to 3 miles because of the sinuosity of the axes of the monoclines. Marine shales which underlie the terrace in the southwestern part of the quadrangle are truncated by erosion in the northern part of the quadrangle, where nonmarine rocks of the Inyan Kara Group are exposed in a shallow syncline and anticline.

Pre-Inyan Kara rocks consist of a succession of marine and nonmarine beds totaling 1,100 feet in thickness. These rocks crop out east of the Elk Mountains escarpment and in several of the deeper canyons cut deep into the Inyan Kara cuesta in the southern part of the quadrangle. Most of the rocks in this succession are incompetent shales and siltstones which have been eroded to form Red Valley in the eastern part of the quadrangle. The rate of erosion in Red Valley has been slowed by thick beds of gypsum in the lower part of the Spearfish Formation and the Minnekahta Limestone; hence, most of the valley is underlain by red beds of the Spearfish Formation.

PERMIAN SYSTEM

MINNELUSA FORMATION

There are no exposures of the Minnelusa Formation of Pennsylvanian and Permian age in the quadrangle; however, about 40 feet of the upper part of the Minnelusa has been inferred to be present in the north wall of Gillette Canyon in the northeastern part of the quadrangle; this upper part of the Minnelusa is of Permian age. Exposures north and east of the quadrangle indicate that the upper 200–300 feet of the formation is a breccia consisting of angular blocks of red sandstone in a sandy matrix. Some of the blocks are composed of red to gray limestone. The long dimension of the blocks ranges from a fraction of an inch to tens of feet. The matrix is commonly a fine-grained sandstone firmly cemented with calcium carbonate. According to D.A. Brobst and C.G. Bowles (oral communication, November 1960), the formation is 700 feet thick where it is exposed but thickens to 900 feet below the zone of oxidation. Beds of evaporite in the upper part of the unit that are probably susceptible to solution near the water table would account for brecciation in the upper part and decrease of the overall thickness.

OPECHE FORMATION

The Opeche Formation underlies covered slopes in Gillette and Ferguson Canyons in the northeastern part of the quadrangle. Exposures in the Fanny Peak quadrangle north of this area indicate that the formation consists of red fine-grained friable silty sandstone which grades to reddish-purple shale near the top of the unit. Thin beds of gypsum are exposed intermittently along Ferguson Canyon north of the quadrangle. J. B. Epstein (oral communication, October 1957) has found that the formation changes in thickness from 75 to 110 feet in distances of less than 400 feet along the outcrop. No fossils have been found in the unit, but because of its stratigraphic position with respect to the overlying Minnekahta Limestone and underlying Minnelusa Formation, it has been given a Permian age by N. H. Darton (1901, p. 513) and others.

MINNEKAHTA LIMESTONE

The Minnekahta Limestone of Permian age was named by Darton (1901, p. 514) for a thin-bedded gray limestone near the hot springs originally known as Minnekahta by the Sioux Indians of the Black Hills. Lacking reliable index fossils, Darton was uncertain about the precise age of this formation. He assigned the Minnekahta to a Permian(?) age but did not preclude the possibility that the formation could be Triassic.

The Minnekahta Limestone is the rimrock on several flat-topped drainage divides in the northeastern part of the quadrangle and crops out intermittently in the stream beds of Coon and Dugout Creeks near the eastern boundary of the quadrangle. It is a distinctive light-gray dense thin-bedded crystalline limestone that weathers light red in outcrop. Although it is rarely more than 60 feet thick, it forms prominent cliffs at many places in the Black Hills. Its characteristic slabby splitting properties and its undulatory outcrop pattern make it easily recognized wherever it is exposed. The limestone is apparently very sensitive to differential stresses, reacting to stresses by flowage in some places and by fracturing elsewhere. Flowage can be seen at many places where beds of the unit tend to follow contours of the land surface. The limestone is fractured locally, however, as can be seen where the unit is involved in the Black Hills monocline in Ferguson Canyon. Bedding-plane faults can be seen at several places along the east wall of the canyon and a strike-slip dip fault can be seen 1,800 feet north of Ferguson Spring. Faults having displacements of several inches to several feet are associated with tight folds in the limestone having amplitudes of a few inches to a few feet.

PERMIAN AND TRIASSIC SYSTEMS

SPEARFISH FORMATION

The Spearfish Formation is a red thick-bedded siltstone containing thin to thick beds of rock gypsum and forms most of the floor of the Red Valley in the eastern part of the quadrangle. The terrain in this area consists of gently rolling hills which are cut locally by steep-sided erosion gullies, notably near the headwaters of Coon and Dugout Creeks. Structure and lithology have controlled erosion of the formation. Because siltstone erodes much more readily than the gypsum, broad, flat interfluves capped by gypsum have resulted. Gypsum is also at or close to the surface in a shallow, doubly plunging anticline that forms the drainage divide between Coon and Dugout Creeks. Boulders of silicified sandstone, several inches to 6 feet in diameter, are distributed in irregular clusters, or boulder fields, on the erosion surface of the Spearfish Formation (fig. 59). These boulders are probably erosional remnants (sarsen stones) derived from the Lakota Formation of Cretaceous age, which crops out near the top of the Elk Mountains in the central part of the quadrangle. A sandstone near the base of the Lakota is the only bedrock in this area that has a lithology similar to that of the sarsen stones. If the sarsen stones were derived from the Lakota Formation, they have survived the erosion of about 450 feet of rocks which formerly overlay the present erosion surface.

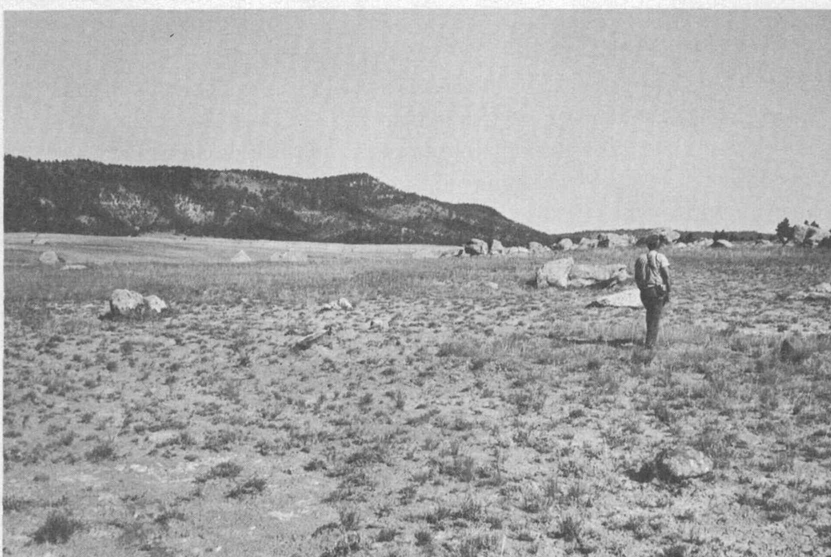

FIGURE 59.—Sarsen stones of silicified sandstone of the Lakota Formation resting on the Spearfish Formation in sec. 17, T. 4 S., R. 1 E., Black Hills meridian. These stones have survived the erosion of 450 feet of rocks which formerly overlay the present erosion surface.

As shown on the geologic map (pl. 23), the Spearfish Formation is divided into three units which are listed below in order of increasing age:

	Thickness (feet)
Upper siltstone unit:	
Sandstone, light-red, fine-grained, thick-bedded, calcareous, cliff-forming, lenticular	7.0
Siltstone, red, thick-bedded, friable; becomes sandy near top	250.0
Thickness of unit	257.0
Middle unit:	
Gypsum, light-red to white, thin-bedded to laminated; includes splits of red siltstone locally	7.0
Siltstone, red; many beds of white gypsum 1 to 3 ft thick	127.0
Gypsum, white, thick-bedded; a few beds of red siltstone 1 to 4 ft thick	18.0
Siltstone, red, friable; a few beds of gypsum 1 to 2 ft thick	45.0
Gypsum, purple to white, thick-bedded; several thin beds of green to red siltstone. Beds of dolomite 1 ft thick are associated with chert nodules at top and bottom of unit	25.0
Thickness of unit	222.0
Lower siltstone unit:	
Siltstone, red, thick-bedded, friable; many veinlets of satin spar	80.0
Total thickness, Spearfish Formation	559.0

The lower siltstone unit increases in thickness from 50 to 90 feet within 2 miles southeast of the quadrangle. Locally, satin spar and selenite are abundant in the silstone, and the upper few feet is green and contains flecks of carbonaceous material. In Ferguson Canyon, lenses of white thick-bedded rock gypsum, 5 to 10 feet thick, underlie the siltstone. Elsewhere, the Minnekahta-Spearfish boundary is marked by a lithic change from limestone to red siltstone.

The middle unit of gypsum and siltstone was established to include all bedded gypsum deposits in the formation, exclusive of the lenticular gypsum at the Spearfish-Minnekahta boundary. The middle unit consists chiefly of red siltstone and many thin beds of white to light-red gypsum which increase in thickness and abundance in the lower part of the map unit. Four varieties of gypsum are present: rock gypsum, selenite, satin spar, and gypsite. Rock gypsum constitutes at least 95 percent of the gypsum in the unit. Selenite, a translucent to transparent platy variety, and the fibrous satin spar form secondary deposits occurring as fracture fillings. Gypsite forms powdery efflorescent deposit on fracture and bedding-plane surfaces. A thick-bedded layer of purple gypsum at the bottom of this unit ranges in thickness from 20 to 30 feet and forms very conspicuous outcrops. Several strata of green to red siltstone occur near the middle of the gypsum, and beds of dolomite, limestone, and chert less than a foot thick are common near the bottom and top of the thick-bedded gypsum. Another thick-bedded gypsum layer, 50 feet above the purple gypsum, is 5 to 10 feet thinner, weathers white, does not contain any chert or dolomite, and becomes thin bedded in the northern part of the quadrangle.

The upper siltstone unit of the Spearfish Formation forms cliffs along the eastern face of the Elk Mountains and extends eastward for half a mile or less under gently sloping grasslands. The unit is generally a red thick-bedded weakly cemented siltstone which becomes sandy and more firmly cemented near the top, where it is exposed in the cliffs at the foot of the Elk Mountains escarpment.

As defined by Darton (1899, p. 387), the Spearfish Formation is a sequence of red beds, sandstones, and bedded gypsum overlying the Minnekahta Limestone of Permian age and underlying the Sundance Formation of Jurassic age. Although the Permian-Triassic boundary is believed to lie somewhere within the Spearfish Formation, its precise location has been the subject of some controversy. In the Hartville uplift of southeastern Wyoming, Denson, and Botinelly (1949) placed the boundary at the top of a gypsiferous interval in a sequence of red shales and gypsum beds overlying the Minnekahta Limestone in that area. Condra, Reed, and Scherer (1940, p. 36) placed the boundary at the same horizon in a similar lithologic sequence in Hot Brook Canyon near Hot Springs, S. Dak. Reeside and others (1957, p. 1485) placed the boundary at the top of a basal shale in the Spearfish Formation in a section measured at Buffalo Gap in the southeastern Black Hills. The most recent study of this problem by McKee and others (1960, p. 11) indicates that the boundary is at the top of the gypsiferous unit. The lithologic sequence in the Clifton quadrangle agrees very closely with the sequence described by Denson and Botinelly (1949), Condra, Reed, and Scherer (1940), and Reeside and others (1957). If this correlation is valid, the upper siltstone unit and the lower siltstone unit of the Spearfish in the Clifton quadrangle correlate with the Chugwater Formation and the Glendo Shale (Condra, Reed, and Scherer, 1940), respectively, of southeastern Wyoming and the Permian-Triassic boundary is at the bottom of the upper siltstone unit. It is possible that the thin beds of gypsum in the upper part of the middle unit of the Spearfish of this report are the result of local deposition and that the top of the gypsiferous interval elsewhere correlates with the top of the thick-bedded layer of white-gypsum 88 feet above the bottom of the middle unit. This correlation has not been established; hence, the Permian Triassic boundary is placed at the top of the middle unit which marks the end of gypsum deposition in this area.

JURASSIC SYSTEM

GYPSUM SPRING FORMATION

In a measured section on the east side of the Elk Mountains in the S½ sec. 19, T. 4 S., R. 1 E., Black Hills meridian, Imlay (1947, p. 272) describes the Gypsum Spring Formation as consisting of 4½ feet of white massive gypsum overlain by a white sandstone, 1 foot thick, which possibly represents the Canyon Springs Sandstone Member of the Sundance Formation. The gypsum is underlain by a salmon-red medium-grained massive sandstone which may be the Nugget Sandstone of southeastern Wyoming. A line symbol is used to indicate the Gypsum Spring Formation on the geologic map (pl. 23) because of the impracticality of using two boundaries to show a unit 0 to 10 feet thick at the scale of the map. Exposures of the formation crop out on the Elk Mountains escarpment, where the formation is concealed at most places by talus and slump blocks. A bed of rock gypsum in the formation reaches a thickness of 8 feet in the northern part of the quadrangle and pinches out southward in the SW¼ sec. 5, T. 5 S., R. 1 E., Black Hills meridian. According to Imlay, the gypsum grades into a gray shale-limestone-dolomite facies in the northwestern Black Hills.

The following section was measured in the SE¼ sec. 31, T. 4 S., R. 1 E., Black Hills meridian, 1½ miles south of the section measured by Imlay.

	Thickness (feet)
Sundance Formation (in part):	
Stockade Beaver Shale Member:	
8. Shale, light-gray, silty, calcareous, fossiliferous; weathers to dark gray; several thin beds of greenish-gray sandstone	40
7. Siltstone, yellow-brown, friable	5
6. Sandstone, greenish-gray, very fine grained, friable, calcareous, fragmented and deformed; oysters abundant	2
Gypsum Spring Formation:	
5. Gypsum, white, microcrystalline, massive, lenticular	4
4. Siltstone, light-red, laminated, friable, ripple-marked; concentrations of yellow-brown oxides of iron	1
3. Sandstone, light-red, very fine grained; weakly cross-stratified; firmly cemented with calcium carbonate	4
2. Sandstone, light-gray, medium-grained, calcareous; ripple marks are heavily stained with yellow-brown oxides of iron	1
Total thickness of Gypsum Spring Formation	10
Spearfish Formation (in part):	
1. Siltstone, dark-red, sandy, fissile, weakly cross-stratified	50+

SUNDANCE FORMATION

The Sundance Formation was originally defined by N. H. Darton (1899) and was subdivided into members by Imlay (1947, p. 246). Imlay's members, from oldest to youngest are: Canyon Springs Sandstone, Stockade Beaver Shale, Hulett Sandstone, Lak, and Redwater Shale. As a standard of reference, Imlay described these members (exclusive of the Canyon Spring Sandstone) in a section measured one mile north-northeast of Spearfish, S.Dak. In the Clifton quadrangle, the Canyon Springs Member is absent and the remainder of the formation consists of a series of shales, claystones, and sandstones 260 to 370 feet thick. These rocks are exposed in the escarpment along the east face of the Elk Mountains and in some of the deeper canyons in the dip slope of the Inyan Kara cuesta. Relatively rapid erosion of these rocks promotes slumping of the overlying rocks and the development of slopes thickly covered with talus and colluvium. Soft shales of the Redwater Shale Member and the overlying Morrison Formation have provided the sliding surfaces for a major landslide southwest of Ferguson Canyon. Most of the variation in thickness of the formation takes place in the Redwater Shale Member, which thins considerably in the northern part of the quadrangle. Best exposures of the formation are in the W½ sec. 19, T. 4 S., R. 1 E., and the NE¼ sec. 31, T. 4 S., R. 1 E., Black Hills meridian.

The following section was measured 0.9 mile northwest of Wildcat Peak in the S½ sec. 19, T.4 S., R.1 E., Black Hills meridian.

	Thickness (feet)
Morrison Formation.	
Covered slope; contact not exposed	106
Sundance Formation:	
Redwater Shale Member (in part):	
22. Claystone, dark-gray, fissile, silty; interbedded light-gray calcareous siltstone	14.0
21. Limestone, brownish-gray, coquinoid; consists of fragments of oyster shells cemented with calcite. Overlain by 4 in of light greenish-gray calcareous glauconitic laminated siltstone	1.0
20. Siltstone, gray, clayey, friable; thin beds of light-gray indurated clacareous siltstone	60.0
19. Siltstone, light-brown, sandy; hackly fracture; becomes slabby and weakly cemented near base. Belemnites 10 ft from top. A few thin beds of light-brown ripple-marked fine-grained sandstone	36.0
18. Siltstone, light-green, clayey, thick-bedded, weakly fissile	8.0
17. Sandstone, light-gray to white, fine-grained, calcareous, well-jointed; weathers light gray	13.0
16. Siltstone, light-gray, weakly laminated, calcareous	4.0
Thickness of exposed Redwater Shale Member	136.0

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Sundance Formation—Continued	Thickness (feet)
Lak Member:	
15. Siltstone, red, sandy, weakly fissile, friable	4.0
14. Siltstone, light-gray, sandy, calcareous, friable	3.0
13. Siltstone, light-gray, sandy, calcareous, firmly cemented; interbedded dark-gray claystone	4.0
12. Sandstone, light-gray, very fine grained, silty, thick-bedded, calcareous	6.0
11. Siltstone, red, sandy, calcareous, weakly fissile	53.0
Total thickness of Lak Member	70.0
Hulett Sandstone Member:	
10. Siltstone, light- to dark-gray; a few thin beds of very fine grained light-gray calcareous sandstone	32.0
9. Sandstone, light-brown, very fine grained, thick-bedded, well-jointed; weathers light to dark gray. Thin-bedded fine-grained glauconitic sandstone near top has symmetrical ripple marks	15.0
8. Sandstone, light-brown, fine-grained, thin-bedded; intercalated with dark-gray claystone	6.0
7. Sandstone, light-brown, very fine grained, ripple-marked, blocky	7.0
Total thickness of Hulett Sandstone Member	60.0
Stockade Beaver Shale Member:	
6. Claystone, dark-gray, strongly fissile, weakly calcareous	41.0
5. Sandstone, light-gray, very fine grained, glauconitic, thick-bedded, friable, calcareous	5.0
4. Siltstone, dark-gray; hackly fracture	3.0
3. Claystone, dark-gray, fissile; microfossils abundant	11.0
2. Siltstone, light-yellow-brown, friable; hackly fracture	2.0
1. Limestone, light-gray, microcrystalline, silty, fossiliferous	1.0
Total thickness of Stockade Beaver Shale Member	63.0
Total thickness of Sundance Formation	329.0

Rocks at the lower boundary of the Stockade Beaver Shale Member are described in the measured section of the Gypsum Spring Formation. At many places, the basal foot of the Stockade Beaver is a microcrystalline light-gray fossiliferous limestone. The fossils consist chiefly of fragments of oyster shells and give the appearance of having been deposited in a near-shore environment where they were exposed to turbulent sedimentary conditions. The boundary of the member with the overlying Hulett Sandstone Member is marked by a sharp change in texture coincident with a change in color. The dark-gray fissile shales of the upper Stockade Beaver are overlain by the light-brown sandstone of the Hulett. The lower part of the Hulett is more sandy than the upper part and forms a prominent ledge in many places. Symmetrical and triangular-shaped ripple marks are common in the thin-bedded sandstones of the lower part. The upper part of the Hulett is commonly poorly consolidated and underlies covered slopes. The change from gray thin-bedded siltstone and sandstone of the upper part of the Hulett to beds of red siltstone of the overlying Lak Member is distinctive and can usually be determined with little difficulty. A light-gray interval, 10 to 15 feet thick, near the top of the Lak is found at many places in the southern Black Hills. The Lak-Redwater boundary is largely based on a color change (from red to gray) although there is a noticeable coarsening of the texture of the Lak near the boundary and the Lak seems to be slightly more indurated. The Redwater Shale Member consists chiefly of light-gray calcareous clayey siltstone but contains many beds of claystone and thin-bedded sandstone. The coquinoid limestone (unit 21 of the measured section) is very persistent. It has been recognized by Imlay in the northern Black Hills and has been observed by the writer wherever rocks of this interval are exposed in the Clifton quadrangle and throughout the southern Black Hills. Fragments of it are commonly found as float 90 to 120 feet above the Lak-Redwater boundary. This limestone has been found 40 feet below the conglomeratic channel sandstone of the Lakota formation in Carr Canyon in the southwestern part of the Clifton quadrangle. This thickness of 40 feet for the interval between the limestone and the conglomeratic channel sandstone contrasts with a thickness of 120 feet for the same interval in the section described above, which is 2½ miles northeast of the exposure in Carr Canyon. Much of this thinning takes place in the Redwater Shale Member and coincides with a similar thinning of the Morrison Formation in the southern part of the quadrangle. The top of a fine-grained pseudo-oolitic yellow sandstone has been used as the boundary between the Redwater Shale Member and the overlying Morrison Formation.

MORRISON FORMATION

The type locality of the Morrison Formation is near the town of Morrison, 10 miles southwest of Denver, Colo.. Eldridge (1896) applied the name to a succession of green, drab, or gray fresh-water marls and interbedded sandstones and limestones. In western South Dakota and eastern Wyoming, the Morrison is underlain by the marine Sundance Formation of Late Jurassic age and overlain by the nonmarine Inyan Kara Group, except in the southeastern Black Hills where the Morrison is absent and the Inyan Kara is underlain by the Unkpapa Sandstone of Late Jurassic age. In the Clifton quadrangle the Morrison is a light greenish-gray calcareous claystone which crops out at many places along the Elk Mountains escarpment and in some of the deeper canyons on the dip slope of the Inyan Kara cuesta. It is commonly 60 to 80 feet thick, thins to 20 feet in some of the canyons on the cuesta southeast of Clifton, and pinches out on the escarpment near the southern boundary of the quadrangle. Thick coarse-grained fluviatile sandstones in the overlying Lakota Formation suggests that much of the thinning in the Morrison is the result of erosion by streams which deposited the Lakota sediments.

Measured section of the Morrison Formation near Guerney Spring in the S½ sec. 6, T. 4 S., R. 1 E., Black Hills meridian

	Thickness (feet)
Lakota Formation (in part):	
14. Channel sandstone, conglomeratic	40.0
13. Siltstone, brown to dark-red, clayey, fissile, carbonaceous; interbedded with light-green carbonaceous silty claystone	44.0
Morrison Formation:	
12. Claystone, yellow, calcareous, silty, cohesive; contains thinly disseminated black nodules	2.0
11. Siltstone, light-yellow, clayey, calcareous; platy fracture	7.0
10. Claystone, light- to dark-green, calcareous	7.0
9. Claystone, red, silty, calcareous; hackly fracture; weathers purple	2.0
8. Claystone, light-green to dark-gray, calcareous; hackly fracture; contains charophytes	12.0
7. Marlstone, light-brown, firmly cemented; weathers white; contains veinlets of chert; conchoidal fracture	1.0
6. Claystone, greenish-gray, subvitreous luster, structureless, calcareous	6.0
5. Marlstone, light-brown, firmly cemented; weathers white; conchoidal fracture; contains veinlets of dark-gray chert	1.0
4. Siltstone, light-yellow to gray-green, clayey, calcareous; hackly fracture; ostracodes abundant	4.0
3. Claystone, gray-green, calcareous	6.0
2. Siltstone, light-yellow-brown; hackly fracture; few sand grains; a thin bed (6 in) of dark-red siltstone near top	5.0
Total thickness of Morrison Formation	53.0
Sundance Formation (in part):	
Redwater Shale Member (in part):	
1. Sandstone, light-yellow, fine-grained, well-sorted; weakly cemented with calcite. Upper foot is laminated and firmly cemented with calcite	7.0

As the upper boundary of the Morrison Formation is exposed in only a few places, its position is commonly inferred on the basis of marker beds in the Redwater Shale Member of the Sundance Formation, float, and the bottom of the conglomeratic channel sandstone in the Lakota Formation. For example, float from the coquinoid limestone of the Redwater occurs within 40 feet of the bottom of the conglomeratic channel sandstone in Carr Canyon and float derived from the marlstone (units 5 and 7 in the section just described) of the Morrison is found above the Redwater float but below an outcrop of the conglomeratic channel sandstone. As no outcrops of the basal siltstone of the Lakota were found in Carr Canyon, it is inferred that the conglomeratic channel sandstone has scoured through the siltstone and into the Morrison Formation in this area with a concomitant thinning of the Morrison to 20 feet.

CRETACEOUS SYSTEM

LOWER CRETACEOUS SERIES

INYAN KARA GROUP

The Inyan Kara Group was named by Rubey (1930) for a succession of discontinuous beds of sandstone, sandy shale, conglomerate, lignite, and variegated siltstones exposed along Inyan Kara Creek in the northwestern Black Hills. These rocks are continuously exposed in the periphery of the Black Hills (fig. 60) where thick-bedded sandstones of the group form prominent hogbacks and cuestas. The stratigraphic interval occupied by this group includes the Fall River Formation of Russell (1928) and the Fuson, Minnewaste, and Lakota Formations of Darton (1901). As a consequence of the discovery of uranium in the Inyan Kara Group in 1951, these rocks have been intensively investigated by the U.S. Geological Survey throughout the southern Black Hills and in parts of the northwestern Black Hills. As a result of these investigations, Waagé (1959) proposed that the Fuson and Minnewaste Formations be reduced to members of the Lakota Formation and that the Inyan Kara Group be comprised of two formations: the Fall River Formation and the Lakota Formation.

Detailed mapping of the Inyan Kara Group has made it possible to correlate lithologic units within the group from Hot Springs, S. Dak., to Newcastle, Wyo., in the southern Black Hills. Letter and number symbols assigned to the lithologic units in the Clifton quadrangle are integrated with symbols used in the other 12 quadrangles. All units are not continuous regionally; hence, the letter and number symbols are not always consecutive at any specific locality. The boundary between the Fall River and Lakota Formations is a regional disconformity which can be readily identified at most places. The Lakota is divided without difficulty into the Fuson, Minnewaste and Chilson Members (Post and Bell, 1961) where the Minnewaste Limestone Member is present. Only by careful continuous mapping at a large scale was it possible to locate the bottom of the Fuson where the Minnewaste is discontinuous or absent and to correlate the Fuson with a succession of rocks in the Clifton quadrangle (where the Minnewaste is absent) that differ considerably in texture and composition from the Fuson in the type locality.

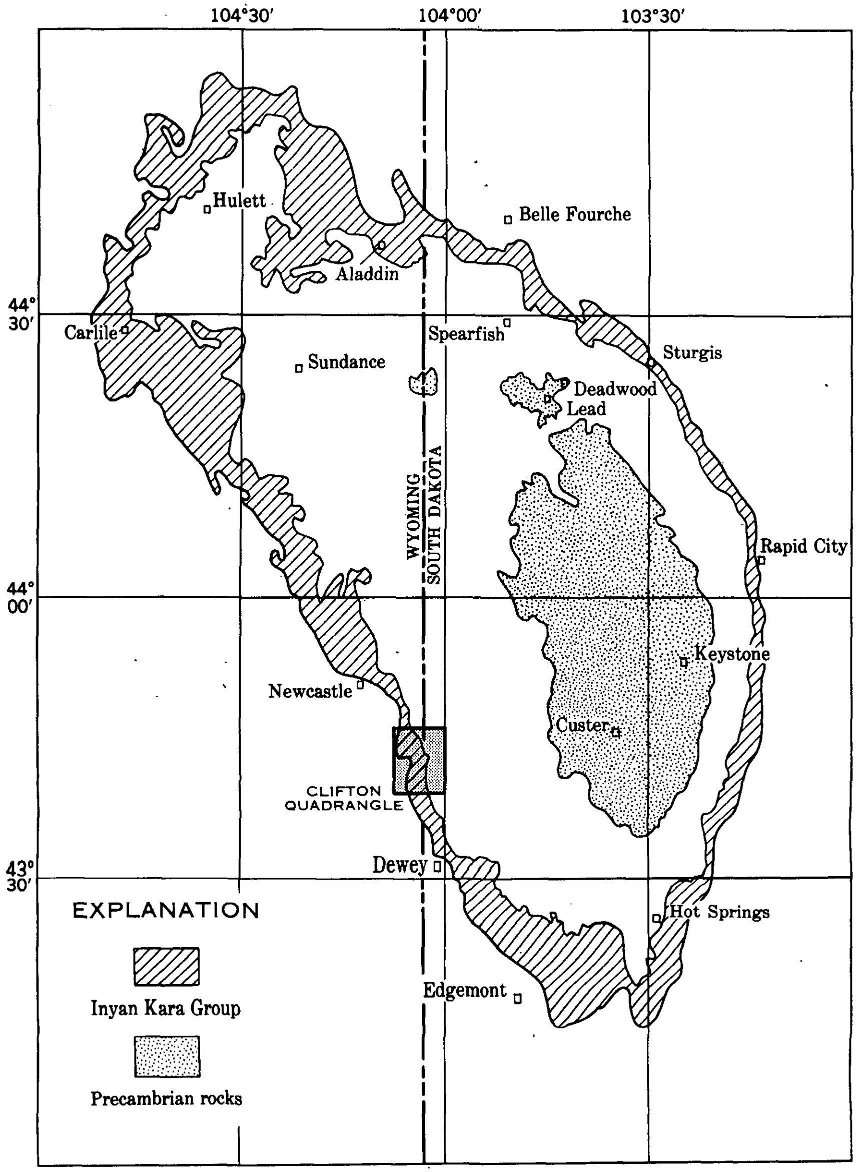

FIGURE 60.—Outcrop patterns of Precambrian rocks and the Inyan Kara Group in the Black Hills of South Dakota and Wyoming. Modified from Darton (1905, pl. 69).

LAKOTA FORMATION

The Lakota Formation consists of a succession of sandstones, siltstones, and claystones which reaches a maximum thickness of 370 feet in the central part of the quadrangle and thins to less than 200 feet in the northern part of the quadrangle. Rocks of the formation underlie the Inyan Kara cuesta and crop out in the canyon of Whoopup Creek. A thick-bedded granule sandstone in the Fuson Member is almost continuously exposed as rimrock on the eastern scarp of the cuesta and underlies much of the dip slope beneath an extensive cover of erosional remnants of siltstone, claystone, and thin sandstones. At most places, the upper and lower contacts of the Lakota Formation are covered by colluvium, talus, or soil. The approximate position of the boundaries can be usually determined by extrapolation from marker beds in the column which commonly form cliffs or steep slopes. For example, the lower boundary is 20 to 60 feet below a distinctive cliff-forming thick-bedded granule sandstone and the upper boundary is 20 to 50 feet below a rim-forming thick-bedded fine-grained sandstone in the middle part of the Fall River Formation.

As shown on the geologic map (pl. 23), the Lakota Formation is divided into the following lithologic units which are listed in order of increasing age.

	Thickness (feet)
Lakota Formation:	
Fuson Member:	
Mudstone, dark-gray; becomes varicolored and clayey in upper part; contains thin beds of light-gray to dark-brown fine- to medium-grained sandstone too small to map	30–200
Sandstone, white, light-yellow, or brown, medium- to coarse-grained, lenticular, thin- to thick-bedded. Occurs as mappable discontinuous beds in the mudstone and overlies the conglomeratic channel sandstone locally	0–60
Channel sandstone, conglomeratic, light-gray to light-brown, fine- to coarse-grained; granules of quartz and siltstone are abundant, poorly sorted, well cemented, thin- to thick-bedded, cross-stratified. Locally, this unit is a pebble conglomerate	1–90
Chilson Member:	
Channel sandstone, light-brown, medium-grained, well-sorted, thick-bedded, moderately cross-stratified	0–60
Siltstone, dark-red, carbonaceous	0–75

The formation is best exposed in the NW¼ sec. 10, T. 42 N., R. 60 W., Wyoming, where the following section was measured at several adjacent exposures in the canyon wall.

	Thickness (feet)
Fall River Formation (in part):	
23. Sandstone, yellow, fine-grained, well-sorted; calcareous nodules common	4.5
22. Siltstone, light- to dark-gray, laminated, carbonaceous	20.0

	Thickness (feet)
Lakota Formation:	
Fuson Member:	
21. Claystone, light-gray, silty; interbedded with strata of of fine-grained light-brown, sandstone, 6 in. to 2 ft thick	15.0
20. Sandstone, light-yellow, fine-grained, well-sorted, calcareous, firmly cemented; becomes poorly sorted and medium-grained near top	9.0
19. Covered	48.0
18. Claystone, silty, white to red to purple; a few medium-sized grains of quartz	13.5
17. Sandstone, light-brown, fine- to medium-grained; poorly sorted, thick-bedded, weakly cross stratified; grains are subrounded; clay particles are abundant; few grains of light-gray chert. Top 5 ft is very fine grained white calcareous thin-bedded sandstone. Unit thickens to 45 ft 150 ft north of the section and pinches out south of the section	25.0
16. Siltstone, dark-brown to dark-red, clayey, carbonaceous	40.5
15. Siltstone, white, sandy, friable	34.0
14. Siltstone, dark-gray to light-brown, clayey, carbonaceous	16.0
13. Sandstone, light-brown, thin- to thick-bedded, weakly cross-stratified; weathers light red	13.5
12. Conglomerate, pebble, light-red-brown, thick-bedded; matrix is fine- to coarse-grained sandstone; well sorted within strata	16.5
11. Sandstone, light-brown, weakly bedded, poorly sorted; many rounded granules of quartz, chert, and siltstone	7.0
10. Sandstone, light-gray, fine-grained, thin-bedded; many beds of light-gray to purple clayey carbonaceous siltstone	16.5
9. Sandstone, light-red-brown, fine-grained, thick-bedded; weathers dark gray	7.0
8. Conglomerate, silt-gall; average intermediate diameter of galls is 1 to 3 in	2.0
7. Sandstone, light-red-brown, medium- to coarse-grained flat bedded; granules of quartz and siltstone	6.0
6. Sandstone, light-brown, medium- to coarse-grained	5.5
5. Sandstone, red-brown, medium-grained; rounded granules of quartz and siltstone abundant in lenses 1 to 3 in. thick; weathers dark brown	6.0
4. Conglomerate, light-brown, firmly cemented; pebbles of quartz and siltstone in a matrix of medium-grained sandstone; scour-and-fill type of cross strata	10.0
3. Sandstone, light-brown, fine- to medium-grained, weakly cemented; angular fragments of light-gray sandstone and claystone are common	2.0
2. Sandstone, light-brown, medium-grained; in beds 2 in. to 5 ft thick and interbedded with strata of pebble conglomerate, 4 in. to 1 ft thick	24.5
Total thickness of Fuson Member (rounded)	317.0
Chilson Member:	
1. Siltstone, dark-red to green, clayey thick-bedded; hackly fracture	18.0

CHILSON MEMBER

The thick-bedded channel sandstone of the Chilson Member is exposed only in the canyon of Whoopup Creek, where it forms cliffs in the canyon walls. The stratigraphic position of this sandstone with respect to the thick-bedded sandstone at the base of the Fuson Member cannot be determined in the Clifton quadrangle because of the separation of exposures of these units. They have markedly different textural and lithologic properties and are distinct facies in the lower part of the Lakota. According to D. A. Brobst (oral communication, December 1957), who mapped these sandstones in the Fanny Peak quadrangle north of the Clifton quadrangle, the sandstone of the Fuson overlies the sandstone of the Chilson Member. This relation is suggested in the Clifton quadrangle by the occurrence of a thin (1 foot) bed of granule sandstone 10 feet above the channel sandstone of the Chilson and by the presence of thinly disseminated granules in the upper part of this sandstone in the canyon of Whoopup Creek. Outcrops of sandstone of the Chilson in the canyon extend 1½ miles southward from the quadrangle boundary, and reach a maximum thickness of 60 feet. Characteristically the sandstone is white to light gray, medium-grained, and well-sorted. Strata composed of deltaic crossbeds, a few inches to a few feet thick, are common. Locally, in the upper 10 to 15 feet, the member is heavily stained with red-brown oxides of iron and contains sparsely distributed granules of siltstone and quartz and the crossbeds increase in thickness.

The best exposures of the siltstone underlying the sandstone are in Clifton Canyon in the SE¼ sec. 32, T. 42 N., R. 60 W., Wyoming, and near Guerney Spring on the Inyan Kara cuesta. In Clifton Canyon, the siltstone ranges from 0 to 11 feet in thickness and overlies a bed of light-green friable calcareous claystone at the top of of the Morrison Formation. Near Guerney Spring, the unit is 75 feet thick and consists of an upper dark-red-brown fissile carbonaceous siltstone and a lower dark-green carbonaceous clayey siltstone. Here, as in Clifton Canyon, the unit is underlain by a light-green calcareous claystone which is considered to be the top of the Morrison Formation. The siltstone is absent in some places, notably in the upper part of Clifton Canyon, in Carr Canyon and on the Elk Mountains escarpment near the southern boundary of the quadrangle.

FUSON MEMBER

Lithologic units of the Fuson Member constitute most of the Lakota Formation on the cuesta where they reach a maximum thickness of 370 feet. The member thins to 30 feet in the canyon of Whoopup

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Creek. The cliff-forming congolmeratic channel sandstone varies considerably in thickness and character but is the most continuous interval in the formation. The best exposure of this sandstone is in the SW¼ sec. 6, T. 5 S., R. 1 E., Black Hills meridian (see fig. 61). In the foregoing measured section, units 2 through 12 constitute the conglomeratic channel sandstone. Size analysis of these lithologic units indicate that the median grain size ranges from 0.15 mm in unit 9 to 1.80 mm in unit 12. Constituent grains within each unit are well sorted, with coefficients of sorting ranging from 1.17 to 3.53 between units. Although the texture of this unit, where measured, can be considered typical for the unit, relative amounts of pebble conglomerate and sandstone range greatly from place to place. There seems to be a positive correlation between the coarseness of the grains and the thickness of the unit. For example, outcrops of the unit in the W½ secs. 16, 21, and 28 are 90 feet thick and have the coarsest texture of any observed in the quadrangle.

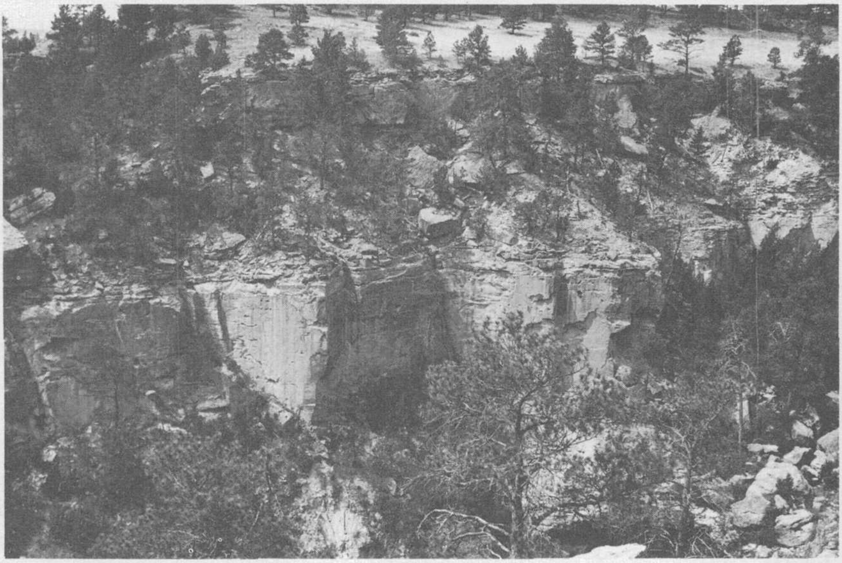

FIGURE 61.—Thick-bedded sandstone in the Fuson Member of the Lakota Formation in the SW¼ sec. 6, T. 5 S., R. 1 E., Black Hills meridian. View is southeast. The upper sequence of claystones and siltstones in the Lakota has been stripped from the top of the sandstone forming the terrace visible at the top of the photograph.

At many places on the dip slope of the Elk mountains, the conglomeratic channel sandstone is overlain by a distinctive sandstone which is shown on the geologic map as an undesignated sandstone. One of the best exposures of the contact between these two sandstones is in the canyon closest to the southwest corner of section

16. The middle reaches of this canyon are narrow, steep walled, and choked with huge talus blocks. Here, the conglomeratic channel sandstone is overlain by a light-brown to light-gray sandstone that is well sorted, fine to medium grained, and very thick bedded. Lithologically this sandstone has strong similarities to the sandstone of the Chilson Member; however, stratigraphic considerations described indicate that it should be included with the undesignated sandstone unit. Granules and pebbled in the conglomeratic channel sandstone range from 2 to 12 mm in diameter and are composed of light- to dark-gray chert and white siltstone. An estimated 40 percent of the volume of the rock consists of granules and pebbles, and sand-size particles constitute the remainder. Bedding features contrast sharply with those of the overlying undesignated sandstone. The undesignated sandstone unit is very thickly bedded and has very poorly defined or no cross-strata, whereas the conglomeratic channel sandstone is a composite of many discontinuous lenses that show well formed deltaic cross-strata. The undesignated unit is more tightly and uniformly cemented than is the conglomeratic sandstone. Many of the lenses of the conglomeratic sandstone are very poorly cemented and are commonly friable where exposed to weathering. Differences in texture, structure, and weathering characteristics produce a sharp boundary between the two sandstones. Polished pebbles of chert, as much as 6 cm in diameter, occur in the conglomeratic sandstone near the boundary with the undesignated sandstone. Locally, pods of coarse sandstone containing pebbles of light-brown to white siltstone and granules of dark-gray chert and rose quartz occur in the undesignated sandstone within 15 feet of the boundary. These pods have a maximum thickness of 15 feet and extend for 75 feet along the canyon wall. Some of the pods have many shallow depressions produced by the weathering of the siltstone pebbles.

Elsewhere, the overlying undesignated sandstone is light gray to white, fine grained, well sorted, thick bedded, and poorly jointed and weathers to rounded forms. This sandstone unit is very lenticular, and its outcrops, which have the shape of an inverted channel, may represent the remnants of a much more extensive sandstone that was severely eroded in Early Cretaceous time. Extensive pavement outcrops of this unit can be seen on the interfluve east of Clifton Canyon in the NW¼ sec. 33, where the unit is 50 to 60 feet thick. Normally, bedding of any kind is poor or absent, but, locally, flat, thin deltaic cross-strata 10 to 15 feet long suggest that this sandstone may be lacustrine. West of Clifton Canyon, this sandstone is light yellow and fine- to medium-grained. It weathers yellow brown in sharp contrast with the underlying conglomeratic channel sandstone, which weathers to light-gray blocky forms. The undesignated sandstone contains thin beds of very friable poorly sorted light-gray silty sandstone which weathers easily and forms covered slopes. A thin bed of silt-pebble conglomerate associated with the thin beds of silty sandstone near the base of the overlying undesignated sandstone is exposed in the canyon wall. This conglomerate contains well-rounded pebbles of light-gray siltstone and light-gray chert in a matrix of medium-grained sandstone. Near Wildcat Peak, the conglomeratic channel sandstone is overlain by nearly 70 feet of light-gray to light-brown fine-grained poorly bedded sandstone containing many laminae of purple sandstone.

The succession of claystones, siltstones, and thin sandstones above the conglomeratic channel sandstone and below the Fall River Formation thins from 200 feet in the southern part of the quadrangle to 30 feet in the canyon of Whoopup Creek (fig. 62). This thinning is probably the result of nondeposition rather than Cretaceous erosion, as suggested by a coincident thinning of a thick-bedded sandstone at the base of the overlying Fall River Formation. Correlation of lithologic units within the upper sequence of the Lakota is difficult because of numerous facies changes and lack of distinctive lithologies; however, two types of sandstone in the upper part of the Lakota can be recognized: a lenticular massive well-sorted fine- to medium-grained sandstone and a thin-bedded medium- to coarse-grained granule sandstone comprising a series of continuous incline-bedded strata. The lenticular type is commonly less than 10 feet thick but reaches a maximum thickness of 45 feet locally. The coarser grained type is 2 to 8 feet thick at most places but thins to 1 foot and thickens to 15 feet locally. Sandstones of each type occur at various positions in the stratigraphic column, and at a few places, notably in the west wall of Carr Canyon, these sandstones bifurcate and rise in the section.

The claystones and siltstones of the upper sequence in the Fuson erode faster than the underlying thick-bedded sandstone, forming gentle slopes and terraces above the sandstone at many localities (fig. 61). The best exposures of the sequence are as follows: In the walls of Whoopup Canyon, one-half mile south of the quadrangle boundary, in the SE¼ sec. 20, T. 43 N., R. 60 W., Wyoming; in Clifton Canyon in the SE¼ sec. 32, T. 42 N., R. 60 W., Wyoming; and in the NW¼ sec. 10, T. 42 N., R. 60 W., Wyoming. The claystones in the upper part of the sequence are commonly silty, poorly bedded, and show varied shades of red, yellow, purple, and gray. Claystones near the Lakota-Fall River boundary contain thinly distributed grains

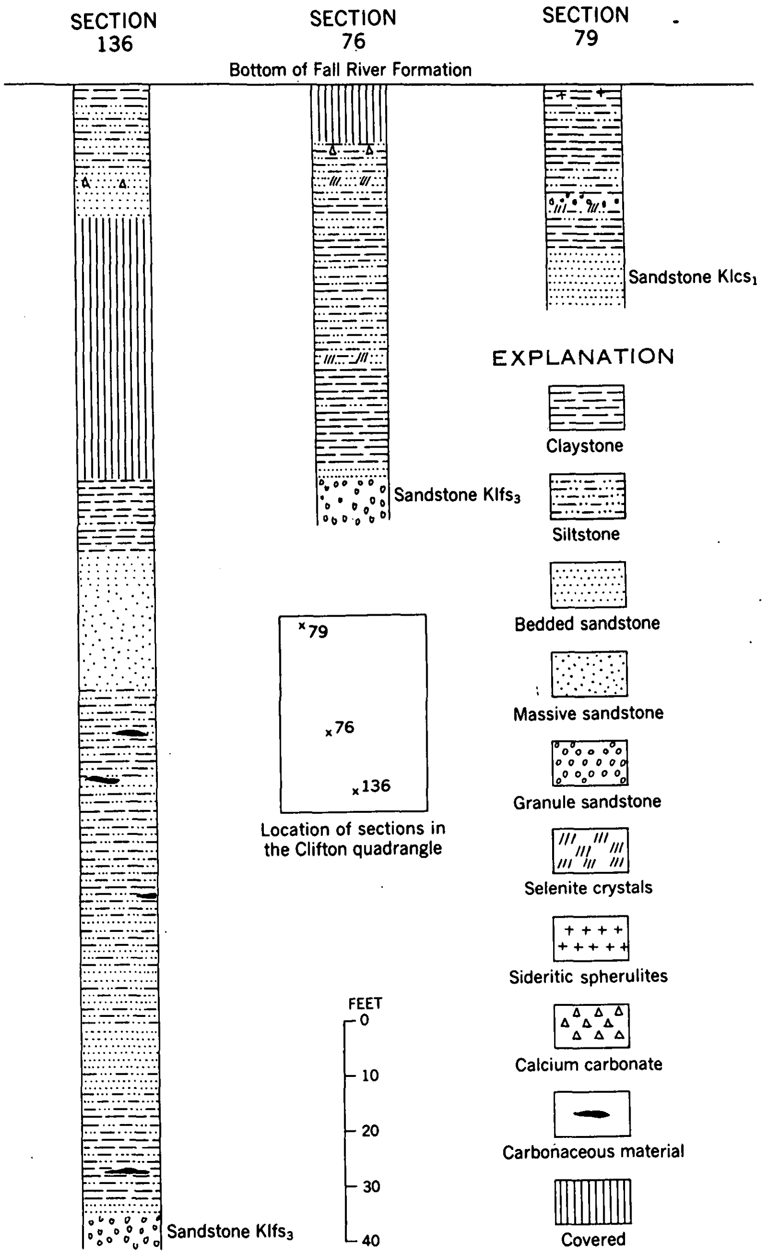

FIGURE 62.—Columnar sections of the upper part of the Lakota Formation.

of medium to coarse sand and yellow-brown spherulites of siderite or limonite derived from siderite. On the interfluve southeast of Carr Canyon, the Fall River Formation is underlain by a claystone, 10 feet thick, which contains concentrations of manganese dioxide along fracture faces and as pods. Gypsum, as fibrous satin spar and as translucent swallow-tailed crystals of selenite is abundant locally in the upper part of the sequence. These crystals are particularly abundant in the SE¼ sec. 20, T. 43 N., R. 60 W.

Near Wildcat Peak the claystones and siltstones are more homogeneous than elsewhere, and the interbedded sandstones are thicker and coarser. At many exposures between Wildcat Peak and Mix Spring, the sequence consists of thick-bedded light-gray to brownish-gray claystone and beds of medium- to coarse-grained crossbedded sandstone. The claystone 2,800 feet southeast of Dugout Spring has similar texture and color through 40 feet of section. The claystone is underlain by at least 10 feet of black carbonaceous material 800 feet north of Mix Spring. Fragments of silicified trees weather from this unit in the S½ sec. 27, T. 43 N., R. 60 W., Wyoming.

FALL RIVER FORMATION

The Fall River Formation consists of a sequence of sandstones and siltstones which crop out chiefly along the west side of the cuesta. Thick-bedded sandstones in the middle part of the formation tend to form cliffs along canyon walls and pavement outcrops on the interfluves. Southeast of Clifton, cliffs of Fall River sandstone face in a downdip direction and are the most westerly exposures of the formation. The upper half of the formation is concealed beneath alluvium. Although the cliffs seem to be the product of stream erosion, the intermittent stream located on the alluvium is much too small to have formed the cliffs. It is possible that the downdip facing cliffs mark the eastern side of a channel formerly occupied by Stockade Beaver Creek which now follows a course parallel with the western margin of the quadrangle and 2½ to 3 miles west of the cliffs.

Exposures of the Fall River Formation are not adequate to permit measurement of a complete stratigraphic section of the formation at any one outcrop. The measured section described below was compiled from descriptions of several outcrops in an area where it is possible to correlate distinctive strata between outcrops.

Section of the Fall River Formation measured in the NE¼ sec. 32 and SE¼ sec. 29, T. 43 N., R. 60 W., Wyoming

	Thickness (feet)
Skull Creek Shale.	
Fall River Formation:	
Upper unit:	
14. Sandstone, light-gray, fine-grained, well-sorted, firmly cemented, flat-bedded, calcareous; weathers grayish orange	1.0
13. Siltstone, dark-gray, clayey, micaceous; contains carbonaceous material and crystals of satin spar	1.0

Fall River Formation—Continued	Thickness (feet)
Upper unit—Continued	
12. Siltstone, yellowish-brown, clayey, carbonaceous; crystals of selenite abundant	5.0
11. Claystone, greenish-gray, silty, carbonaceous, weakly fissile	4.0
10. Siltstone, light-gray, clayey, micaceous; beds of fine-grained light-gray sandstone 2 to 3 in thick	7.0
9. Sandstone, light-gray to light-brown, very fine-grained, well-sorted, ripple-marked, calcareous locally; opaque heavy minerals abundant	6.0
8. Siltstone, light-gray, clayey, micaceous, carbonaceous; thin beds of very fine-grained micaceous friable sandstone	20.0
Middle unit:	
7. Sandstone, yellow to light-gray, fine- to medium-grained, well-sorted, well-cemented, thin- to thick-bedded; where yellow, it has many ferruginous, calcareous, and siliceous nodules	60.0
Lower unit:	
6. Siltstone, dark-gray to black, clayey, laminated, carbonaceous; fracture surfaces are coated with white efflorescent material	2.0
5. Siltstone, light-gray to white, carbonaceous, strongly indurated; contains beds, 1 to 3 in thick, of very fine-grained ripple-marked light-gray sandstone and sheets of black carbonaceous material. Siltstone is commonly laminated	8.0
4. Sandstone, very fine-grained, light-gray to light yellow-brown; cross-stratified; strata are 2 to 5 in thick, symmetrical ripple marks are common	7.0
3. Siltstone, dark-gray, fissile, carbonaceous; laminae of very fine-grained light-gray sandstone. Fracture surfaces are coated with jarosite in many places	9.0
2. Claystone, sandy; light-gray at top changing to red and yellow near base. Veinlets of satin spar are common in upper 5 ft. Manganese is abundant as nodules and as fracture coatings	10.0
1. Siltstone, yellow, clayey; spots of yellow-brown limonite are abundant; contains many laminae of dark-brown carbonaceous material	4.0
Total thickness for Fall River Formation	140.0
Lakota Formation.	

Although many of the strata described in the measured section cannot be correlated regionally, groups of the strata form distinctive lithologic units which can be recognized at most places within the quadrangle. These units appear on the geologic map (pl. 23) and are listed as follows:

Fall River Formation:

Upper unit:

Siltstone, carbonaceous; light- to dark-brown fine-grained thin sandstones in upper part.

Middle unit:

Sandstone, yellow to light-gray, fine- to medium-grained, well-sorted, firmly cemented, thick- to thin-bedded; composed of subrounded grains of quartz. Where yellow, it has many ferruginous, calcareous, and siliceous nodules. Uranium-bearing locally.

Lower unit:

Siltstone, carbonaceous; many thin beds of fine-grained ferruginous sandstone intercalated with laminated light-colored siltstone. Fossils of the crustacean *Estheria* are abundant locally.

LOWER UNIT

The most complete exposures of the succession of claystones, siltstones, and laminated sandstones of the lower unit are in the canyon of Whoopup Creek in the SE¼ sec. 7, T. 43 N., R. 60 W., Wyoming, and southeast of Clifton in the NE¼ sec. 9, T. 42 N., R. 60 W., Wyoming. This interval is characterized by heavy concentrations of dark-brown oxides of iron, coatings of jarosite, and efflorescent material on bedding and joint surfaces, abundant carbonaceous material, and thin laminated sandstones which show symmetrical ripple marks in many places. A black paperlike shale, 6 feet thick, occurs 10 feet below the sandstone of the middle unit in Whoopup Canyon in the SW¼ sec. 31, T. 44 N., R. 60 W., Wyoming. Although most of the strata described in this interval in the measured section are exposed at many places, the strata are not ubiquitous. For example, the middle unit is underlain by 15 feet of light-gray friable, carbonaceous fossiliferous siltstone in the SE¼ sec. 9, T. 42 N., R. 60 W., Wyoming. The crustacean *Estheria* is abundant in the siltstone in this area. The bottom of this unit is the Fall River-Lakota boundary and is marked by a distinctive light-gray carbonaceous silty claystone which contains numerous yellow-brown spots of limonite averaging less than one-eighth of an inch in diameter.

One of the best exposures of the strata near the Fall River-Lakota boundary is on the east wall of Whoopup Canyon in the SW¼ sec. 31, T. 44 N., R. 60 W., Wyoming, where the following section was measured.

	Thickness (feet)
Fall River Formation (in part):	
Middle unit:	
13. Sandstone, light-gray to light-brown, fine-grained, thin-bedded; interbedded with laminated dark-gray to black carbonaceous siltstone and shale	10.0
Lower unit:	
12. Siltstone, light-gray; interlaminated with dark-gray to black shale. Carbonized plant fragments and jarosite are abundant in the black shale	3.0
11. Claystone, brownish-gray, silty, poorly bedded; contains a few grains of medium-grained sand; breaks with a hackly fracture	2.0

	Thickness (feet)
Fall River Formation—Continued	
Lower unit—Continued	
10. Siltstone, yellow, well-cemented; contains many thin laminae of dark-brown carbonaceous material; specks of yellow-brown limonite are abundant	4.0
Lakota Formation (in part):	
Fuson member:	
9. Claystone, red, yellow, and light-gray; specks of limonite are abundant	3.0
8. Siltstone, yellow to light-gray, friable	3.0
7. Claystone, gray-yellow, silty, friable, poorly bedded; becomes green-yellow near base	7.0
6. Siltstone, dark-red, clayey; breaks with a hackly fracture	5.0
5. Claystone, green-gray, poorly bedded	2.0
4. Sandstone, light-gray to dark-brown, well-cemented; contains many granules of chert, silt, and clay	1.0
3. Siltstone, green, dense, well-cemented; crystals of selenite are abundant; upper few inches are composed of yellow-green unctious platy claystone	3.0
2. Claystone, blue-gray to dark-gray, silty; platy fracture	5.0
Chilson Member (in part):	
1. Sandstone, brown, medium-grained; many subrounded granules of siltstone and chert	20.0+

MIDDLE UNIT

The thick-bedded sandstone of the middle unit crops out in a narrow band along the foot of the Elk Mountains and in the canyon of Whoopup Creek. The sandstone forms prominent cliffs in the lower reaches of Clifton, Carr, and Kouba Canyons in the southern part of the quadrangle (fig. 63). The sandstone changes abruptly from a thick-bedded to a thin-bedded unit at five places within the quadrangle. The magnitude and abruptness of these changes suggest that the thick-bedded facies was deposited in channels scoured into basal sediments of the Fall River Formation. The thick-bedded facies may be parts of a continuous meandering channel or they may be erosionally truncated segments of different channels tributary to a larger drainage system. At most places, the thin-bedded facies has no distinctive beds of sandstone in the sequence. In Whoopup Canyon near the northern quadrangle boundary, however, the thin-bedded facies contains two beds of sandstone, 5 to 10 feet thick, which can be traced 7,000 feet eastward from Whoopup Creek. In the outcrop area of these two thin beds, the upper sandstone bed rises in the section to within 30 feet of the Skull Creek-Fall River boundary.

In general, the middle unit is a light-brown to light-gray fine- to medium-grained sandstone that is well sorted, well cemented, and thin to thick bedded. It is composed of subangular grains of quartz. Grains of smoky and rose quartz, muscovite, and opaque heavy

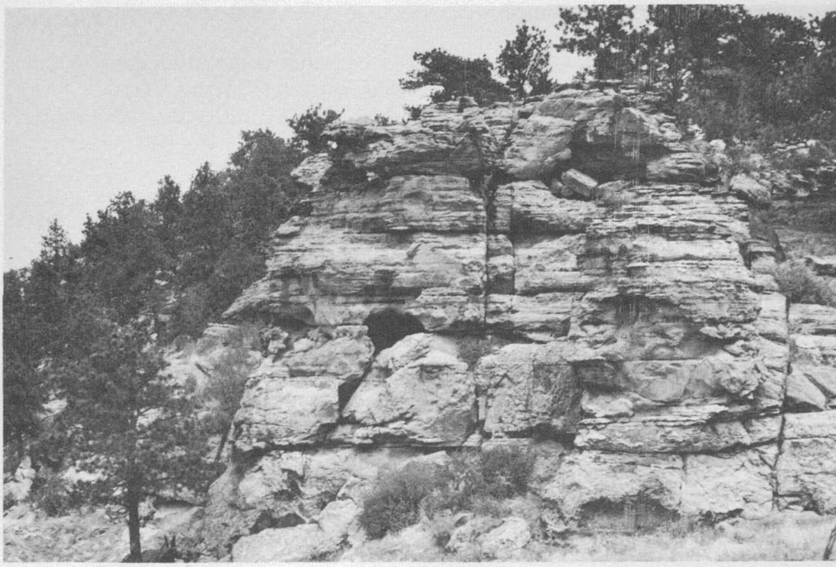

FIGURE 63.—The middle unit of the Fall River Formation at the mouth of Clifton Canyon, Weston County, Wyo.

minerals can be seen at many exposures but are not quantitatively important. Locally, silica, calcium carbonate, iron oxide, jarosite, and manganese dioxide are concentrated in nodules and irregular masses, or along bedding planes and joint surfaces. Calcium carbonate is particularly abundant in outcrops of the sandstone in and near Kouba Canyon. At many places, outcrop surfaces are pitted where galls and pods of silt have weathered and eroded faster than the sandstone. Bedding planes are generally flat, although deltaic-type cross-strata are common and, locally, scour-and-fill type of cross-strata are conspicuous. Symmetrical- and triangular-shaped ripple marks can be seen at many places near the base of the sandstone.

Color changes in the sandstone are abrupt and conspicuous. The most striking of these color changes is east of Clifton where a boundary has been drawn between the two colors. The sandstone is dark sulfur yellow, east of the boundary and light gray, with patches of red and yellow, west of the boundary. The boundary is very well exposed on the west wall of Clifton Canyon where the yellow and gray parts interfinger over a distance of 20 to 30 feet. The yellow sandstone, 1 to 2 feet thick, extends for at least 1,000 feet up Clifton Canyon beyond the boundary and below the gray sandstone. The locus of uranium deposition in the Alray uranium prospect is at this color boundary. A uniform distribution of siliceous cement in the light-gray sandstone contrasts sharply with the irregular distribution of the siliceous and calcareous cement in the yellow sandstone. Nodules cemented with calcium carbonate and silica are common in the yellow sandstone, and, locally, ferruginous nodules are abundant. These dissimilar features of the cement in the yellow and gray sandstone are reflected in the weathering characteristics of the sandstone. The yellow sandstone tends to be friable in the outcrop, forming narrow interfluves and rounded weathering forms (fig. 63) in contrast to the firmly cemented outcrops, broad interfluves, and blocky weathering forms in the area underlain by the light-gray sandstone. The yellow sandstone is much more conspicuously cross-stratified than the gray sandstone which tends to have thicker and flatter strata. Two 500-gram samples of the sandstone, one from each side of the color boundary, were collected for size analyses. Cumulative curves derived from the results of the analyses showed no significant differences in the statistical parameters of the frequency distributions of the two samples.

Another conspicuous color change in the sandstone occurs in the S½ sec. 10, T. 42 N., R. 60 W., Wyoming, where the sandstone is colored bright red in a band 300 to 500 feet wide and 1,500 feet long. The band of red rock trends N. 35° E. and is surrounded by the sulfur-yellow sandstone. The western boundary between the two colors is very sharp and does not seem to be controlled by jointing or texture of the sandstone. The eastern boundary is indefinite. The sandstone is bleached white in an irregular area in the NW¼SE¼ sec. 32, T. 43 N., R. 60 W., Wyoming. Boundaries of the white sandstone are indefinite. Calcium carbonate and silica have been concentrated in nodules and irregular masses in the white sandstone. In this area, the middle unit is friable and weathering has produced rounded forms and many caves and pits in the cliff faces.

Four samples were collected from the sandstone along the west side of Clifton Canyon for size analysis. Statistical data derived from the analyses are as follows:

	Median grain size (mm)	Sorting coefficient
Gray sandstone	0. 275	1. 0
Gray sandstone	. 275	1. 19
Yellow sandstone	. 310	1. 18
White sandstone	. 210	1. 11

If one uses the Wentworth scale as a standard, this sandstone is fine to medium grained with the yellow facies slightly coarser than the gray and the white facies is slightly finer than the gray. Sorting coefficients are used by Trask (1932) to indicate relative sorting of sediments as follows: Well sorted, less than 2.5; normal sorting, 3; poorly sorted, more than 4.5. The excellent sorting of the sand in this rock supports the contention that the sedimentary environment of the Fall River Formation was marginal marine (Waage, 1959, p. 63). Although the sorting coefficients of marginal-marine sandstones range from 1.0 to 2.0 (Hough, 1940, p. 26), other environments will produce equally well sorted sediments. A 1,300-gram sample of gypsum sand collected by the author from the lee slope of a barchan dune at White Sands, N. Mex., has a sorting coefficient of 1.21.

UPPER UNIT

The upper unit of the Fall River Formation is well exposed in erosion gullies of the interfluve between the canyon of Whoopup Creek and Rock Canyon. The boundary of this unit with the overlying Skull Creek Shale is clearly marked by bed 14 of the measured section. The calcareous sandstone of bed 14 is overlain by a light-gray carbonaceous siltstone at some exposures, but the sandstone is rarely more than 5 feet from the Fall River-Skull Creek boundary. Although the maximum thickness of this sandstone is 4 feet, it is commonly 6 inches to 1 foot thick and is one of the most persistent beds in the quadrangle. Talus and float produced by the weathering of the sandstone are easily recognized because of the grayish-orange platy pebbles and boulders which litter the ground surface in areas where the bed is covered by colluvium or soil. Satin spar and clear crystals of selenite are abundant in the dark-brown to dark-gray siltstones which underlie this sandstone. The gypsiferous siltstone extends downward to a massive greenish-gray claystone that is 4 to 12 feet thick and that changes color locally to a dark red. The unit becomes coarser below the claystone and contains many thin beds of light-gray to light-brown fine-grained sandstone and a siltstone conglomerate interbedded with the siltstone. The conglomerate seems to be a lens which crops out only in the W½ sec. 29, T. 43 N., R. 60 W. The pebbles consist of poorly sorted well-rounded fragments of sandstone and siltstone in a matrix of poorly sorted sandstone which is strongly cemented with dark-brown limonite. The pebbles have an average intermediate diameter of 2 inches and constitute 50 percent of the volume of the rock. The conglomerate has a maximum thickness of 5 feet and is 15 to 20 feet below the top of the formation. The unusual concentration of limonite in this lens may be due to the oxidization of placer minerals.

SEDIMENTARY ENVIRONMENT OF THE INYAN KARA GROUP

The lithologic associations of rocks in the Inyan Kara Group are similar to those described by Krumbein and Sloss (1951, p. 358) as being characteristic of sediments deposited in a stable shelf environment of a continental platform. The platform on which the Inyan Kara sediments were deposited was probably a westward extension of the Sioux uplift of eastern South Dakota and the shelf was marginal to the inland sea which invaded the area at the close of Inyan Kara time. The Sioux uplift may also have been a major source of the Inyan Kara sediments, as indicated by subsurface correlations made by Gries (1954, p. 447) of Lower Cretaceous rocks between the Black Hills and eastern South Dakota. According to Gries, the bottom of the Inyan Kara Group correlates with the bottom of the Dakota Sandstone of eastern South Dakota and Nebraska, but the upper part of the Dakota interfingers with marine shales of the Skull Creek, Mowry, and Belle Fourche Formations of the Black Hills. G. B. Gott believes (oral communication, 1957) that fluvial sediments which formed Inyan Kara rocks in the southern Black Hills were deposited by streams flowing from a southeasterly direction. In the Clifton quadrangle stream direction, as determined from cross-stratification of the fluvial sandstones, varies with geographic and stratigraphic position. Northeastward-flowing streams deposited the thick-bedded conglomeratic channel sandstone of the lower part of the Fuson Member, the thin-bedded sandstones of the upper part of the Fuson in the southern part of the quadrangle, and the channel sandstone of the Fall River. Northwestward-flowing streams deposited the thick-bedded undesignated sandstone which overlies the conglomeratic sandstone of the lower part of the Fuson in the south-central part of the quadrangle and the thin-bedded sandstones of the upper part of the Fuson in the north-central part of the quadrangle.

The large-scale heterogeneity of the texture of the Inyan Kara rocks, the intertonguing lenses of cross-stratified sandstones showing cut-and-fill structures, and the paucity of fossils indicate that sediments which formed these rocks were deposited in a fluvial environment. Early Lakota streams which deposited thick beds of sand in this area lost much of their energy by late Lakota time, when carbonaceous silts accumulated in widespread swamps and quiet-water sedimentation in many small lakes produced a succession of red to green variegated clays and sheets of fine-grained poorly bedded sand which is calcareous in the southern part of the quadrangle. Deposition in all environments was at a minimum at the end of Lakota time, as indicated by the unconformity between the Lakota and Fall River Formations, after which time laminated sands and carbonaceous silts accumulated in extensive shallow lakes in a dominantly paludal environment. This period of deposition ended in middle Fall

River time when renewed stream activity cut channels in the fine-grained swamp and lake deposits and buried them beneath a discontinuous sheet of thin- to thick-bedded sand. Carbonaceous silt and thin sheets of fine-grained ripple-marked sand which were deposited after the thick-bedded sands suggest a marginal marine environment that preceded invasion of the area by the sea in which the black shales of the overlying Skull Creek Shale were deposited.

SKULL CREEK SHALE

The Skull Creek Shale generally is a black fissile incompetent rock with a low resistance to weathering. It underlies grass-covered flats and low-level deposits of Tertiary gravel in the southwestern part of the quadrangle. Outcrops of the formation are poor in this area, and are found only in small gullies where erosion has been locally accelerated by human activities. In the west-central part of the quadrangle, however, many good exposures of the shale have been preserved by differential erosion of the Whoopup Canyon anticline and the Rock Canyon syncline and by a cap of Newcastle Sandstone. The overlying Newcastle Sandstone in the west-central part of the quadrangle pinches out in sec. 20, T. 43 N., R. 60 W., Wyoming. South of where the Newcastle pinches out, the Skull Creek is overlain by the Mowry Shale. The boundary between the Skull Creek and Newcastle is abrupt but irregular. Talus blocks of the Newcastle commonly conceal the contact between the two formations. At several localities, slump blocks several hundred feet long have slid along surfaces lubricated by the shales of the Skull Creek. Where the Newcastle is absent, the boundary between the Skull Creek and the Mowry is not exposed; however, there are good exposures of the lower part of the Mowry and upper part of the Skull Creek in the Dewey quadrangle to the south. In the Dewey quadrangle, Brobst (1960) has mapped a continuous sandstone zone, 3 to 5 feet thick, about 50 feet above the Skull Creek-Mowry contact. This zone of sandstone is exposed at many places in the Clifton quadrangle and has been used extensively to locate the boundary between the two formations. The Skull Creek Shale is 200 feet thick in Rock Canyon where the formation underlies the Newcastle Sandstone, and its upper and lower boundaries can be accurately determined. The shale thickens southward and reaches a thickness of at least 250 feet in the southwestern part of the quadrangle where the Newcastle Sandstone is absent and the Skull Creek Shale underlies the Mowry. Thinning of the Skull Creek Shale beneath the Newcastle Sandstone may be the result of partial erosion of the shale by streams which deposited the sandstone.

The upper half of the Skull Creek appears to be less well cemented and less uniform in composition than the lower half. Secondary minerals are much more abundant in the upper half and tend to be concentrated in zones parallel to the bedding. These secondary minerals include well-formed crystals of selenite, concretions and cone-in-cone structures of siderite, limonite concretions, a septarian calcite, coatings of jarosite on fracture and bedding planes, and crystalline marcasite and pyrite. Most of the zones containing these secondary minerals are discontinuous laterally; however, several are nearly continuous throughout the area mapped. One of the most persistent of these zones is a ferruginous interval, 10 to 15 feet below the Newcastle-Skull Creek boundary. Within this zone, yellow-brown to black oxides (and possibly carbonates) of iron are concentrated as concretions and as cement in the shale. Several feet below this ferruginous zone is another persistent zone containing siderite in the form of cone-in-cone structures. At many places, these cone-in-cone structures occur as coalesced masses having a shape approximating a triaxial ellipsoid with axes averaging 2.0, 1.5, and 1.0 feet.

NEWCASTLE SANDSTONE

At its type locality on U.S. route 85, one-half mile east of the post Office at Newcastle, Wyo., the Newcastle Sandstone comprises 94 feet of discontinous beds of ripple-marked and crossbedded sandstone, sandy shale, and carbonaceous shale and impure lignite. The lenticular habit of this sandstone and the impermeable shales above and below it have produced many stratigraphic traps favorable for the accumulation and preservation of petroleum, which accounts for this sandstone being the chief oil-bearing formation in northeastern Wyoming. In the Clifton quadrangle, it reaches a maximum thickness of 83 feet in the west-central part of the quadrangle and pinches out southward in sec. 20, T. 43 N., R. 60 W., Wyoming. Small lenses of sandstone, less than 50 feet long and 2 feet thick, in the southwestern part of the quadrangle may be genetically related to the Newcastle, but positive correlation cannot be made because of the uncertainty of their stratigraphic position. Where best exposed in the Rock Canyon syncline and on the south and west flanks of the Whoopup anticline, the Newcastle is in sharp contact with the overlying Mowry Shale and the underlying Skull Creek Shale.

The chief characteristics of the Newcastle are its lenticularity, its carbonaceous material, and its cross-stratification. In addition to being discontinuous regionally, it pinches and swells locally, ranging in thickness from 5 to 40 feet within a distance of 150 feet laterally. Carbonaceous material in the form of discrete charcoallike fragments and as comminuted material in shale partings is common throughout the sandstone but is particularly abundant in the lower half. Many of the charcoallike fragments are oriented parallel to the bedding planes of the sandstone. The upper and lower parts of the sandstone tend to be flat lying and thick bedded and contrast sharply with the sets having high-angle planar cross-stratification in the middle part of the sandstone. Sets of cross-bedded strata are commonly wedge-shaped and sharply truncated by the flat-lying strata.

The Newcastle is a well-sorted fine- to medium-grained sandstone, as shown by the results of size analyses made of four samples collected from an outcrop of the formation 78 feet thick in the SW¼ sec. 17, T. 43 N., R. 60 W., Wyoming. The median grain size and sorting coefficients of the four samples are listed as follows:

Sample	Median (millimeters)	Sorting coefficient
66FC-1	0.18	1.15
2	.20	1.15
3	.15	1.26
4	.11	1.56

MOWRY SHALE

The Mowry Shale consists of dark-gray to black shale that is silty, hard, siliceous, and fossiliferous and that contains many thin beds of siltstone, laminated sandstone, and bentonite. It can be readily distinguished from the overlying Belle Fourche Shale and the underlying Skull Creek Shale by its light-silvery-gray color when weathered. At many places it forms a low, discontinuous ridge. The formation is estimated to be 130 feet thick, on the basis of many partial sections measured in the southwestern part of the Clifton quadrangle and the northwestern part of the Dewey quadrangle. The Mowry-Belle Fourche contact is at the top of the first conspicuous bed of bentonite below a zone of heavy concentrations of iron oxides near the base of the Belle Fourche Shale. Where exposed, the bentonite weathers to a distinctive popcornlike clay bloom. At most places the contact is covered by colluvium and soil; however, the zone of iron oxides is extensively exposed, permitting accurate extrapolation of the position of the boundary.

UPPER CRETACEOUS SERIES

Rocks of the Upper Cretaceous Series are found only in the western part of the quadrangle and, in order of decreasing age, include: Belle Fourche Shale, Greenhorn Formation, and Carlile Shale.

These formations are described by Cobban and Reeside (1952, chart 10b) as part of the standard reference sequence for the western interior. The Niobrara Formation probably underlies alluvium in the southwestern part of the quadrangle but is not exposed. The boundary between the Lower and Upper Cretaceous Series is at the top of the Mowry Shale. This age determination is based largely on the recognition of the ammonite genera *Gastroplites* and *Neogastroplites* in the Mowry Shale by Cobban and Reeside (1951).

BELLE FOURCHE SHALE

The Belle Fourche Shale is a black soft fissile shale approximately 417 feet thick and underlies grass-covered slopes on the Fanny Peak monocline in the southwestern part of the quadrangle. The upper and lower parts of the formation are exposed at many places, but more than 200 feet of the middle part of the formation is covered at most places within the quadrangle. In general, the upper part is composed of black soft, fissile shale that contains many thin beds of bentonite; concretions of limestone, concentrations of iron oxide, and bentonitic shale tend to occur in zones, 1 to 5 feet thick. Ammonoids are distributed throughout the formation and seem to be slightly larger in the lower part. Yellow-brown to black oxides and carbonates of iron are common in the shale of the lower 40 feet of the formation (fig. 64). Septaria of siderite are particularly abundant in two horizontal zones 5 to 10 feet thick in this stratigraphic interval. The upper zone is 35 feet above the base of the Belle Fourche and the lower zone is 10 feet above the base. These zones are conspicuous and continuous and therefore make excellent marker beds. Many of the concretions have a triaxial ellipsoid shape, whose axes reach a maximum length of 10 by 3 by 2 feet. Some are septarian and the fractures are filled with calcite.

GREENHORN FORMATION

The Greenhorn Formation consists of an upper unit of interbedded limestone and shale and a lower unit of brown to black soft fissile shale. Beds of limestone in the upper unit form a low hogback along the Fanny Peak monocline in the southwestern part of the quadrangle. This hogback is paired with another parallel hogback formed by steeply dipping beds of sandstone in the middle part of the overlying Carlile Shale. These twin hogbacks are less than 700 feet apart and are conspicuous land forms in this part of the quadrangle. The upper unit of the Greenhorn is well exposed along the hogback, but the lower part is generally concealed beneath grass-covered flats east of the hogback.

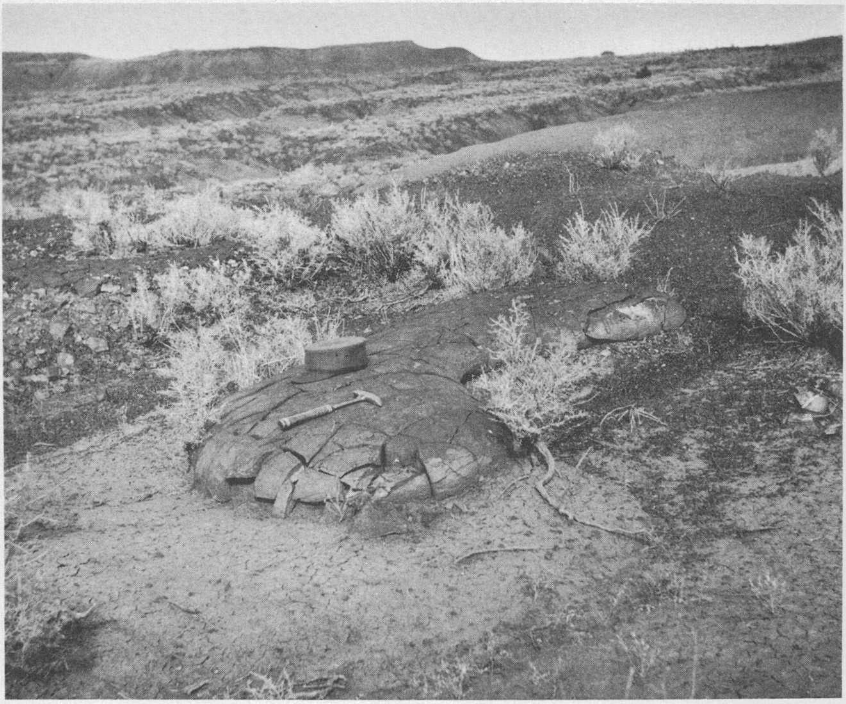

FIGURE 64.—Siderite concretion in the Belle Fourche Shale in the SW¼ sec. 19, T. 43 N., R. 60 W., Wyoming. Dark-colored soil near the concretion is a layer of shale fragments cemented with siderite and oxides of iron.

The Greenhorn Formation was named by G. K. Gilbert (1896) for a succession of limestone beds, 3 to 12 inches thick, separated by somewhat thicker beds of shale at Greenhorn Station, 14 miles south of Pueblo, Colo. At the type locality, the formation is 25 to 40 feet thick and lies above the Graneros Shale and below the Carlile Shale. The formation is much thicker in the Black Hills where, according to Cobban (1951, p. 2183): "The Greenhorn Formation attains its maximum known thickness of 360 feet on the east flank of the Colony-Albion anticline in the E½ sec. 9, T. 57 N., R. 61 W., Crook County, Wyoming." Cobban (oral communication, 1957) also measured a section of the Greenhorn a few miles northwest of the Clifton quadrangle near Newcastle, Wyo., in the NW¼ sec. 31, T. 45 N., R. 61 W., where the Greenhorn was found to be 295 feet thick.

In the Clifton quadrangle, the formation is about 260 feet thick. The upper unit consists of 70 feet of thin beds of calcareous sandstone and siltstone, fossiliferous limestone, and blue-black silty, calcareous shale. The brown soft fissile shales of the lower unit contrast sharply with the color and texture of the upper unit near the boundary between the two units. For 110 feet below the boundary, the shale becomes progressively less calcareous, but secondary calcite increases in abundance in the form of fracture fillings and concretions, some of which are septarian. The brown shale is underlain by 80 feet of black, bentonitic shale in which the bentonite occurs as thin ferruginous discontinuous partings less than 6 inches thick. The bottom of the bentonitic shale is also the bottom of the Greenhorn Formation and is marked by a bed of fossiliferous limestone 2 to 3 feet thick, containing abundant fragments of the pelecypod *Inoceramus* and shark teeth as long as 1.5 inches. No bedded limestone or *Inoceramus* fossils were found below this limestone.

CARLILE SHALE

In northeastern Wyoming, the Carlile Shale is 225 to 325 feet thick and consists of gray mudstone and shale; an interval of thin-bedded sandstone and sandy shales in the upper part constitutes the Turner Sandy Member. In the Clifton quadrangle, approximately 220 feet of the lower part of the formation is exposed in and near a low hogback on the Fanny Peak monocline southwest of Clifton. The boundary between the Carlile and the underlying Greenhorn Formation is in a strike valley separating two low twin hogbacks; the upper boundary is covered with alluvium deposited by Stockade Beaver Creek which flows parallel to and less than 1 mile west of the quadrangle boundary.

The lower 90 feet of the Carlile is a friable blue-black to black bentonitic shale, which underlies the strike valley. The blue-black shale tends to be more calcareous, less bentonitic, and more weakly fissile than the black shale. Lenticular beds of bentonite and fossiliferous concretions of calcium carbonate are abundant in the upper 10 feet of this interval. Fossils in the concretions are chiefly ammonites. The succession of rocks above the zone of fossiliferous concretions is lithologically similar to the Turner Sandy Member as described by Rubey (1930, p. 3–5). In the Clifton quadrangle, this succession consists of a lower sandy shale unit and an upper interval of thin-bedded sandstone. The lower unit consists of gray strongly indurated fissile seleniferous shale that is 45 feet thick and that contains many thin partings of laminated sandstone and siltstone. The thin-bedded fine-grained slabby sandstone that overlies the sandy shale is 32 feet thick, caps the hogback, and becomes calcareous and medium-grained near the base. The formation is poorly exposed above the sandstone but seems to be dark noncalcareous shale with a few thin beds of lenticular sandstone and fossiliferous limestone 45 to 55 feet above the sandstone.

TERTIARY(?) SYSTEM

HIGH-LEVEL GRAVELS

Deposits of high-level unconsolidated cobble gravel occur in the valley of Whoopup Creek, in Gillette Canyon, at the foot of the Black Hills monocline, and on the interfluve south of Gillette Canyon. In fresh artificial exposures, the matrix constitutes an estimated 60 percent of the deposit; however, in most natural exposures, the fines are selectively removed by erosion and form a cover of lag gravel 12 inches thick. Calcium carbonate forms calichelike encrustations on many of the cobbles and, in some places, cements the matrix. In fresh exposures, cobbles more than 3 feet below ground level do not have a carbonate coating, suggesting that the carbonate is being deposited in the present erosion cycle. The matrix is gray to brown poorly sorted silty subangular quartz sand with many grains of light-gray clay and rounded fragments of sandstone. An estimated 70 percent of the well-rounded cobbles have diameters ranging from 1 to 3 inches, although boulders 1 foot or more in diameter are not uncommon. The estimated frequency distribution of the cobbles by composition is as follows: Limestone, 50 percent; medium-grained sandstone, 30 percent; chert, silicified granule sandstone, and silicified siltstone, 20 percent. Much of the limestone is a pink to light-gray dense variety very similar in appearance to the Pahasapa Limestone of Mississippian age which crops out several miles east of the quadrangle and to the Minnekahta Limestone of Permian age. A few cobbles of dark-gray to black limestone occur in the gravel locally. A mollusk resembling Pecten was found in a cobble of the light-gray limestone in the SE¼ sec. 5, T. 42 N., R. 60 W., Wyoming. The cobbles of sandstone may be fragments of sandstone from the Inyan Kara Group but could be from sandstones of the Minnelusa or older formations. There are no cobbles of igneous or metamorphic rocks in the gravels.

The gravels range in altitude from 3,950 feet above sea level in the valley of Whoopup Creek to 4,460 feet on the divide west of Whoopup Creek in the SW¼ sec. 31, T. 44 N., R. 60 W., Wyoming High-level gravels in this area are as much as 250 feet above creek level. Geomorphically, the gravels occur as a capping on interfluves and as discontinuous terraces in the canyon of Whoopup Creek and along the Black Hills monocline, northeast of Clifton (fig. 65), where five distinct levels have been correlated. The terraces near the monocline range in altitude from 3,955 to 4,200 feet above sea level; the altitude decreases southward at a rate of 50 feet per mile.

The age of these high-level gravels has not been determined. The gravel on the interfluve west of the canyon of Whoopup Creek and

FIGURE 65.—Aerial photograph of terraces capped with Tertiary(?) gravel in the NW¼ sec. 5, T. 42 N., R. 60 W., Wyoming. View is southeast toward the Inyan Kara cuesta. The top of the grass-covered terraces in the middle background slopes southward at a rate of 50 feet per mile.

the gravel forming the terraces northeast of Clifton were deposited before the canyon of Whoopup Creek was cut. The terraces were probably formed at a time when the Greenhorn Formation and the Turner Sandy Member of the Carlile Shale formed a prominent hogback west of the present course of the Chicago, Burlington and Quincy Railroad, and are considered to be of Tertiary(?) age. This hogback could have provided the western wall of a valley cut by a stream capable of depositing the gravel of the terraces. Terrace gravels deposited along the former hogback were redistributed as terrace No. 2 when the hogback was subsequently reduced to its present size by rapid erosion of the relatively incompetent Greenhorn and Carlile Formations.

QUATERNARY SYSTEM

Quaternary deposits in the Clifton quadrangle consist of the fine- to coarse-grained sediments in the flood plains of the intermittent streams and landslide debris on the dip slope of the Black Hills monocline. Streams of the present drainage system lack the capacity to form flood plains of the size of those in the quadrangle or to undercut a valley wall sufficiently to cause a landslide of the magnitude of the one shown on the dip slope of the Black Hills monocline south of Ferguson canyon. For these reasons, it is probable that most of the Quaternary deposits were formed by vigorous streams under the more humid conditions which may have prevailed in this area during the Pleistocene Epoch.

STRUCTURAL GEOLOGY

Parts of four regional structural elements of the Black Hills are included within the quadrangle as follows: The Fanny Peak monocline, the Dewey terrace, the Black Hills monocline, and a structural terrace which forms the Limestone Plateau of the western Black Hills. The terrace of the plateau is represented in the quadrangle by the Red Valley which forms the western boundary of the terrace at many places. All these structures are shown on the simplified diagram of figure 58 and by structure contours in plate 23.

BLACK HILLS MONOCLINE

The northwest-trending Black Hills monocline is a major structural feature of the western Black Hills and in some places forms the boundary between the Black Hills and the Powder River Basin. South of the quadrangle, the monoclinal dip decreases and merges with the regional dip of the southern periphery of the Black Hills. North of the quadrangle, the monocline is expressed by steeply dipping rocks which have been eroded to form conspicuous hogbacks. One mile north of the quadrangle in Ferguson Canyon, gypsum of the Spearfish and Gypsum Spring Formations crops out as flatirons dipping 70° W. Within the quadrangle, the axis of the upper break in slope trends southward at a reasonably constant altitude between the northern quadrangle boundary and Wildcat Peak. Between Wildcat Peak and the southern quadrangle boundary, the axis, shown by the broken line in figure 58, plunges 600 feet. The dip slope of the monocline is interrupted at many places by small subsidiary monoclines which merge imperceptibly with the regional dip along the strike and successively increase in altitude northward. Dips along the western edge of the Black Hills monocline are much steeper than those farther eastward and thereby form a gently sloping upland, or cuesta, which composes the Elk Mountains.

The north-trending cuesta extends across the central part of the quadrangle and is the most conspicuous land form in the area. The Elk Mountains escarpment, a prominent cliff 400 to 600 feet high, bounds the cuesta on the east. The cuesta ends abruptly in the northern part of the quadrangle where the escarpment has been eroded back to Ferguson Canyon. The cuesta is underlain by a thick-bedded granule sandstone of the Fuson Member of the Lakota Formation which has a regional slope of about 10° WSW. Erosional remnants of siltstone, mudstone, and thin sandstones of the upper part of the Fuson conceal the sandstone at many places on the dip slope. The relatively incompetent beds of the Morrison and Sundance Formations which underlie the Fuson are truncated in the escarpment along the eastern edge of the cuesta.

A sinuous zone characterized by many small faults, sharp deflections of the regional strike, anomalous directions of canyon cutting, and opened joints extends eastward for nearly 6 miles from the SW¼ sec. 32, T. 43 N., R. 60 W., Wyoming, to the eastern quadrangle boundary in the S½ sec. 16, T. 4 S., R. 1 E., Black Hills meridian.

Many of the small faults in this disturbed zone on the cuesta are subtle and were detected only after a field check for inconsistencies found in the process of map compilation. Detection of a fault is made difficult by sedimentary structures and abrupt facies changes in the Fuson Member, by rapid obliteration by weathering of evidence of faulting such as brecciation, slickensides, fault planes, and displaced stratigraphy, and by subsidiary slumping and sliding of the units involved down the regional dip or down canyon walls. Fragments of sandstone showing slickensides are abundant in some places near these faults. Field evidence for faulting is clear near Mix Spring in the NE¼ sec. 28, T. 43 N., R. 60 W., Wyoming, where the top of the Morrison Formation is displaced at least 40 feet upward in an arcuate horst. The only fault plane clearly exposed in the quadrangle is in the SW¼ sec. 21, T. 43 N., R. 60 W., Wyoming. The nearly vertical fault plane trends N. 25° E. and is exposed for 50 feet along the strike. The highly polished surface is coated with hematite and contains hortizontal mullion structures and scratches, suggesting horizontal movement along the fault. A spring flows from a talus-choked gully on the trace of the fault. Topographic alinement, displaced rocks, slickensided talus, and veinlets of secondary silica in the sandstone indicate that this fault extends for at least 2,400 feet in a sinuous southeastward direction and possibly makes a tenuous connection with the disturbed zone near the center of sec. 28, T. 43 N., R. 60 W., Wyoming. The fault trace seems to be an extension of the axis of one of the small monoclines previously described. A joint parallel to and 600 feet east of the fault has opened 6 to 8 feet and has formed a steep-walled trench which is partly filled with boulders of sandstone. This fault and open joint are clear evidence that movement of the rocks on the cuesta has been, in part, very recent.

The configuration of the structure contours, the arcuate pattern of the fault zones, the monoclinal axes, and the opened joints on the cuesta may be the surficial manifestations of the subsidence of the sedimentary rocks around a structural high in the basement rocks. This interpretation is supported by a close correlation of structural highs, as shown by the structure contours, with columnar-shaped highs in the basement rocks, as determined by gravity measurements taken in the area by Rudolph Black of the Geological Survey.

The most prominent set of joints in the rocks of the cuesta are nearly vertical and trend N. 40° to 50° E. Joint blocks are well defined with smooth faces (fig. 61). Locally, particularly near monoclinal axes, the walls of joints have formed open fissures. Joints in this set are longer, straighter, and more widely distributed than in any other set. Another distinct but relatively minor set of high-angle joints strike N. 50° to 60° W. Joints in this set tend to be short, irregular, and poorly defined. The attitude of joints in the rocks of the cuesta are not affected by changes in the regional strike or dip, nor does the character or abundance of joints differ materially between formations, except for a slight increase in the abundance of joints in the northwest-trending set in the Fall River Formation.

DEWEY TERRACE

The Dewey terrace is bounded by the Black Hills monocline on the east and by the Fanny Peak monocline on the west; it ranges in width from 1 to 3 miles because of the sinuosity of the monoclinal axes. Regional dip on the terrace is varied but averages about 6° W. in the southern part of the quadrangle. Marine shales which underlie the terrace in the southern part of the quadrangle are truncated by erosion in the northern part of the quadrangle where nonmarine rocks of the Inyan Kara Group are exposed in two local structures: the Whoopup anticline and the Rock Canyon syncline. Both these structures are about 4 miles long and 1¼ miles wide, have a structural relief of 115 feet, and plunge southward at the rate of 300 feet per mile. The east limb of the anticline forms the west limb of the syncline and is steeper than the west limb of the anticline or the east limb of the syncline. The canyon of Whoopup Creek is a short distance east of the anticlinal axis, and the synclinal axis is parallel to and a short distance west of Rock Canyon. An erosional remnant in the form of a mesa is composed of Skull Creek Shale and capped by Newcastle Sandstone in the synclinal valley.

A normal fault in the Newcastle Sandstone on the west limb of the anticline (in the E½ sec. 13, T. 43 N., R. 60 W., Wyoming) has a displacement of 30 to 40 feet, and a similar but smaller normal fault near the axis of the syncline at the head of Rock Canyon (SW¼ sec. 5, T. 43 N., R. 60 W., Wyoming) has displaced the upper part of the Fall River Formation through a vertical distance of about 10 feet. Both of these faults are parallel to the structural axes and have the upthrown side on the west. Faults in the marine shales on the Dewey terrace south of the Whoopup anticline are probably more extensive than shown on the geologic map (fig. 23), but were not detected because of the scarcity of outcrops of these rocks. Marine shales in much of this area underlie flat grass-covered prairie or Tertiary(?) gravel deposits. A series of normal faults in the shales southwest of Clifton is probably related to the disturbed zone which crosses the cuesta and was described earlier in this section of the report. A northeastward projection of the fault in the SE¼ sec. 7, T. 42 N., R. 60 W., Wyoming, would coincide with the color boundary in the channel sandstone of the Fall River Formation southeast of Clifton and would pass close to the Alray uranium prospect. A northeastward projection of the fault zone in the NE¼ of the same section would bring the fault zone into an area of sharp change in regional strike in the SE¼ sec. 32, T. 43 N., R. 60 W., Wyoming, which is part of the disturbed zone just described. Small normal and reverse faults in the marine shales are exposed in gullies and stream banks elsewhere on the Dewey terrace.

FANNY PEAK MONOCLINE

The Fanny Peak monocline is expressed by steeply dipping thin-bedded sandstones and limestones in the upper part of the Greenhorn Formation and middle part of the Carlile Shale in the southwestern part of the quadrangle. Regional dip on this monocline averages 22°; locally, however, dips of as much as 51° can be measured in the field. Dips are steepest in the NW¼ sec. 6, T. 42 N., R. 60 W., Wyoming, and flatten north and south of this area.

ECONOMIC RESOURCES

URANIUM

All the uranium produced in the Black Hills has been mined from rocks of the Inyan Kara Group. Despite active prospecting of extensive outcrops of these rocks in the Clifton quadrangle, no minable deposits of uranium have been found. The thick-bedded sandstone of the middle unit of the Fall River Formation in the southern part of the quadrangle is the most favorable host rock for uranium deposits. Most radioactivity anomalies found in the area are in this sandstone, particularly where authigenic changes in the sandstone resemble similar changes in the host rocks of uranium deposits in other parts of the Black Hills. Sedimentary, structural, and chemical features of the channel sandstone of the Fall River, which are probably genetically related to the radioactivity anomalies, are summarized below. This sandstone is described more thoroughly on pages 29–32.

Near the radioactivity anomalies, this channel sandstone is a light-gray to sulfur-yellow fine- to medium-grained thick-bedded unit with distinctive variations in color and cement (fig. 63). A color boundary within the sandstone trends northward for 6,000 feet from the Alray uranium prospect; the sandstone is yellow east of the boundary and light-gray west of the boundary. A uniform distribution of siliceous cement in the light-gray sandstone contrasts sharply with the irregular distribution of the siliceous and calcareous cement in the yellow sandstone. Nodules cemented with calcium carbonate and silica are common in the yellow sandstone and, locally, ferruginous nodules are abundant. Siliceous and calcareous nodules are also abundant where the thick-bedded sandstone has a bleached white appearance and 2 miles north of Clifton where the thick-bedded sandstone changes abruptly to interlayered thin-bedded sandstones and siltstones. Where the sandstone is white or yellow, it tends to be friable, crumbling quickly when exposed to weathering. The Alray uranium prospect is near the eastern margin of the Dewey terrace where the dip flattens from 15° on the Fanny Peak monocline to 3° on the terrace. Most of the terrace is underlain by marine shales of the Skull Creek and Mowry Formations, with the Fall River-Skull Creek boundary being covered by alluvium and colluvium along the eastern margin of the terrace.

One of the greatest of the radioactivity anomalies of the Fall River Formation has been explored by means of a tunnel at the Alray uranium prospect where the channel sandstone is irregularly mineralized in a zone several feet thick extending from the color boundary eastward into the yellow sandstone. A secondary yellow uranium-bearing material having a pale-yellow fluorescence is concentrated in bands peripheral to siliceous nodules and as tabular bodies near a thin bed of fragmented pyritiferous, carbonaceous siltstone. Black uraniferous material irregularly distributed in the siltstone may have been the source of the yellow material. No uraniferous minerals have been identified, but the results of chemical analyses shown in the following table and the fluorescence suggest that the yellow material is a combination of uranium phosphates and vanadates. The following samples collected at the Alray uranium prospect were analyzed by Clifford G. Angelo, Edward J. Fennelly, Henry H. Lipp, and John P. Schuch, of the U.S. Geological Survey:

Sample and lithology	Uranium (ppm)	Equivalent uranium (ppm)	Vanadium (ppm)	Arsenic (ppm)	Phosphorus (ppm)
94. Quartz sandstone	1, 200	1, 200	500	22	1, 700
95. Quartz sandstone	800	610	700	14	500
97. Carbonaceous pyritiferous siltstone	650	690	300	14	5, 200
100. Gypsiferous siltstone	30	70	300	14	200
92. Calcareous sandstone	10	10	300	6	200

Mineralized rocks at the Alray prospect could be interpreted as evidence for the movement of uranium-bearing ground-water solutions through the rocks. If movement in a favorable geochemical environment occurred subsequent to the Black Hills uplift, substantial quantities of uranium could have been carried to the Dewey terrace and concentrated at or near the water table. Work by Garrels and Christ (1959, p. 81–89) has outlined some of the features of an environment favorable for the migration and precipitation of uranium in ground-water solutions. When tetravalent uranium is oxidized to the hexavalent state, it is "fixed" in stable compounds of vanadium, arsenic, and phosphorus; in the absence of these elements, the hexavalent ion will tend to migrate with ground water until it is precipitated in a reducing environment. Carbonaceous material at the Alray prospect probably localized the uranium, which was subsequently stabilized by phosphorus and vanadium. The high concentration of phosphorus in the black pyritiferous, carbonaceous siltstone (sample 97 in the above table) indicates that this unit may have been the source of stabilizing as well as localizing agents. The siltstone appears quantitatively inadequate, however, to form a significantly extensive chemical barrier to the migration of uranium in solution. In the absence of other localizing agents, migrating solutions could have reached the water table on the Dewey terrace where a change from oxidizing to reducing conditions could have caused precipitation of uranium in significant quantities. In the northern and southern Black Hills, where the rocks are gently dipping, uranium-bearing solutions apparently have migrated slowly; this condition has resulted in survival of ore deposits in the areas in the zone of oxidation. In contrast, solutions have moved rapidly through the relatively steeply dipping rocks of the Clifton quadrangle, and therefore conditions have not been favorable for the preservation of ore deposits in the zone of oxidation. Conditions, however, should be favorable for the preservation of ore deposits below the zone of oxidation in the gently dipping rocks of the Dewey terrace.

GYPSUM

The gypsiferous unit of the Spearfish Formation contains an estimated 590 million tons of rock gypsum at depths of less than 127 feet. Thick-bedded gypsum crops out at many places in the eastern part of the quadrangle where it has a regional dip of less than 5° W. and S. The dip steepens to 39° in Ferguson Canyon in the northern part of the quadrangle, where erosion has exposed the gypsum in the Black Hills monocline.

The gypsiferous unit is chiefly a red siltstone with many thin beds of white to light-red gypsum in the upper part and two intervals of thick-bedded gypsum in the lower part separated by 40 to 45 feet of the red siltstone. Only the gypsum in the two thick-bedded intervals has been considered in estimating gypsum reserves. The gypsum in the lower interval is commonly 20 to 30 feet thick and weathers purple in the outcrop. Several thin beds of green to red siltstone occur near the middle of the interval, and beds of dolomite, limestone, and chert less than a foot thick are found at many places near the top and bottom of the interval. The upper interval of thick-bedded gypsum is 15 to 25 feet thick, weathers white, and tends to become thin bedded in the northern part of the quadrangle.

In order to be classified as commercial, most gypsum must contain a minimum of 85 percent by weight of $CaSO_4 \times 2H_2O$ (Larson, 1960, p. 369). Darton (1901, p. 585) reports the following analysis of gypsum in percent, from the Spearfish Formation, near Hot Springs, S. Dak., which is about 30 miles southeast of the Clifton quadrangle: CaO, 32.44; MgO, 0.33; Al_2O_3, 0.12; SiO_2, 0.10; SO_3, 45.45; CO_2, 0.85; H_2O, 20.80. This compares with the following composition of pure gypsum in percent: CaO, 32.5; SO_3, 46.6; and H_2O, 20.9.

Gypsum is important because of its ability to lose 75 percent of its combined water upon application of a moderate heat (250° to 400° F.) and its ability to be molded upon the addition of water before it returns to its rigid state by "setting." Calcined gypsum is used principally in the manufacture of building materials and industrial plasters; uncalcined gypsum is used as a retarder in portland cement and as a fertilizer. Gypsum has been mined on a small scale in the Black Hills to satisfy local demand, but large-scale production has been inhibited by transportation costs to other markets.

BENTONITE

Bentonite is a rock term for decomposed volcanic ash which contains at least 75 percent of the clay minerals montmorillonite or beidellite. Unweathered bentonite is a light-colored unctuous clay commonly containing small amounts of mica, feldspar, quartz, gypsum, and other clay minerals. Some bentonites absorb several times their own volume of water and are used as drilling muds, as a binder for foundry sands, and as a filler for coffer dams or reservoir linings. Nonswelling bentonite is used chiefly as insecticide fillers and industrial filters. Wyoming leads all other States in the production of bentonite. Weston County was the third-ranking producer of bentonite in Wyoming in 1957. Most of the bentonite mined in Weston County is from the Clay Spur Bentonite Bed just below the top of the Mowry Shale.

In the Clifton quadrangle, the Belle Fourche and Mowry Formations contain many discontinuous beds of light-colored bentonite, a few inches to 1 foot thick, but the thickest and most continuous beds are near the top of the Mowry in the SW¼ sec. 19, T. 43 N., R. 60 W., and in the NE¼ sec. 7, T. 42 N., R. 60 W., Wyoming. Both localities are near the western edge of the Dewey terrace. Bentonite, 1 to 2 feet thick, in the Mowry shows marked dilatancy, is white to dark-gray, and is associated with carbonates, sulfates, and oxides of iron at many places along the strike.

PETROLEUM

By the end of 1948, the Mush Creek and Skull Creek oil fields, 8 to 15 miles northwest of the Clifton quadrangle, had produced 1,270,011 barrels of oil from the Newcastle Sandstone. Petroleum in these two fields is produced from a lens of the Newcastle Sandstone, 50 to 60 feet thick. The main oil sand in the lower part of the sandstone is 6 to 28 feet thick. The Newcastle is the main source of oil at the Osage, Fiddler Creek, Mush Creek, and Skull Creek oil fields in Weston County. The Fall River Formation yields oil at the Lodgepole and Kuemmerle areas (Dobbin and Horn, 1949), 30 to 40 miles northwest of the Clifton quadrangle. Most of the oil is found in stratigraphic traps in gently dipping rocks of the Powder River Basin, a few miles west of the Fanny Peak monocline.

The most favorable locality for oil exploration in the Clifton quadrangle is in sec. 19, T. 43 N., R. 60 W., Wyoming, where the axis of the Rock Canyon syncline converges with the axis of the Whoopup anticline. The Newcastle Sandstone pinches out in this area and, so, forms a stratigraphic trap that, in combination with faulting, as suggested by the syncline and small surficial faults, may have produced a favorable environment for the preservation of an oil pool in the Newcastle Sandstone. Pinch outs in the Fall River Formation and faulting on the Dewey terrace southwest of Clifton also provides structural and stratigraphic conditions favorable for the formation of oil traps. The sulfur-yellow sandstone described elsewhere in this report may owe its color to the former presence of hydrogen sulfide in this sandstone.

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