Geology of the Cascade Springs Quadrangle Fall River County South Dakota

GEOLOGICAL SURVEY BULLETIN 1063-L

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

P—GEOLOGY OF THE CASCADE SPRINGS QUADRANGLE, FALL RIVER COUNTY, SOUTH DAKOTA—Geological Survey Bulletin 1063-L

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By EDWIN V. POST

GEOLOGY AND URANIUM DEPOSITS OF THE SOUTHERN BLACK HILLS

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GEOLOGY OF THE CASCADE SPRINGS QUADRANGLE FALL RIVER COUNTY, SOUTH DAKOTA

By Edwin V. Post

ABSTRACT

The Cascade Springs quadrangle comprises 54 square miles at the extreme south end of the Black Hills of South Dakota. Sedimentary rocks that crop out in the quadrangle range in age from Permian through Late Cretaceous and have an aggregate thickness of 2,800 feet. These rocks are overlain in places by unconsolidated Quaternary alluvium and landslide debris.

Permian rocks, which average 200 feet in thickness, consist of red beds of the Opeche Formation and slabby limestone of the Minnekahta Limestone. The Spearfish Formation of Permian and Triassic age consists of 335 feet of red siltstone and interbedded white gypsum. Jurassic rocks aggregate about 625 feet in thickness and include the dominantly marine sandstones and shales of the Sundance Formation and the nonmarine Unkpapa Sandstone and Morrison Formation.

The Inyan Kara Group of Early Cretaceous age consists of about 525–600 feet of terrestrial sandstones, siltstones, and mudstones, which have been subdivided into the Lakota and Fall River Formations. Abrupt changes in lithology characterize these rocks, which were deposited in fluviatile, lacustrine, and paludal environments. The Lakota Formation includes the Chilson, Minnewaste Limestone, and Fuson Members. Marine rock that overlies the Inyan Kara Group comprises the Skull Creek and Mowry Shales, respectively 250 and 150 feet thick, which are of Early Cretaceous age, and the Belle Fourche Shale, 200 feet thick, Greenhorn Formation, 250 feet thick, and Carlile Shale, about 250 feet thick—all Late Cretaceous in age.

In the eastern part of the quadrangle these rocks are folded into the asymmetric southward-plunging Cascade anticline, which dips about 5° SE. and 40°–70° SW. The west half of the quadrangle includes part of the east limb of the Chilson anticline, a similar southward-plunging asymmetric anticline.

Two small uranium deposits have been found in the Fall River Formation, and high radioactivity has been noted in the Spearfish Formation; however, none of these occurrences is commercially significant. The lower part of the Fall River Formation and a channel sandstone at the top of the Lakota Formation are considered most favorable for uranium prospecting. Other possible economic resources include gypsum, limestone, sand and gravel, ground water, and oil and gas.

INTRODUCTION

The Cascade Springs quadrangle covers about 54 square miles at the extreme south end of the Black Hills in Fall River County, S. Dak. (fig. 86). The area is bounded by meridians 103°30′ and 103°37′30″ W. and parallels 43°15′ and 43°22′30″ N. It is accessible by State Highway 87, which extends south from the city of Hot Springs, S. Dak.

Most of the Cascade Springs quadrangle consists of the "Hogback Ridge" of Lower Cretaceous sandstones, as described by Darton and Paige (1925, p. 1). Dissection of this hogback by several intermittent streams has produced a youthful topography of flat intercanyon divides separated by steep-walled canyons having a maximum local relief of about 600 feet. Total relief in the quadrangle is 1,282 feet between Angostura Reservoir (alt 3,187 ft) and the summit of Roundtop Hill (4,469 ft).

The major drainage in the quadrangle is provided by the Cheyenne River which meanders eastward across the south third of the area. Most of the canyons in the area head in the hogback ridge and drain into the Cheyenne River. Three notable exceptions are Cascade

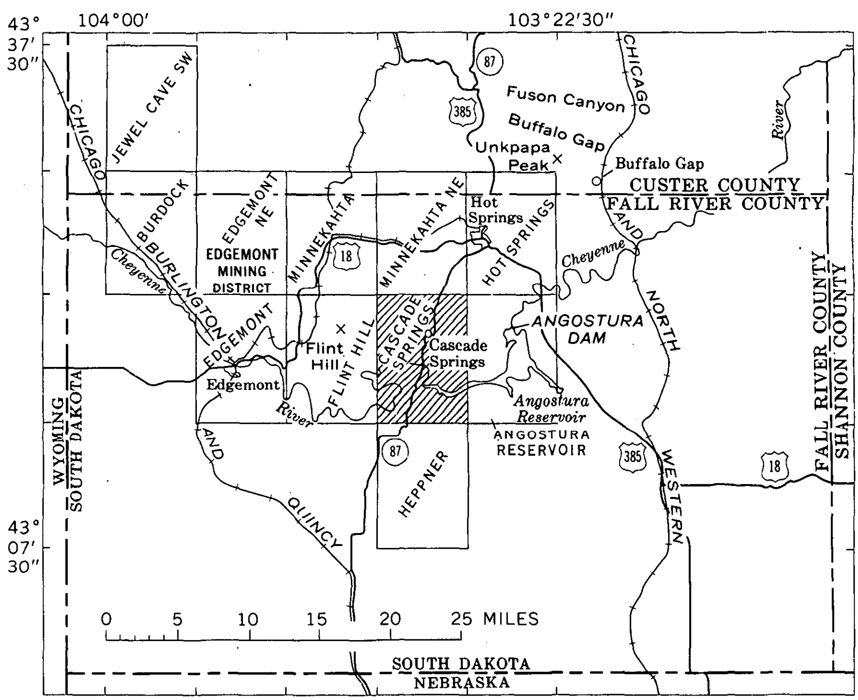

FIGURE 86.—Location of Cascade Springs quadrangle.

Creek and Red Gulch canyons and Sheps Canyon, all of which breach the hogback and drain the Red Valley north of the hogback ridge. Cascade Creek and the stream in Red Gulch, which are spring fed, are the only perennial streams in the quadrangle.

Parts of the area are covered with a sparse pine forest which is thickest on the sandy soil over rocks of the Inyan Kara Group. These trees and an extensive short-grass cover are supported by an average annual precipitation of less than 15 inches.

This work was done on behalf of the U.S. Atomic Energy Commission. Fieldwork was begun in June 1955 and completed in October 1956. Preliminary large-scale geologic and structure-contour maps showing all outcrops in this quadrangle have been published (Post, 1959a, b; Post and Cuppels, 1959a, b; Post and Lane, 1959 a, b). The writer was assisted in the field at various times by D. W. Lane, N. P. Cuppels, W. B. Bryan, and C. L. Rogers. Lane mapped most of the pre-Cretaceous rocks in the northeastern part of the quadrangle.

Much of the quadrangle was mapped with surveying altimeters on a topographic base at 1: 7,200. The steeper cliffs, especially those northeast of Horseshoe Bend and southeast of Flagpole Mountain, were mapped by graphic locator on a 1: 7,200 topographic base (Varnes and others, 1959). Stratigraphic sections were measured by hand level or tape and Brunton compass methods. Most of the rock colors described herein were determined by reference to the National Research Council "Rock-color chart" (Goddard and others, 1948).

Nearby areas have been mapped by the U.S. Geological Survey as part of a study of the geology and mineral resources of the southern Black Hills. Particular attention was given to the Inyan Kara Group of Early Cretaceous age—the host rock for commercial uranium deposits in the area. The only comprehensive geologic work in the immediate area previous to the present study was that done by Darton and Smith (1904). The South Dakota Geological Survey has published several reports on various aspects of the geology of southwestern South Dakota (Petsch, 1960; Rothrock, 1931, 1938, 9149; Spivey, 1940).

STRATIGRAPHY

Sedimentary rocks that crop out in the Cascade Springs quadrangle comprise 15 formations ranging in age from Permian through Late Cretaceous with an aggregate thickness of about 2,800 feet (table 1). Major emphasis in the mapping was placed on the rocks of the Inyan Kara Group of Early Cretaceous age because these rocks contain economically important deposits of uranium minerals in the Edgemont mining district to the northwest. The Paleozoic and Mesozoic rocks

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TABLE 1.—*Formations exposed in the Cascade Springs quadrangle*

System	Series	Group	Formation	Member	Thickness (feet)
Quaternary			Alluvium		0–90
			Windblown sand		0–100
			Terrace gravel		0–50
			Landslide debris		Variable, 0–400(?)
Cretaceous	Upper Cretaceous		Carlile Shale	Sage Breaks [1]	57
				Turner Sandy	49
				Lower unnamed	148
			Greenhorn Formation		250 (approx)
			Belle Fourche Shale		200 (avg)
	Lower Cretaceous		Mowry Shale		150 (avg)
			Skull Creek Shale		250 (avg)
		Inyan Kara	Fall River Formation		135–180 (avg 160)
			Lakota Formation	Fuson Member	85–110
				Minnewaste Limestone	0–80 (normally <5)
				Chilson Member	209–410 (avg 325)
Jurassic	Upper Jurassic		Morrison Formation		0–20
			Unkpapa Sandstone		50–230 (avg 150)
			Sundance Formation	Redwater Shale	128 (avg)
				Lak Member	80 (avg)
				Hulett Sandstone	35 (avg)
				Stockade Beaver Shale	27 (avg)
				Canyon Springs Sandstone	10–100 (variable)
Triassic and Permian			Spearfish Formation	Upper siltstone unit	150
				Gypsiferous unit	135
				Lower siltstone unit	50
Permian			Minnekahta Limestone		50 (avg)
			Opeche Formation		150 (approx)

[1] Not exposed in quadrangle.

are overlain in some places by landslide debris and by unconsolidated sand, silt, and gravel of Quaternary age. The gravel, sand, and silt form older terrace gravel deposits, windblown sand and silt possibly of alluvial origin, and younger alluvium that fills the floor of many canyons.

PERMIAN SYSTEM

OPECHE FORMATION

Darton (1901a, p. 513) gave the name Opeche Formation to the red slabby sandstones and sandy shales between the Minnelusa Formation and Minnekahta Limestone in the Black Hills region.

The formation is well, but incompletely, exposed in the north-central part of the Cascade Springs quadrangle along the east side of Alabaugh Canyon and in the upper reaches of Whaley Canyon. Approximately 150 feet of Opeche was measured along the crest of the Cascade anticline. This thickness is only approximate because the base of the formation is not exposed, and measurement of the true thickness may have been complicated by the abrupt change in dip to the west.

Most of the formation consists of moderate-reddish-brown friable siltstone. Dark-yellowish-orange to red thin-bedded fine-grained sandstone is interbedded with the siltstone in the lower part of the formation. Locally, the top 5 feet of the Opeche is a tough pale-red color-banded calcareous siltstone that weathers to 1- to 2-foot-thick beds. Thin lenses of white gypsum occur in places in the upper part of the Opeche.

MINNEKAHTA LIMESTONE

The Minnekahta Limestone was originally defined by Darton (1901a) as the thin-bedded gray limestone 30–50 feet thick between the Opeche Formation and the Spearfish Formation in the Black Hills. He named it for exposures near Hot Springs, S. Dak., the Sioux Indian name for Hot Springs being Minnekahta.

The Minnekahta is widely exposed in the northeastern part of the Cascade Springs quadrangle, where it forms a rolling knobby land surface. This surface is probably a reflection of the structure in the formation, which is intricately folded and crumpled and locally faulted and brecciated. The major folds have an amplitude of as much as 50 feet.

The thickness of the Minnekahta Limestone is difficult to measure because of the crumpled nature of the formation and because the upper contact is rarely exposed near good exposures of the basal contact. In the center of sec. 20, T. 8 S., R. 5 E., 40½ feet was measured, but the top of the unit is not present; 50 feet is probably a good approximate thickness for the formation in the Cascade Springs quadrangle.

The Minnekahta consists predominantly of pale-brown to grayish-red laminated finely crystalline limestone which weathers into slabs 1–6 inches thick. It is dolomitic, as indicated by the analyses of a sample collected at Cascade Springs which contained 19.85 percent magnesia (Darton and Smith, 1904, p. 3). According to Pettijohn (1949, p. 314), the rock approximates the theoretical composition of an ideally pure dolomite.

Darton (Darton and Paige, 1925, p. 10) favored a Permian age for the Minnekahta on the basis of pelecypods and fish fossils found in the limestone. No fossils were found during the present study, but Braddock (1963, p. 229) found some fragmentary fish remains in the Minnekahta Limestone in the Jewel Cave SW quadrangle. These remains proved unidentifiable as to generic or specific name but resembled a group of fishes known to be of Mississippian to Late Permian age. Gastropods and pelecypods found by Braddock (1963, p. 229) were reported to be of Permian age.

PERMIAN AND TRIASSIC SYSTEMS, SPEARFISH FORMATION

The Spearfish Formation was named for Spearfish, S. Dak., by Darton (1899, 1901a). He described the formation as 350–500 feet of red sandy clays or shales containing gypsum beds overlying the Minnekahta Limestone and unconformably underlying the Sundance Formation.

The Spearfish is well exposed in the northeastern part of the quadrangle, where it underlies a segment of the Red Valley which almost continuously encircles the Black Hills (Darton, 1901a, p. 501). Alabaugh Canyon, in the north-central part of the quadrangle, is cut in the Spearfish, which is less resistant to weathering than the adjacent Minnekahta Limestone and Sundance Formation.

Because of its softness and erodability, the thickness of the Spearfish is not readily measured, especially where the formation is relatively flat lying. Calculations from the geologic map (pl. 29) indicate that the formation is about 335 feet thick. This thickness may be subdivided into three units: (1) a lower reddish-brown siltstone unit approximately 50 feet thick; (2) a middle unit of interbedded reddish-brown siltstone and thin gypsum beds about 135 feet thick, and (3) an upper reddish-brown siltstone unit about 150 feet thick.

The following stratigraphic section measured in Alabaugh Canyon, where the beds dip steeply westward, compares very favorably with calculated thicknesses based on the mapping.

Rocks other than reddish-brown siltstone and white gypsum are not common in the Spearfish, but there is a small outcrop of light-gray dolomite in the NW¼SW¼ sec. 28, T. 8 S., R. 5 E. The black mudstone (unit 3 in the measured section), although thin, is very widespread in the quadrangle and forms a good marker bed. Locally it is radioactive.

Stratigraphic section of Minnekahta Limestone and Spearfish Formation measured in NE¼ sec. 18, T. 8 S., R. 5 E.

[Measured by E. V. Post and C. L. Rogers]

	Feet
Sundance Formation, not measured.	
Spearfish Formation:	
11. Siltstone, moderate-reddish-brown; contains a few 6-in.-thick gypsum seams	142.0
10. Gypsum, white	12.0
9. Siltstone, moderate-reddish-brown	31.0
8. Gypsum, white	13.5
7. Siltstone, moderate-reddish-brown	14.0
6. Gypsum, white	5.0
5. Siltstone, moderate-reddish-brown	15.0
4. Gypsum, white	41.0
3. Mudstone, black, carbonaceous	0.5
2. Siltstone, moderate-reddish-brown	54.5
Total thickness of Spearfish Formation	328.5
Minnekahta Limestone (in part):	
1. Limestone, pinkish-gray, laminated, slabby; base not exposed	33.0

High radioactivity, as much as 35 times background, was noted at a bleached and structurally disturbed zone in the Spearfish Formation on the south side of State Highway 87 in the SW¼SE¼ sec. 20, T. 8 S., R. 5 E. (See fig. 87.) This disturbed zone is approximately 15 feet wide and extends vertically up the face of the roadcut. Bedding in the zone is obliterated. The rock consists of a mass of disoriented fragments of siltstone, gypsum, and black mudstone. The siltstone, which is the major constituent, has been bleached to a moderate greenish gray from its normal, reddish-brown color. The character of this disturbed zone, its proximity to the hot springs at Cascade Springs, and the presence of caverns in the gypsum at the top of the roadcut just to the east of this zone suggest that the structural disturbance and bleaching were caused by a hot spring similar to those presently active at Cascade Springs. The disturbed zone may, in fact, be the upper part of a breccia pipe similar to those described by Bowles and Braddock (1963).

Darton (1901a, p. 518–519) considered the Spearfish to be of Triassic age because of its stratigraphic position between rocks of known Permian and Jurassic age. Nevertheless, he stated (1901a, p. 519) that "it is possible that the lower portion of the formation is Permian * * *"—a proposal that has been borne out by later work. By projecting subsurface units eastward from Wyoming into the Black Hills region, Goldsmith (in McKee and others, 1959, p. 4) determined that the Permian-Triassic boundary is at the top of the upper gypsum bed of the Spearfish Formation.

FIGURE 87.—Disturbed and bleached zone in lower part of Spearfish Formation, SW¼SE¼ sec. 20, T. 8 S., R. 5 E. Notice lack of bedding in bleached zone, as contrasted with bedding marked by gypsum stringers in unaltered rock.

JURASSIC SYSTEM

SUNDANCE FORMATION

The name Sundance Formation was first used for the lowermost Jurassic rocks in the Black Hills region by Darton (1899, p. 387), who described in general terms a section of the formation 400 feet thick "at Cascade." In all his early papers on the Jurassic of the Black Hills, Darton (1899, 1901a, and Darton and Smith, 1904) recognized the five major lithologic subdivisions of the Sundance that Imlay (1947) later formally named. These subdivisions of the Sundance were readily recognized and mapped during the present study in the Cascade Springs quadrangle, although no attempt was made to measure extremely detailed sections or to collect fossils. The paleontology of the formation has been adequately described by Imlay (1947, 1948, 1952, 1953), Swain and Peterson (1951, 1952), and Loeblich and Tappan (1950a, b).

The Sundance Formation is well exposed at the foot of the hogback ridge in the northeastern and east-central parts of the Cascade Springs quadrangle; the lower part of the formation is shown in figure 88. The upper part of the formation is poorly exposed in the upper part of

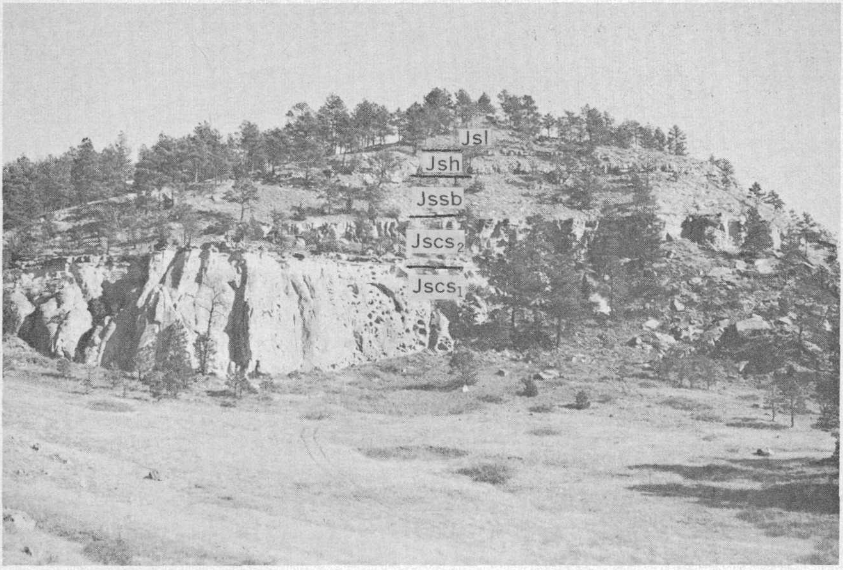

FIGURE 88.—Lower part of Sundance Formation in SE¼ sec. 10, T. 8 S., R. 5 E. Jsl, Lak Member; Jsh, Hulett Sandstone Member; Jssb, Stockade Beaver Shale Member; Jscs$_2$, upper tabular-bedded part of Canyon Springs Sandstone Member; Jscs$_1$, lower crossbedded cavernously weathering part of Canyon Springs Sandstone Member.

Falls Canyon in the northwestern part of the quadrangle and at the base of the cliffs southeast of Flagpole Mountain in the east-central part of the quadrangle. The thickness of the Sundance was measured at three localities where the complete formation is well exposed (table 2).

TABLE 2.—*Thickness, in feet, of Sundance Formation at three localities in the Cascade Springs quadrangle*

	Locality		
	1	*2*	*3*
Redwater Shale Member	137	} 207	122
Lak Member	77		81
Hulett Sandstone Member	34	39	38
Stockade Beaver Shale Member	26	28	42
Canyon Springs Sandstone Member	83	54	89
Total thickness, Sundance Formation	357	328	372

1. NE. cor. SE¼ sec. 10, T. 8 S., R. 5 E.
2. Alabaugh Canyon; NE¼SE¼ sec. 18, T. 8 S., R. 5 E.
3. South of Cascade Springs; center of sec. 29, T. 8 S., R. 5 E.

CANYON SPRINGS SANDSTONE MEMBER

The Canyon Springs Sandstone Member of the Sundance may be divided into two units. The lower unit, which ranges in thickness from 0 to 85 feet, consists of sandstone that is fine grained, well sorted, indistinctly crossbedded, pale yellowish orange to moderate reddish brown, and locally calcareous. The weathered surface is either smoothly rounded or cavernous. The basal 1–2 feet contains scattered polished pitted black chert pebbles about 1 inch in diameter. The upper unit of the Canyon Springs Sandstone Member is more uniform in thickness, averaging about 15 feet. It consists of thin tabular-bedded color-banded fine-grained argillaceous friable sandstone. The unit becomes more ferruginous and ripple marked at the top and is locally highly calcareous. At one locality the upper unit of the Canyon Springs Sandstone Member appears to have been deposited on an erosional unconformity with a relief of about 5 feet.

The Canyon Springs rests with an erosional unconformity on the Spearfish Formation. This unconformity has a local relief of 1–2 feet but apparently has major relief almost equal to the thickness of the Canyon Springs, which ranges from less than 10 feet to almost 100 feet in thickness. The Canyon Springs was apparently deposited in depressions in an erosion surface cut on the top of the Spearfish red beds by the encroaching Jurassic sea.

STOCKADE BEAVER SHALE MEMBER

The Stockade Beaver Shale Member is a light-olive-gray calcareous fossiliferous shale. It ranges from 26 to 42 feet in thickness within the quadrangle and generally forms a topographic bench or swale between the more resistant sandstones above and below. The contacts with the overlying and underlying sandstone members of the Sundance Formation are sharp.

HULETT SANDSTONE MEMBER

The Hulett Sandstone Member is more resistant to weathering than the adjacent members of the formation and thus forms an excellent widely exposed marker bed within the Sundance. It is characteristically a pale-grayish-orange to pale-reddish-brown calcareous sandstone that is fine grained, thin bedded, slabby, and ripple marked. The member contains olive-gray shale splits between sandstone beds and has many worm trails on bedding surfaces. The top 10 feet of the member commonly consists of calcareous light- to olive-gray shale and siltstone. Only 15–20 feet of the Hulett Sandstone Member is exposed in most places, but the total thickness of the unit averages about 35 feet.

LAK MEMBER

The Lak Member of the Sundance Formation is rarely well exposed because of its extreme friability. It commonly weathers to a slope or gully which supports grass, above the more resistant sandstone of the underlying Hulett Sandstone Member. The unit averages about 80 feet in thickness throughout the Cascade Springs quadrangle; the lower 75 feet consists of moderate-reddish-brown to grayish-red siltstone, and the upper 5 feet, pale-yellowish-orange very fine grained sandstone. The rock commonly splits roughly parallel to the bedding into irregular slabs 2–3 inches thick.

REDWATER SHALE MEMBER

The Redwater Shale Member of the Sundance Formation is 122–137 feet thick. The member is widely exposed in the Cascade Springs quadrangle, where it is typically an olive-gray shale and argillaceous siltstone containing several thin beds of extremely fossiliferous limestone and greenish- to yellowish-gray glauconitic sandstone. The glauconitic sandstone beds are more common near the top of the member. The shale is the youngest marine deposit of Jurassic age in this area; younger rocks of Jurassic age are considered to be of continental origin.

The following stratigraphic section, measured at the best exposure of the complete Sundance in the Cascade Springs quadrangle, is representative of the formation:

Stratigraphic section of Sundance Formation in S½ sec. 10, T. 8 S., R. 5 E.

[Measured by D. W. Lane and E. V. Post]

Unkpapa Sandstone, not measured.	
Sundance Formation:	
Redwater Shale Member:	
16. Siltstone, grayish-red to dark-reddish-brown and dark-yellowish-orange, calcareous, thinly laminated; basal 2 ft olive gray; glauconitic	11.0
15. Siltstone, light-olive-gray, glauconitic, slightly calcareous, thinly laminated; some red iron-oxide stain along laminae	27.5
14. Siltstone, light-yellowish gray, slightly calcareous, thinly laminated, ripple-marked	1.3
13. Shale, olive-gray, calcareous; contains very finely crystalline limestone concretions and thin fossiliferous limestone beds	57.5
12. Siltstone, light-olive-gray, calcareous, sparsely glauconitic; contains scattered specks of iron-oxide stain; massive 3-ft-thick ledge at top	27.0
11. Siltstone, pale-yellowish-gray, calcareous, thinly laminated; cross-laminated in upper part	5.5
10. Shale, olive-gray, slightly calcareous; contains thin moderate-orange-pink very fine grained sandstone beds; contains selenite crystals near base	7.5
Total thickness of Redwater Shale Member	137.3

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Stratigraphic section of Sundance Formation in S½ sec. 10, T. 8 S., R. 5 E.—Con.

	Feet
Sundance Formation—Continued	
Lak Member:	
9. Sandstone, pale-yellowish-orange, very fine grained, calcareous, very friable	5.0
8. Siltstone, moderate-reddish-orange to moderate-brown, calcareous, massive; contains 2-in.-thick medium-gray shale and 2 ft of laminated light-olive-gray siltstone	72.0
Total thickness of Lak Member	77.0
Hulett Sandstone Member:	
7. Siltstone, mottled, very light gray and light-brown, calcareous	5.5
6. Shale, olive-gray, locally silty, calcareous; basal part is dark-greenish-gray shale and laminated moderate-reddish-orange siltstone	6.0
5. Sandstone, pale-grayish-orange, fine-grained, calcareous; friable in part; thin-bedded to laminated; shale splits between beds; current ripple marks indicate westerly to northwesterly current flows; worm trails on bedding surfaces	22.0
Total thickness of Hulett Sandstone Member	33.5
Stockade Beaver Shale Member:	
4. Shale, olive-gray, calcareous, fossiliferous	26.0
Total thickness of Stockade Beaver Shale Member	26.0
Canyon Springs Sandstone Member:	
3. Sandstone, moderate-orange-pink, fine-grained, well-sorted; contains some interstitial white clay and flakes of light-olive clay; calcareous; very friable; thin bedded; upper beds indistinctly ripple marked and ferruginous	24.0
2. Sandstone, light-brown to grayish-orange, fine-grained, calcareous, thin-bedded to laminated, moderately hard	4.5
1. Sandstone, pale-yellowish-orange, fine-grained, well-sorted; well-rounded grains of quartz and pink chert; some interstitial white clay; calcareous, very friable	54.5
Total thickness of Canyon Springs Sandstone Member	83.0
Total thickness of Sundance Formation	356.8
Spearfish Formation, not measured.	

UNKPAPA SANDSTONE

The Unkpapa Sandstone was named by Darton (1899, p. 387 and 393), who first (1901a) ascribed the name to "one of the tribes of Dakota Indians which was at one time located about the southeast part of the Black Hills." The name was later said to have been derived from Unkpapa Peak, near Buffalo Gap, S. Dak. (Darton and O'Harra, 1909).

The Unkpapa Sandstone is widely distributed in the northern and eastern parts of the Cascade Springs quadrangle. Its maximum thickness is well exposed in cliffs beneath Lakota sandstone north of Sheps Canyon in the northeastern part of the quadrangle. Excellent exposures are found in the east-central part of the quadrangle east of Horseshoe Bend, where the Unkpapa has been channeled and the resulting depressions filled with Lakota sandstone. (See fig. 89.) The formation is also exposed in Green Canyon, in cliffs southeast of Flagpole Mountain, and in scattered outcrops in Alabaugh Canyon, as well as in the northwestern part of the quadrangle in Falls, Buck, and Hell Canyons.

The maximum thickness of the Unkpapa Sandstone, about 250 feet, was recorded in the northeast corner of the Cascade Springs quadrangle in the SE¼ sec. 10, T. 8 S., R. 5 E. The minimum thickness, 50 feet, was recorded southeast of Flagpole Mountain in the NW¼ sec. 3, T. 9 S., R. 5 E. This minimum thickness resulted from pre-Lakota channeling in the top of the Unkpapa. The average thickness of the formation over much of the quadrangle is about 150 feet.

The Unkpapa Sandstone includes three lithologic units. In general, the lower half of the formation, ranging from 50 to 100 feet in thickness, consists of sandstone that is fine grained, well sorted, argillaceous, and indistinctly crossbedded. The rock ranges in color from white through pale orange to moderate reddish brown and commonly forms a cliff. The upper part of the formation, ranging from 0 to

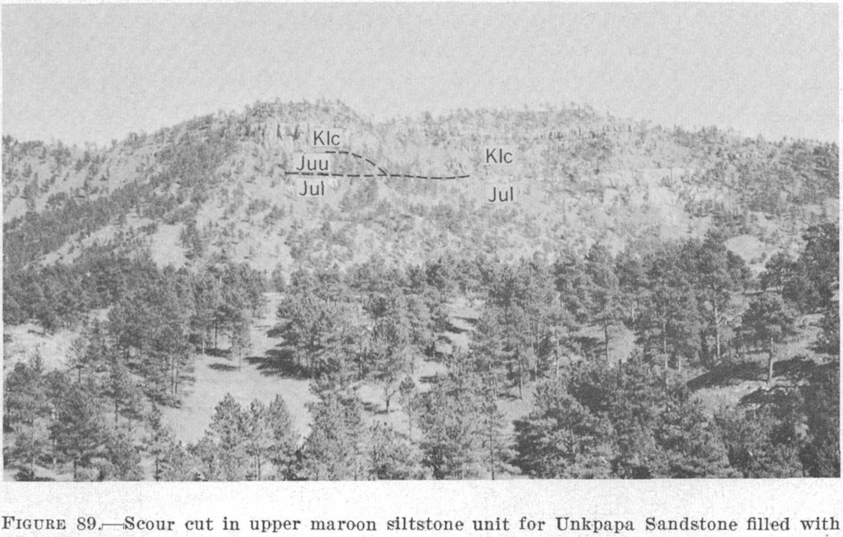

FIGURE 89.—Scour cut in upper maroon siltstone unit for Unkpapa Sandstone filled with sandstone of Lakota Formation. Klc, Chilson Member of Lakota Formation; Juu, upper maroon siltstone unit of Unkpapa Sandstone; Jul, lower white sandstone unit of Unkpapa Sandstone. Cliff in E½ sec. 28, T. 8 S., R. 5 E., north of Horseshoe Bend.

100 feet in thickness, is friable slope-forming maroon to yellowish-orange very fine grained sandstone or siltstone without apparent internal structure. As much as 30 feet of varicolored argillaceous siltstone and claystone occurs at the top of the Unkpapa in places where the formation has not been deeply scoured by pre-Lakota erosion. This rock generally is overlain abruptly by Lakota sandstone, but in a few places it grades upward into gray or greenish-gray mudstone that appears to be more typical of the Lakota than of the Unkpapa.

An exposure on the east side of Falls Canyon opposite the mouth of Buck Canyon illustrates the gradation in both color and texture of the upper part of the Unkpapa from very fine grained friable pale-red sandstone at the canyon floor, through a mottled maroon-green sandstone to green siltstone and thence to maroon silty clay, and finally to a green silty clay. Because these changes in color commonly take place through an interval of mottled red-green rock, the green color is thought to be the result of reduction of the ferric iron in the red zones.

Mudstones at the top of the Unkpapa are also exposed in the hogback ridge south of State Highway 87 at Cascade Springs, at Horseshoe Bend, in the east-central part of sec. 32, T. 8 S., R. 5 E., along the ridge north of Sheps Canyon in the northeastern part of the quadrangle, and north of Angostura Reservoir in the SE¼NW¼ sec. 10, T. 9 S., R. 5 E.

In hand specimen the white sandstone of the Unkpapa is difficult to distinguish from sandstone of the Lakota Formation, but where exposed, the contact between the two generally is apparent, as shown in figure 89. The Lakota weathers to a dark yellowish orange and forms a more irregular jagged outcrop, whereas the Unkpapa weathers to white and forms a smoother, more rounded exposure. In exploratory drilling where the Lakota has not weathered to yellowish orange, the cuttings of the Unkpapa Sandstone are more argillaceous and commonly contain interstitial light-green clay.

Buck Canyon, at the west edge of the quadrangle, is the only place where the Unkpapa is overlain by the Morrison Formation. The contact is quite apparent—the top of the Unkpapa is a very fine grained light-yellowish-gray friable sandstone containing calcium carbonate concretions, and the Morrison consists of calcareous green sandy mudstone containing thin limestone beds.

The basal contact of the Unkpapa with the Redwater Shale Member is rarely exposed. Where it is exposed the Unkpapa consists of white or pale-red very fine grained sandstone, and the upper part of the Redwater is glauconitic siltstone that ranges from dark reddish brown to light olive gray.

The Unkpapa probably is mostly of terrestrial origin, as indicated by the lithology, proximity to the nonmarine Morrison Formation, and limited extent; it may be partly eolian, as indicated by the indistinct crossbeds. The mudstone unit at the top of the Unkpapa may indicate a transition from an eolian to a lacustrine or paludal environment in which the Morrison Formation was deposited.

Although no fossils have been found in the formation, the Unkpapa Sandstone is considered Late Jurassic in age because of its stratigraphic position.

MORRISON FORMATION

The fresh-water marls of Jurassic age along the front of the Rocky Mountains in Colorado were named Morrison Formation by Eldridge (in Emmons and others, 1896, p. 60). This terminology was extended by Darton (1901b) to the Black Hills region for rocks of similar lithology and stratigraphic position.

The Morrison Formation is widespread in the western Black Hills, where it reaches a thickness of as much as 120 feet, but it pinches out eastward in the southern Black Hills. The eastern limit of the formation is, for the most part, in the Flint Hill and Minnekahta quadrangles adjacent to the Cascade Springs quadrangle on the west and northwest. The only exposures of the Morrison within this quadrangle are in Buck Canyon, where the formation consists of not more than 20 feet of greenish sandy calcareous mudstone including a 1½-foot-thick dense gray limestone in the middle and thin limestones at the top. The uppermost thin limestone is taken as the top of the formation. The overlying noncalcareous gray mudstones are considered to be Lakota.

CRETACEOUS SYSTEM, LOWER CRETACEOUS SERIES

INYAN KARA GROUP

The Inyan Kara Group was named by Rubey (1930), who intended it to include rocks of the Lakota, Fuson, and Dakota Formations that he was unable to differentiate in the western part of the Black Hills. The history of the stratigraphic terminology of the rocks of the Inyan Kara Group is long and varied and has best been summarized by Waagé (1959).

Briefly, the first designation of rocks including those of the Inyan Kara Group was made by Hall and Meek (1856), who called the lowermost unit of the Cretaceous of the western interior "formation no. 1." Meek and Hayden (1861) named the basal sandy beds of "formation no. 1" the Dakota Group, and Newton and Jenney (1880) limited the term Dakota to those rocks now included in the Inyan Kara Group.

Darton (1899) first used the name Lakota for the lowermost Cretaceous rocks, and in his preliminary report on the geology of the southern Black Hills (1901a), he restricted the term Dakota to presumed Upper Cretaceous rocks and subdivided the supposed Lower Cretaceous into the Lakota Formation, Minnewaste Limestone, and Fuson formation.

The name Fall River was substituted for Dakota by Russell (1927, 1928) after the recognition that plant fossils in the rocks indicated the former Dakota of the Black Hills to be older than the type Dakota of the Missouri River area and probably of Early Cretaceous age.

Rubey's (1930) grouping of the Lakota, Fuson, and Fall River (Dakota) into the Inyan Kara Group was the last major change in the nomenclature until that made by Waagé (1959). This change was a result of work by the Geological Survey which showed that the Fuson as described by Darton was not a mappable unit over much of the western and northern Black Hills.

During a reconnaissance of the Inyan Kara Group through the Black Hills in the summers of 1955–56, Waagé recognized a twofold division of the Inyan Kara Group similar to the one he proposed for the Purgatoire Formation of south-central Colorado (Waagé, 1953) and the Dakota Group of the Front Range of Colorado (Waagé, 1955). The contact between the two units composing the Inyan Kara Group, the Dakota Group and the Purgatoire Formation, was recognized by Waagé as a regional transgressive disconformity presumably marking the change from rocks deposited in a continental environment to those deposited in a marginal marine environment.

In view of the widespread twofold divisibility of the Inyan Kara Group and the difficulty in tracing the Fuson Formation of Darton throughout the Black Hills, Waagé (1959) revised the terminology of the Inyan Kara Group, enlarged the scope of the former Lakota Formation to include all those rocks previously called Lakota, Minnewaste, and Fuson, and made the Minnewaste and Fuson Formations members of the redefined Lakota Formation. The lithology of the Fall River Formation remains virtually unchanged except for the inclusion at the base and above the regional transgressive disconformity of a unit of thin-bedded or laminated carbonaceous siltstone and fine-grained sandstone formerly in the Fuson. This terminology is adopted for the present report. The former Lakota Formation of Darton is called the Chilson Member of the Lakota Formation, as proposed by Post and Bell (1961). Changes in stratigraphic terminology for rocks of the southern Black Hills and the classification used in this report are summarized in table 3.

TABLE 3.—*Summary of changes in stratigraphic terminology for rocks of the Inyan Kara Group*

Darton (1901a)	Russell (1928)	Rubey (1930)		Waagé (1959)			This report (from Post and Bell, 1961)		
Dakota formation	Fall River formation	Inyan Kara group	Fall River sandstone	Inyan Kara group	Fall River formation		Inyan Kara Group	Fall River Formation	
Fuson formation	Fuson formation		Fuson formation		Lakota formation	Fuson member		Lakota Formation	Fuson Member
Minnewaste limestone	Minnewaste limestone					Minnewaste limestone member			Minnewaste Limestone Member
Lakota formation	Lakota formation		Lakota sandstone			Unnamed lower unit			Chilson Member

Prominent sandstone units within the Inyan Kara Group have been informally numbered to aid in their identification. Sandstones included in this quadrangle are S_2 and S_4 in the Lakota Formation and S_5 and S_6 in the Fall River Formation. Sandstones S_1 and S_3 are recognized in areas to the west. Mudstone units believed to be lateral equivalents of the numbered sandstones have been assigned the same number.

LAKOTA FORMATION

The Lakota Formation in the Cascade Springs quadrangle includes three distinct subdivisions, in ascending order: the Chilson Member, the Minnewaste Limestone Member, and the Fuson Member. The Lakota is the most widespread formation in the quadrangle and occupies most of the northwestern and east-central parts of the area. Limited exposures of the formation are found south of the Cheyenne River in the west-central and southeastern parts of the quadrangle.

Exposures of the Lakota Formation are generally good, with the exception of the lower part of the Fuson Member, which commonly forms a grassy-covered slope, and the more argillaceous facies of the Chilson Member, which form rubbly slopes littered with sandstone debris. The S_2 sandstone of the Chilson Member forms prominent cliffs such as those northeast of Horseshoe Bend and southeast of Flagpole Mountain. The S_4 sandstone of the Fuson Member also weathers into cliffs which resemble those formed by thick sandstones in the Fall River Formation. The most prominent S_4 sandstone cliffs occur in Hell Canyon.

Where present, the Minnewaste Limestone Member of the Lakota almost invariably is exposed in a thin gray rough-surfaced ledge 1–2 feet thick which forms an excellent marker bed. South of Angostura Reservoir, the Minnewaste is as much as 80 feet thick and forms a prominent ledge on the steep slope west of Tepee Mountain and along Tepee Creek.

The boundary between the Lakota Formation and Unkpapa Sandstone can be mapped with more or less accuracy, depending on the character of the rocks in each of these formations near the contact. The various criteria that have been used in identifying the Lakota-Unkpapa contact in the Cascade Springs quadrangle are tabulated in table 4.

TABLE 4.—*Criteria for recognizing Lakota Formation–Unkpapa Sandstone contact*

Lithology of Lakota Formation at contact	Lithology of Unkpapa Sandstone at contact	Character of units above and below contact
1. Sandstone	Sandstone	Lakota sandstone yellowish-gray or grayish-yellow, locally carbonaceous, includes 1–4-ft-thick conglomerate at base; sandstone of the Unkpapa is white, argillaceous, commonly friable, noncarbonaceous, nonconglomeratic.
2. Sandstone	Mudstone	Lakota sandstone is silty, carbonaceous, iron-stained, not highly argillaceous; rests with sharp contact on greenish to varicolored noncarbonaceous Unkpapa claystone, which grades downward through siltstone into sandstone.
3. Mudstone	Sandstone	Lakota mudstone commonly gray to greenish-gray—no reds, locally carbonaceous; contact with underlying white, fine-grained argillaceous sandstone of the Unkpapa is abrupt.
4. Mudstone	Mudstone	Lakota mudstone commonly greenish- to brownish-gray, locally carbonaceous, locally contains ostracodes; contact gradational; Unkpapa mudstone is commonly greenish-gray to varicolored, noncarbonaceous, and grades downward through siltstone to argillaceous sandstone.

CHILSON MEMBER

The Chilson Member includes all rocks considered by Darton to be part of the Lakota Formation. Three distinct lithologies have been mapped within the Chilson Member—the dominant S_2 sandstone, interbedded sandstone and mudstone, and mudstone. The last two are lateral facies of sandstone S_2.

The thickness of the Chilson Member ranges from 209 feet, measured just east of the quadrangle boundary in the north-central part of sec. 2, T. 9 S., R. 5 E., to 410 feet, measured in the outcrop southeast of Flagpole Mountain in the NW¼ sec. 3, T. 9 S., R. 5 E. The maximum thickness of the Chilson Member results from the filling of a scour perhaps 150 feet deep in the underlying Unkpapa Sandstone.

The Chilson Member consists almost entirely of S_2 sandstone in the central part of the quadrangle. The lower part of the sandstone finers laterally into mudstone near the east and west margins of the area. The Chilson Member contains almost 200 feet of mudstone and a thin cap of sandstone on the north side of Buck Canyon in the northwestern part of the quadrangle. The mudstone includes beds of S_2 sandstone 10–15 feet thick that were not mappable at 1:24,000. This sandstone includes a few thin beds of mudstone that weather to benches, such as on the walls of Hell, Wildcat, and Green Canyons and in the Horseshoe Bend area. The S_2 sandstone becomes thin bedded or laminated or includes beds of friable silty sandstone in some places, particularly in upper Falls Canyon and Lindsley Canyon. In these places, S_2 sandstone weathers to a rubbly slope similar to slopes formed by mudstone lenses in the sandstone.

S_2 sandstone

The S_2 sandstone is the second major channel sandstone deposited during Early Cretaceous time in the southern Black Hills. It is restricted to the southern and southeastern Black Hills and is not recognized northwest of the Jewel Cave SW quadrangle. The earliest or S_1 sandstone is present from the west half of the Flint Hill quadrangle northwestward through much of the outcrop area of the Inyan Kara Group in the western part of the Black Hills.

S_2 sandstone is generally fine grained, well sorted, and quartzose and ranges from grayish yellow through yellowish orange to dark yellowish orange. In the eastern part of the Cascade Springs quadrangle, much of the sandstone is reddish brown. White clay grains are locally abundant, as are green clay pellets or galls and clots of interstitial green and white clay. These are especially common in the more silty units at the base of sandstone lenses or beds. Scattered local concentrations of calcium carbonate, either along joints or as golf-ball-sized concretions, are common.

S_2 sandstone is lenticular and commonly irregularly crossbedded, particularly in the lower parts of lenses. Generally, cross-laminae throughout the sandstone strike from N. 30° E. to N. 70° E. and dip northwestward. The bedding becomes thinner and more tabular near the tops of lenses, a condition resulting in slabby-weathering sandstone. Some of the thin sandstones in the lower part of the unit, particularly where interbedded with mudstone, are very fine grained and silty and consist of thin planar beds. Locally, bedding is marked by coarse-grained sandstone seams, one of which in Falls Canyon includes a well-rounded highly polished siliceous pebble about 3 inches in diameter. Bedding surfaces are irregular as a result of the presence of interference ripple marks or "tadpole nests." The bedding surfaces are commonly coated with a thin layer of iron oxide and green or gray clay.

Where the S_2 sandstone has been subjected to stress, as in places along the hogback ridge marking the west flank of the Cascade anticline, it is commonly crisscrossed by a network of silica-cemented shear fractures.

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The top of the S_2 sandstone, and thus the top of the Chilson Member, throughout much of the quadrangle is marked by a prominent pale- to moderate-reddish-brown sandstone ranging in thickness from 1 to 10 feet. Where the Minnewaste Limestone Member is present, this sandstone immediately underlies the limestone almost everywhere. The red sandstone has been traced discontinuously westward as far as Chilson Canyon in the Flint Hill quadrangle where it is exposed in the SW¼ sec. 13, T. 8 S., R. 3 E. The sandstone is widely exposed in the Cascade Springs quadrangle where it has been used as a marker bed for the Chilson-Fuson contact in the absence of the Minnewaste Limestone Member.

The red sandstone generally is fine grained, well sorted, and quartzose and locally contains scattered white clay grains, interstitial silt or clay, and tan clay pellets. It is commonly slightly calcareous, but the calcium carbonate may have washed down from the overlying Minnewaste Limestone Member or the limy rocks in the lower part of the Fuson Member.

The red sandstone is underlain by a variety of rock types. Most commonly it rests on typical grayish-yellow fine-grained S_2 sandstone. As much as 35 feet of olive-gray to yellowish-orange mudstone or siltstone occurs in places below the red sandstone and above the uppermost typical thick S_2 sandstone. The red sandstone forms a thin rim above green to gray mudstone as much as 25 feet thick in Cedar Canyon and in Lindsley Canyon at the center of sec. 12, T. 8 S., R. 4 E. The mudstone laterally becomes so thin as to be unmappable, and in Cedar Canyon it pinches out to the southeast leaving a section of continuous grayish-yellow sandstone with a red cap. Mudstones interbedded with S_2 are particularly well exposed on the north side of Buck Canyon near its mouth and along the west side of the hogback ridge south of Red Gulch gap.

The upper part of the Chilson Member contains abundant calcium carbonate in the southeastern part of the Cascade Springs quadrangle, particularly in the areas southwest of Horseshoe Bend and west of Tepee Mountain. The calcium carbonate is in limy sandstone and limy mudstone, and in some areas it forms a thin limestone similar to the Minnewaste about 10 feet below the true Minnewaste. The rocks underneath the limestone of the Minnewaste in the NE¼ sec. 9, T. 9 S., R. 5 E., consist of 12 feet of red sandstone that marks the top of S_2, underlain by 3–5 feet of limestone similar to the Minnewaste, which in turn is underlain by about 5 feet of red sandstone and a 5-foot-thick limestone. The Minnewaste in the south-central part of sec. 4, T. 9 S., R. 5 E., is underlain successively by about 25 feet of mudstone and 5 feet of limestone.

Interbedded sandstone and mudstone

Where the S_2 sandstone fingers laterally into a mudstone section, there is in places an intermediate interval in which neither the sandstones nor the mudstones are sufficiently thick to be mapped separately. These intervals have been mapped (with arbitrary boundaries in some places) as interbedded sandstone and mudstone.

The relative proportions of sandstone and mudstone vary from place to place. The units mapped as interbedded sandstone and mudstone consist in part of thin-bedded fine-grained to very fine grained yellowish-gray sandstones which are commonly thin bedded and locally irregularly or wavy bedded. These sandstones are interbedded with mudstone that ranges from shaly dark-brownish-gray siltstone to massive dark-gray or green claystone. Locally, such as on the east side of Hell Canyon in the SW¼ sec. 26, T. 8 S., R. 4 E., the sandstones of this unit are carbonaceous and contain abundant jarosite.

Mudstone

Mudstone, a major constituent of the Chilson Member in the northwestern and east-central parts of the quadrangle, varies considerably in character. In Hell Canyon in the western part of the quadrangle, mudstone in the lower part of the Chilson Member consists of brownish-gray silty claystone and green claystone that is locally silty, calcareous, and carbonaceous and contains abundant ostracodes. West of Lindsley Canyon in sec. 12, T. 8 S., R. 4 E., mudstone in the upper part of the Chilson Member ranges from green through yellowish olive gray to grayish red and includes several thin sandstones. On the south side of Sheps Canyon in the NE¼ sec. 28, T. 8 S., R. 5 E., the mudstone is characteristically a clean grayish-orange-pink to greenish-gray claystone. Near Green Canyon much of the mudstone in the upper part of the Chilson Member is light gray to greenish gray, locally silty, and calcareous and contains abundant dense finely crystalline light-gray limestone concretions 1½–6 inches in diameter.

Depositional environment of Chilson Member

The rocks of the Chilson Member of the Lakota Formation were deposited in a complex of fluviatile, lacustrine, and swamp environments similar to the valley-flat environment of Twenhofel (1950, p. 74). The S_2 sandstone was undoubtedly deposited by a stream or river system. The orientation of cross-laminae and the general distributive pattern of the unit suggest that the sediment came from the southeast and was carried northwestward through the southern Black Hills. The streams initially must have had considerable erosive power—enough to scour out 150 feet of the Unkpapa Sandstone prior to the deposition of S_2.

One characteristic of S_2 is the lack of carbonaceous material; in contrast, sandstone S_1, to the west, contains abundant carbonaceous material scattered particularly along bedding planes. The chemical and physical conditions that would allow the preservation of carbonaceous material in one channel sandstone and not in another are obscure—particularly inasmuch as the general petrographic characteristics of the two units are similar. The presence of reddish-brown sandstone in S_2 in the eastern part of the quadrangle and at the top of the unit over much of the quadrangle suggests that oxidizing conditions which would tend to destroy organic matter were more prevalent during the deposition of S_2 than during S_1 time. Perhaps climatic conditions were more arid during S_2 time than during S_1 time. Twenhofel (1950, p. 74) stated: "If climatic conditions permit a floodplain to maintain a plant cover, organic materials are mingled with the sediments. This reduces iron oxides, eliminates yellow to red colors, and produces gray to black colors. Flood plains of dry climates do not maintain a good vegetable cover, and the sediments tend to retain the colors of deposition; and if these are in the range from yellow to red, they may be expected to remain so."

S_2 sandstone is noticeably more yellow and reddish than S_1, particularly in the central and eastern parts of the Cascade Springs quadrangle where the Chilson Member includes practically no carbonaceous material. In the western part of the quadrangle, where there is some carbonaceous material in the mudstone units, the S_2 sandstone is not so noticeably yellow or red, except at the top.

The widespread red sandstone at the top of S_2 suggests that there was a period of subaerial exposure and consequent oxidation prior to the deposition of the overlying rocks. Further evidence of subaerial exposure and some erosion at the end of Chilson time is afforded by the disconformable relations of the basal parts of the Fuson Member and the Minnewaste Limestone Member with the red sandstone at the top of the Chilson Member along the east side of the Cheyenne River in the west-central part of sec. 2, T. 9 S., R. 4 E. Here the bedding of the Fuson and Minnewaste is wavy; and the waves, which have an amplitude of 1–2 feet, are parallel to an undulating, apparently scoured upper surface on the red standstone.

The interbedded sandstone and mudstone facies of the Chilson Member presumably are those rocks deposited along the margins of the main stream channels, where local flooding deposited coarse clastic material that became interbedded with the mudstones of the floodplain lakes and swamps. Fossils that represent a fresh-water fauna, according to I. G. Sohn and D. H. Dunkle of the Geological Survey, were found by Henry Bell and E. V. Post in the sandstone and mudstone unit of the Chilson Member in Buck Canyon in the Flint Hill quadrangle, just west of the Cascade Springs quadrangle. The general dark-gray to green colors of the mudstones in the interbedded sandstone and mudstone units, plus the presence of carbonaceous materials in some of these rocks in the western part of the quadrangle, suggest that these rocks were deposited in deeper, more permanent flood-plain lakes and swamps where they were rarely exposed to surface oxidizing conditions.

Mudstones of the Chilson Member—particularly those in the upper part of the member in the east-central part of the quadrangle—are interpreted as having been deposited in relatively quiet flood-plain lakes that perhaps dried up sufficiently at times to allow some oxidation of iron and the resultant production of some of the more vivid reds, yellows, and browns found in these rocks. The calcareous mudstones and abundant limestone concretions in the mudstone indicate that the lake waters were most probably hard.

MINNEWASTE LIMESTONE MEMBER

The Minnewaste was named by Darton (1901a, p. 529), who described it as a "nearly pure light-gray limestone, presenting a nearly uniform character throughout * * *" and ranging in thickness from 0 to about 25 feet. The Minnewaste is now considered to be a member of the Lakota Formation, as redefined by Waagé (1959), lying between the Chilson and Fuson Members. It is continuously exposed southeast of Red Gulch, and scattered exposures can be found throughout a considerable part of the west-central part of the quadrangle. The thickness of the limestone ranges from 0 in the northwestern part of the quadrangle to 80 feet in a gully draining into the east side of Tepee Creek in the NW¼ sec. 15, T. 9 S., R. 5 E. It is commonly 1–15 feet thick and generally thickens southeastward. Where the limestone is a foot or more thick it usually forms a good outcrop that weathers to a characteristic rough dark-gray surface.

The Minnewaste ranges in color from light olive gray to grayish orange pink and in composition from clean dense finely crystalline limestone through sugary-textured limestone to highly calcareous fine-grained sandstone. In some places the more sandy facies of the rock is a conglomerate of sugary-textured limestone pebbles in a calcareous sandstone matrix.

Rocks assigned to the Minnewaste Limestone Member in the SE¼ sec. 10, T. 9 S., R. 5 E., include, from the base upward, about 10 feet of pink calcareous very fine grained planar-bedded sandstone containing abundant tabular lenses of dense sandy gray limestone; about 10–15 feet of irregularly bedded stylolitic limestone that contains a thin very fine grained pink sandstone bed and weathers to a smooth cliff; and 15 feet of massive dense limestone that weathers to an irregular blocky or hackly surface. Where the member is 80 feet thick, the lower 50–60 feet consists of alternating thin beds of dense gray to pinkish-gray limestone and calcareous fine-grained sandstone, and the upper 20–30 feet consists of massive dense hackly-weathering limestone.

The Minnewaste Limestone Member commonly rests directly on the red sandstone that marks the top of the S_2 sandstone unit in the Chilson Member, but as much as 10 feet of olive-gray mudstone separates the two in some places, as in the south-center of sec. 18, T. 8 S., R 5 E. Where the red sandstone is absent, the Minnewaste rests on a yellowish-orange soft clayey sandstone as on the east side of Wildcat Canyon in the SE¼ sec. 22, T. 8 S., R. 4 E., and on the hogback ridge south of Cascade Springs in the SE¼ sec. 29, T. 8 S., R. 5 E. Where the Minnewaste Limestone Member is not present, the top of the Chilson Member is locally marked by a yellowish- to reddish-brown calcareous very fine grained sandstone that contains angular irregularly shaped tan clay fragments.

A fossil found in the Minnewaste Limestone Member in the NW¼ NE¼ sec. 9, T. 9 S., R. 5 E., was submitted to Richard Rezak of the Geological Survey, who, in collaboration with S. H. Mamay, stated: "Identification was not possible; however, it was agreed that the specimen is probably a plant representing some intermediate stage of development between the algae and vascular plants."

Small white siliceous concretionary grains were noted in the Minnewaste along the hogback ridge in sec. 7, T. 8 S., R. 5 E., at the north end of the quadrangle, and along the east side of Tepee Creek in the southeastern part of the quadrangle. These resemble microfossils but are apparently tiny siliceous concretions.

Table 5 contains the results of semiquantitative spectrographic analyses of limestone from three units of the Minnewaste at Tepee Mountain in the SE¼ sec. 10, T. 9 S., R. 5 E. The results are remarkably consistent, not only within the Minnewaste, but also between the Minnewaste and concretions of barite and limestone from the overlying Fuson Member. Remarkable also is the cerium content of the last four samples, which is at least 10 times the average abundance in the earth's crust (Taylor, 1964, p. 1281).

The Minnewaste Limestone Member was apparently deposited in a relatively local fresh-water lake restricted to the southeastern Black Hills. Isolated remnants of the Minnewaste in the Flint Hill and Edgemont NE quadrangles may represent outlying ponds formed at the same time and under virtually the same conditions as the main Minnewaste lake. Relatively clean limestone composes the upper part

TABLE 5.—*Semiquantitative spectrographic analyses of Minnewaste Limestone Member and concretions of barite and limestone from the Fuson Member of the Lakota Formation, Cascade Springs quadrangle, Fall River County, S. Dak.*

[Analyst, J. C. Hamilton. M, major constituent (>10 percent); 0, looked for but not detected]

Sample No.	1	2	3	4	5
Lab. No.	252509	252511	252512	252513	252514
Si	1.5	3	3	7	3
Al	1.5	3	1.5	1.5	1.5
Fe	.3	.7	.7	.7	.3
Mg	.3	1.5	.7	.3	.3
Ca	M	M	M	M	M
Na	.15	.15	.3	.3	.15
K	0	1.5	0	0	0
Ti	.03	.03	.03	.03	.03
Mn	.3	.3	.07	.07	.07
Ba	M	.07	.03	.03	.015
Ce	0	.05	.05	.05	.05
Cr	.0003	.0007	.0007	.0007	.0007
Cu	.0003	.0007	.0007	.0007	.0007
Sr	.7	.07	.15	.07	.03
V	.003	.003	.003	.003	.003
Y	.0015	.003	.0015	.0015	.0015
Yb	.00015	.0003	.0003	Tr	Tr
Zr	.003	.0015	.003	.003	.003

NOTE.—Looked for but not detected: Ag, As, Au, B, Be, Bi, Cd, Co, Dy, Er, Eu, Ga, Gd, Ge, Hf, Hg, Ho, In, Ir, La, Li, Lu, Mo, Nb, Nd, Ni, Os, P, Pb, Pd, Pt, Re, Rh, Ru, Sb, Sc, Sn, Sm, Ta, Tb, Te, Th, Tl, U, W, Zn.
Not looked for: Cs, F, Pr, Rb. Figures are reported to the nearest number in the series 7., 3.,1.5, 0.7, 0.3, 0.15 . . ., in percent. Sixty percent of the reported results may be expected to agree with the results of quantitative methods.

1. Barite concretion from Fuson Member, sec. 2, T. 9 S., R. 4 E.
2. Limestone concretion from Fuson Member at Tepee Mountain, SE¼ sec. 10, T. 9 S., R. 5 E.
3. From upper few feet of Minnewaste Limestone Member at Tepee Mountain.
4. From lower stylolitic Minnewaste Limestone, Tepee Mountain.
5. From concretionary limestone lens in lower calcareous sandstone part of Minnewaste, Tepee Mountain.

of the Minnewaste, particularly where the member is thickest. Near the present margins of the member, the rock becomes extremely sandy, in places grading into a calcareous sandstone. This facies of the limestone is interpreted as having formed near the shores of the lake where more clastic materials were deposited.

Inasmuch as there is no field or laboratory evidence of organic precipitation of the limestone and there are no known evaporites interbedded with the Minnewaste, the calcium carbonate was probably precipitated as cold carbonate-bearing waters were warmed in a shallow lake.

FUSON MEMBER

The Fuson Shale was named by Darton (1901a) for exposures in Fuson Canyon northeast of Hot Springs, S. Dak., and was reported by him to consist of 30–100 feet of very fine grained sandstone and varicolored massive shales and clay underlying the Dakota Sandstone and overlying the Minnewaste Limestone. Fuson Formation was used by Cobban (1952), and the unit was reduced to member rank in the redefined Lakota Formation by Waagé (1959).

The Fuson Member of the Lakota Formation is widespread in the north-central, west-central, and southeastern parts of the Cascade Springs quadrangle. It consists of two principal parts—the lower is dominantly mudstone and the upper is entirely sandstone.

The thickness of the lower part of the Fuson Member ranges from 10 feet, where it has been almost removed by erosion prior to the deposition of the overlying sandstone, to about 100 feet. It averages about 85 feet where the upper sandstone is absent. The thickness of the upper sandstone ranges from 0 to about 100 feet and averages about 65 feet. The thicknesses of the lower mudstone and upper sandstone parts of the Fuson Member compensate one another; thus, the usual thickness of the entire member is about 85–110 feet. The thicker sections occur where the upper sandstone is thickest.

The lower part of the Fuson is rarely exposed but normally forms a slope of clayey soil covered with grass. It is well expressed topographically along the hogback ridge south of Cascade Springs by a grassy gully between the sandstone of the Chilson Member of the Lakota Formation and the Fall River Formation. The best exposure in the quadrangle of the lower part of the Fuson Member is in the west-central part of sec. 2, T. 9 S., R. 4 E. Post and Bell (1961) proposed this section as a reference section for the Fuson in the southern Black Hills.

Five main rock types have been observed in the lower part of the Fuson. The most prominent and widespread of these is mudstone that ranges from clean claystone through sandy claystone to argillaceous siltstone. None of these rocks are fissile. The dominant color is medium to olive gray, but reddish-brown and grayish- to yellowish-green colors are locally dominant. The top of the Fuson Member in the east-central and southeastern parts of the quadrangle is marked by a white tough siltstone 2–3 feet thick, that weathers into irregularly shaped fragments less than one-half inch across.

Two types of sandstone, both characteristic of the lower part of the Fuson Member, are locally interbedded with the mudstone unit. The more prominent of these sandstones is as much as 20 feet thick, fine grained, white, highly argillaceous, and generally friable. It contains abundant white to pale-green interstitial clay and small red hematite spots. The rock is generally massive, although locally it is thin bedded or faintly cross-laminated. Outcrops of this standstone are generally small and scattered and probably represent relatively small isolated lenses enclosed within the mudstone of the Fuson rather than a continuous bed. Most of the exposures of this sandstone are shown on the preliminary geologic maps of the quadrangle (Post, 1959a, b; Post and Cuppels, 1959a, b; Post and Lane, 1959a, b) but are too small to be shown at 1:24,000 on plate 29.

The other type of sandstone in the lower part of the Fuson is thin bedded, ripple bedded, fine grained to very fine grained, yellowish gray to dusty yellow, locally reddish brown, and very calcareous. It commonly includes "worm tracks" on bedding surfaces and weathers with small circular pits ½ to 1 inch in diameter on bedding surfaces and lens-shaped pits on fracture surfaces normal to the bedding. This sandstone is generally less than 5 feet thick and is commonly found in the lower 15 feet of the Fuson. It has not been mapped separately from the mudstone.

About 5 feet from the base of the member, a characteristic conglomerate less than 1 foot thick is locally present, but it also is too thin to be mapped. The rock consists of dense olive-gray limestone and white silty claystone pebbles in a matrix of poorly sorted medium-gray calcareous sandstone. Ostracodes have been found in this unit on the east side of the Cheyenne River in the west-central part of sec. 2, T. 9 S., R. 4 E., and on the east side of Falls Canyon in the SE¼ sec. 14, T. 8 S., R. 4 E., as well as in Dick Canyon in the Flint Hill quadrangle. The ostracodes from the Flint Hill quadrangle were described by I. G. Sohn of the Geological Survey (written commun., March 1, 1966) as a "large smooth genus similar to *Petrobrasia* Krömmelbein, 1965, described from nonmarine lower Cretaceous rocks of Brazil and West Africa." Sohn added that, "Nested specimens suggest a lacustrine environment."

Colloform barite concretions as much as 6 inches in diameter occur locally above the conglomerate. The lower 15 feet of the Fuson Member in much of the quadrangle characteristically contains dense finely crystalline gray limestone concretions 1–2 feet in diameter. Semiquantitative spectrographic analyses of material from these concretions are given in table 5.

Highly rounded and polished siliceous pebbles have been found widely scattered throughout mudstone of the Fuson Member. Such pebbles apparently are widespread in the Lower Cretaceous throughout the western interior of the United States. They have been described variously as gastroliths and as wind-polished or stream-polished pebbles. They are characteristic of the unit, but their origin is obscure.

Rocks of the lower part of the Fuson Member represent a marked change in depositional environment from that in which the Chilson Member was deposited. The general massive character of the rocks constituting the lower part of the Fuson suggests continuous deposition in quiet water—presumably a lake. Limy mudstone and sandstone as well as limestone and barite concretions near the base of the unit indicate a gradual change in the chemical composition of the

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lake waters from Minnewaste time into Fuson time. The ripple-bedded sandstone in the lower part of the Fuson may indicate the existence of near-shore currents; the white argillaceous massive sandstone in the middle of the member appears to represent a discontinuous beach sand.

S_4 sandstone

The upper part of the Fuson Member in the Cascade Springs quadrangle consists entirely of the S_4 sandstone, which fills a channel scoured in places (for example, NE¼SE¼ sec. 26, T. 8 S., R. 4 E.) almost completely through the underlying dominantly mudstone part of the Fuson Member. The S_4 sandstone is exposed only in the west-central part of the quadrangle, where it forms cliffs that resemble very closely those formed by the S_5 sandstone of the Fall River Formation. The sandstone is exposed on the divide between Buck and Wildcat Canyons in the NE¼ sec. 22 and the NW¼ sec. 23, T. 8 S., R. 4 E.; it appears to pinch out along a line running southward from the NW¼ sec. 23, T. 8 S., R. 4 E., to the NW¼ sec. 26, T. 8 S., R. 4 E., and thence westward into the NE¼ sec. 27, T. 8 S., R. 4 E. The unit reappears in the central part of sec. 26 and extends southward to the Cheyenne River, where it dips under the alluvium in the north-central part of sec. 36, T. 8 S., R. 4 E. (See fig. 90.)

The basal contact of sandstone S_4 with the underlying Fuson mudstone is generally sharp and represents a marked erosional unconformity. The upper contact with the Fall River Formation is also sharp and, according to Waagé (1959), represents a regional transgressive disconformity between the terrestrial rocks of the Lakota Formation and the supposed marginal marine rocks of the Fall River Formation. Some evidence of subaerial oxidation after deposition of S_4 is afforded by the local occurrence of reddish-brown to reddish-orange thin-bedded sandstone at the top of the S_4 unit. The S_4 sandstone is overlain everywhere in the Cascade Springs quadrangle by the basal interbedded sandstone and siltstone unit of the Fall River Formation.

Most of sandstone S_4 is medium grained to fine grained, although there is characteristically an interval near the base that ranges from medium-grained sandstone to pebble conglomerate. Near the top the sandstone is locally coarse grained, as in Hell Canyon in the west-central part of sec. 26, T. 8 S., R. 4 E. Hand specimens are generally clean and well sorted and consist of well-rounded quartz grains. Pink quartz grains appear to be more common in S_4 than in other sandstone units in the Inyan Kara Group. Conglomerate is not so characteristic of the S_4 sandstone in the Cascade Springs quadrangle as it is in the Flint Hill quadrangle to the west. The thickest conglomerate in the

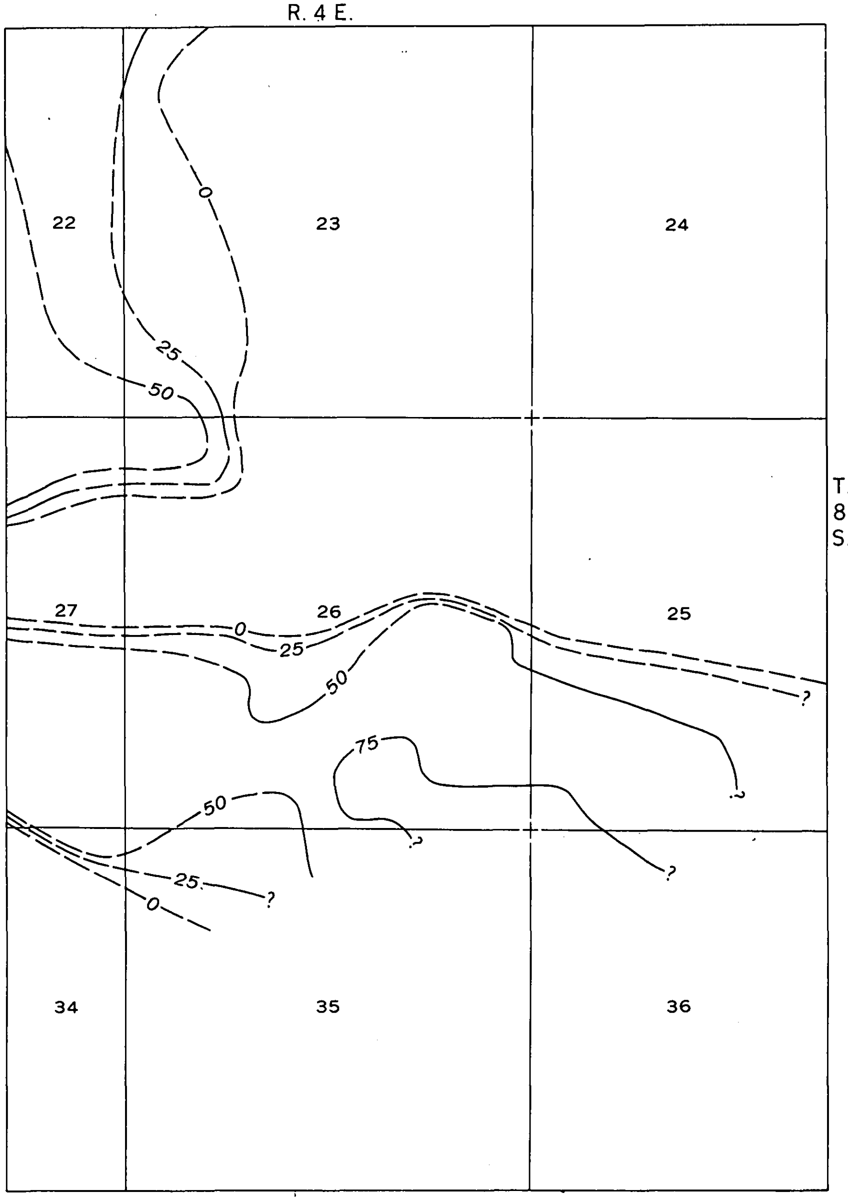

FIGURE 90.—Isopach map of S_4 sandstone in west-central part of Cascade Springs quadrangle. Isopachs show thickness in feet; dashed where approximately located.

unit in this quadrangle is along the divide between Buck and Wildcat Canyons, in particular on the Buck Canyon side of the divide, where S_4 consists of about 5 feet of silicified highly ferruginous chert-pebble conglomerate. Pebbles in this conglomerate range in diameter from ¼ inch to 1½ inches.

S_4 sandstone ranges from yellowish gray to light orange brown; the rock characteristically weathers to orange brown, giving it a distinct resemblance to the S_5 sandstone of the Fall River Formation.

In a few places, particularly near the mouths of Wildcat and Cedar Canyons, S_4 sandstone includes groups of siliceous or carbonate concretions, as well as some black manganese-carbonate concretions and joints stained with black manganese oxide. Iron oxides are commonly concentrated at the base of the unit, giving the rock a dark-reddish-brown color.

Crossbedding in sandstone S_4 is common; most of the cross-laminae dip northwestward, indicating that the stream that deposited the sandstone flowed northwestward. The crossbedding consists of wedge-shaped sets of cross-laminae separated by tabular sets of planar beds. This type of crossbedding is typical of aqueous cross-lamination, as illustrated by Twenhofel (1950, p. 588).

Sandstone S_4 apparently is a stream deposit laid down in a deep northwest-trending channel cut as a result of rejuvenation following the quiet depositional conditions of early Fuson time. The erosional disconformity at the base of this sandstone is perhaps the greatest in the entire Inyan Kara Group, with the possible exception of that at the base of the Lakota Formation.

FALL RIVER FORMATION

The Fall River Formation is exposed in much of the west half of the quadrangle, along the hogback ridge south of Cascade Springs, and in the southeast corner of the quadrangle. For mapping the formation has been subdivided into three informal units, each of which includes one or more different lithologies.

The complex interrelations among the various lithologies of the formation in the southeastern part of the quadrangle are shown in the panel diagram of plate 30, which was compiled from logs of exploratory drill holes prepared by R. L. Erickson, geologist for the Uranium Research and Development Co. These holes were drilled under an exploration contract with the Defense Minerals Exploration Administration, and the logs were submitted in reports to that agency. Facies changes in this area are so abrupt as to preclude the assignment of any lithology to any one of the three informal mapping units of the Fall River.

The Fall River Formation is thinner and generally more uniform in thickness than the Lakota. It ranges in thickness from 135 to about 180 feet; 160 feet is the common thickness throughout most of the quadrangle.

Like the Lakota, the Fall River Formation is a composite of clastic sediments deposited in stream and adjacent flood plain lake and swamp environments. However, the mudstones of the Fall River are more silty and contain more carbonaceous material than mudstones of the Lakota. Fall River sandstones exhibit more tabular bedding and more ripple marks and generally are micaceous, as compared with Lakota sandstones.

LOWER UNIT

The lower, laminated carbonaceous sandstone and siltstone is one of the most widespread and characteristic units of the Fall River Formation in the southern Black Hills. This unit ranges in thickness from 0 to 100 feet and averages about 50 feet; the unit is present everywhere at the base of the formation except where it has been removed by erosion and replaced by thick ledge-forming channel sandstone of the middle unit.

The contact at the base of this unit was considered by Waagé (1959) to represent a regional transgressive disconformity between the terrestrial rocks of the Lakota Formation and what are considered marginal marine rocks of the Fall River Formation. Broad interpretations such as these are beyond the scope of a report on such a limited area as this; nevertheless, the contact at the base of the interbedded sandstone and siltstone does represent a marked change in the character of the sediments, and it is one of the most widely recognized geologic boundaries in the southern Black Hills.

The character of the lower unit varies considerably from place to place within the quadrangle, but in general the unit is tabular and thin bedded to laminated, consists of gray to grayish-red siltstone interbedded with yellowish-gray fine-grained poorly sorted sandstone, and contains abundant finely divided carbonaceous material. At some localities, thin beds, laminae, and small spherical concretions of reddish-brown ironstone are interlayered with the siltstone. "Worm tracks" and ripple marks are abundant locally on bedding surfaces. Ripple marks generally trend northeastward, and some are asymmetric, indicating a northwesterly current flow.

One of the best exposures of the lower unit is in the opencut at the Canyon Lode uranium deposit in the SW¼SE¼ sec. 25, T. 8 S., R. 4 E. Here the unit, which is about 75 feet thick, consists of gray thin-bedded fine-grained carbonaceous sandstone containing thin seams of carbonaceous siltstone, thin beds of gray carbonaceous mudstone, abundant pyritic concretions, and black manganese oxide. Much of the sandstone sparkles as a result of secondary silica overgrowths on the quartz grains.

Sixty feet of the basal unit is exposed in the south-central part of sec. 35, T. 8 S., R. 4 E.; the lower 20 feet consists of thin-bedded sandstone with siltstone partings, and the upper 40 feet contains approximately equal parts of interbedded thin standstone and laminated carbonaceous siltstone.

The basal laminated carbonaceous sandstone and siltstone unit is also well exposed in a bulldozer road up the steep hill north of the Brainerd Indian Training School in the NE¼ sec. 19, T. 8 S., R. 5 E., and along a bulldozer road on the south side of the canyon in the NW¼NE¼ sec. 24, T. 8 S., R. 4 E.

MIDDLE UNIT

S_5 sandstone

The so-called "Dakota sandstone" mentioned so frequently in the geologic literature of the Black Hills is largely represented in the southern Black Hills by the S_5 sandstone of the middle unit of the Fall River Formation. This sandstone caps many of the interstream divides in the western part of the Cascade Springs quadrangle, where it forms thick vertically jointed yellowish-orange cliffs considered characteristic of the "Dakota."

The S_5 sandstone ranges in thickness from 0 to about 110 feet. It appears to interfinger southeastward with mudstone of the middle unit. These rocks have been mapped as sandstone and mudstone where beds are too thin to be mapped individually. The thin sandstone beds in the sandstone and mudstone unit are probably lateral extensions of the S_5 channel sandstone on the flood plain of the stream that deposited sandstone S_5. The S_5 sandstone forms the basal unit of the Fall River Formation where it fills scours cut through the interbedded sandstone and siltstone of the lower unit.

The thick S_5 sandstone is at the base of the Fall River Formation along much of the hogback ridge south of Cascade Springs, in sec. 9, T. 9 S., R. 5 E., and southeast of Angostura Reservoir. Sandstone S_5 in these areas does not seem to interfinger with mudstone of the middle unit, as it does in the western part of the quadrangle where interbedded sandstone and mudstone is mapped.

S_5 sandstone is generally yellowish gray to yellowish orange, but locally a concentration of iron oxide colors the lower 1–2 feet dark reddish brown to moderate brown. The rock is characteristically fine grained and well sorted, contains little interstitial material, and consists largely of well-rounded to subrounded quartz grains with only minor amounts of chert and very sparse feldspar grains. Muscovite is locally abundant and is considered diagnostic of Fall River sandstones. It is usually more apparent in crushed samples of sandstone.

Silica cement in S_5 locally produces a tough quartzite. Perhaps the best exposure of this quartzite in the quadrangle is on Roundtop Hill in the northwestern part of the area, where all degrees of silicification from uncemented sandstone to tough, tightly cemented quartzite can be observed. The cement is concentrated along northwestward-trending joints. Silica cement also occurs in one small patch along the hogback ridge in the SE¼ sec. 32, T. 8 S., R. 5 E., as well as on Flagpole Mountain and on the small northwestward-trending topographic terrace at 4,025-foot elevation in the NE¼ sec. 4, T. 9 S., R. 5 E.

Blocks of silicified S_5 sandstone litter the mudstone slopes of the Fuson Member along the ridge north of Green Canyon in the south-central part of sec. 27, T. 8 S., R. 5 E. These blocks were probably dropped by undercutting of the less resistant mudstone and eventual collapse of the overhanging quartzite ledge.

From a distance sandstone S_5 appears massive, but on close examination scour-and-fill structures and cross-stratification are common. Cross-stratification generally falls into the categories of planar or trough, as described by McKee and Weir (1953). Some cross-strata are slumped and overturned in their direction of dip, which in general is northwestward; this may indicate the direction of flow of the stream which deposited the sandstone.

Joints are more conspicuous in sandstone S_5 than in any other unit in the Inyan Kara Group, with the possible exception of sandstone S_4. The prevailing joint system consists of a dominant N. 30°–40° W. set, with a secondary N. 70° E. set. The intersection of these two joint sets in the thick S_5 cliffs produces a pseudocolumnar jointing that is typical of the sandstone.

Mudstone, interbedded sandstone and mudstone, and interbedded sandstone and siltstone

The middle unit of the Fall River Formation consists principally of mudstone where the S_5 sandstone is absent. Claystone is dominant, but massive to laminated carbonaceous siltstone is locally common. The average thickness of the mudstone is about 60 feet, and the minimum is probably about 10–20 feet.

This interval has been mapped as interbedded sandstone and mudstone in the center of the quadrangle where several beds of sandstone 2–10 feet thick occur. These sandstones are dark yellowish orange, fine grained, and ripple marked and apparently are extensions of S_5 sandstone on the flood plain of the stream which deposited S_5. Ripple marks on these thin sandstones commonly trend northeastward; some are asymmetric, indicating a current flow to the northwest.

Much of the Fall River Formation in the south half of secs. 35 and 36, T. 8 S., R. 4 E., consists of thin interbedded carbonaceous siltstone and fine-grained sandstone. In this area, the middle part of the formation has been mapped as interbedded sandstone and siltstone. The contact between this unit and similar rocks in the upper unit of the formation is inferred.

UPPER UNIT

The upper unit of the Fall River is 25 to more than 75 feet thick and averages about 35 feet in thickness. It consists principally of the S_6 sandstone and variegated mudstone and is widely exposed in the quadrangle on dip slopes on the Fall River Formation.

Variegated mudstone

Reddish-brown or variegated mudstone forms an excellent marker bed at the base of the upper unit through much of the Cascade Springs quadrangle. This mudstone is equivalent to the red or variegated mudstone mapped in the Edgemont NE quadrangle (Gott and Schnabel, 1963) and in the Burdock quadrangle (Schnabel, 1963). Particularly good exposures are visible in a bulldozed road north of the center of sec. 18, T. 8 S., R. 5 E.; in Mike Canyon in the SW¼ sec. 30, T. 8 S., R. 5 E.; on the south side of Lindsley Canyon in the NW¼ sec. 19, T. 8 S., R. 5 E.; and in the NE¼NW¼NE¼ sec. 16, T. 9 S., R. 5 E.

S_6 sandstone

The S_6 sandstone forms most of the upper unit. In many places this sandstone comprises two beds about 10 feet thick separated by as much as 10 feet of dark-gray silty mudstone. The sandstone is typically yellowish gray to dark orange brown, fine grained, and micaceous. It commonly becomes more silty, thin bedded, slabby, and ripple marked near the top. Almost without exception, the ripple marks trend northeastward; some are asymmetric and indicate a current flow to the northwest.

Sandstone S_6 is overlain by laminated carbonaceous siltstone which rarely exceeds 5 feet in thickness. The siltstone grades upward into the Skull Creek Shale, but the generally poor exposure of the gradational interval has necessitated the mapping of the well-exposed top of the uppermost S_6 sandstone bed as the top of the Fall River Formation.

Interbedded sandstone and siltstone

South of Cascade Springs the S_6 sandstone is interbedded with gray carbonaceous siltstone, and no sandstone bed is thick enough to be mapped. In this area the unit has been mapped as interbedded sandstone and siltstone. The interbedded unit grades up into the Skull Creek Shale through laminated carbonaceous siltstone; the top of the uppermost sandstone bed is mapped as the contact.

DEPOSITIONAL ENVIRONMENT OF FALL RIVER FORMATION

The rocks of the Fall River Formation were deposited in a variety of geologic environments that ranged from an aggrading stream through flood plain swamps and marshes to flood plain lakes. The products of these environments were, respectively, channel sandstones such as S_5, laminated carbonaceous siltstone and sandstone, and clayey mudstone. The uppermost laminated carbonaceous siltstone that grades into the Skull Creek Shale must have been formed in a marginal marine swamp or marsh that was subjected to frequent flooding by marine waters. Rubey (1930, p. 5) stated that marine fossils have been found in the upper 20 feet of the Fall River Formation. The drab gray colors of the carbonaceous mudstones of the Fall River Formation suggest that reducing conditions were more prevalent than they were during Lakota time when the more varicolored and less carbonaceous mudstones of the Lakota Formation were formed.

STRATIGRAPHIC SECTIONS OF INYAN KARA GROUP

Several representative stratigraphic sections of all or parts of the Inyan Kara Group measured in the Cascade Springs quadrangle follow. They are presented in the general order of their geographic position—primarily from west to east and secondarily from north to south.

Stratigraphic section of part of the Inyan Kara Group measured in the center W½ sec. 2, T. 9 S., R. 4 E.

[Measured by E. V. Post and D. W. Lane]

	Feet
Fall River Formation, in part (top not present):	
Upper unit:	
16. Sandstone S_6, light-gray, medium- to fine-grained, crossbedded; forms prominent ledge	25.0
15. Covered; probably underlain by mudstone and thin sandstones	50.0
Middle unit:	
14. Clay-fragment breccia probably equivalent to S_5; gray clay fragments in a fine-grained yellowish-gray sandstone matrix; alternating friable and well-cemented beds; the better cemented beds contain relatively few clay fragments and consist largely of dark-yellowish-orange micaceous fine-grained sandstone; top is slabby	30.0
Lower unit:	
13. Siltstone, dark-gray, carbonaceous, laminated; becomes sandy and more massive at top	30.0
12. Sandstone, yellowish-gray, fine-grained, locally micaceous; contains white clay grains in streaks along bedding, bedding wavy; weathers cavernous	12.0
Thickness of Fall River Formation	147.0

Stratigraphic section of part of the Inyan Kara Group measured in the center W½ sec. 2, T. 9 S., R. 4 E.—Continued

	Feet
Lakota Formation:	
Fuson Member:	
11. Sandstone, white to pink, medium- to fine-grained; contains abundant interstitial white clay in streaks along bedding; friable; broad low-angle crossbeds; weathers rounded; becomes clayey at top; grades laterally within 10 ft to light-gray silty claystone	38.0
10. Claystone, variegated green to maroon; silty at base	10.0
9. Mudstone, yellow; jarositic, limonitic, gypsiferous; in part a boxwork of selenite with little mudstone	1.0
8. Claystone, dark-gray to medium-greenish-gray; largely clean, some apparently carbonaceous; hackly fracture	26.0
7. Conglomerate, medium-gray; consists of olive-gray dense limestone pebbles and white silty claystone pebbles in a very calcareous medium- to fine-grained sandstone matrix; a discontinuous zone of dense medium-gray limestone concretions 1–2 ft in diameter at top	1.5
6. Claystone, dark-gray to olive-gray	5.5
5. Sandstone, light-yellowish-gray, calcareous, tightly cemented; wavy bedding	3.0
Total thickness of Fuson Member	85.0
Minnewaste Limestone Member:	
4. Limestone, pinkish-gray, dense; contains streaks of coarsely crystalline calcite	2.0
Chilson Member, in part (S_2 sandstone):	
3. Sandstone, pinkish- to yellowish-orange, fine grained to very fine grained, moderately well cemented; sparkles because of secondary silica overgrowths on quartz grains; color banded with red iron-oxide bands along laminae of abundant white clay grains; 5 ft of moderate-reddish-brown sandstone at top	35.0
2. Sandstone, mottled light-green to pale-red, very fine grained, well-consolidated; interbedded with light-green siltstone	30.0
1. Sandstone, somewhat mottled pinkish- to grayish-orange, fine-grained, well-sorted; subangular to subrounded quartz grains, little interstitial material; forms a massive cliff composed of several festoon-type scours, the boundaries of which are marked by extremely friable sandstone streaked with interstitial green clay and containing abundant purplish-green siltstone fragments; contains silicified fossil logs, some lenses of coarser sandstone, and scattered blebs of green clay, especially in the upper part	47.0
Base of unit not exposed.	
Thickness of Chilson Member measured	112.0
Thickness of Lakota Formation measured	199.0
Thickness of Inyan Kara Group measured	346.0

Stratigraphic section of Inyan Kara Group measured at Red Gulch in the SW¼SE¼ sec. 29, T. 8 S., R. 5 E.

[Measured by E. V. Post and D. W. Lane]

	Feet
Skull Creek Shale, not measured.	
Fall River Formation:	
Upper unit:	
17. Mudstone, gray, silty; upper contact indefinite	5
16. Sandstone S_6, fine-grained	11
15. Mudstone, silty, gray to reddish-gray; contains thin discontinuous sandstone beds	58
Middle unit:	
14. Mudstone, silty, gray; replaced by thin-bedded sandstone in stream gully	58
13. Sandstone S_5, yellowish-orange, fine-grained, well-sorted; lower 2–3 ft conspicuously crossbedded; generally thin bedded with thin siltstone seams along bedding planes; upper part contains abundant clay galls and some ferruginous wood fragments on bedding planes	33
Total thickness of Fall River Formation	165
Lakota Formation:	
Fuson Member:	
12. Claystone, varicolored dark-gray, very dusky red, grayish-yellow-green; includes one thin red fine-grained ripple-bedded sandstone	47
11. Sandstone, very pale orange, fine-grained, well-sorted, ripple-laminated	13
10. Claystone, medium- to dark-gray, slightly calcareous; 1 ft very calcareous shaly siltstone at base	10
Total thickness of Fuson Member	70
Minnewaste Limestone Member:	
9. Lower 6 ft medium-gray clean limestone; upper 2 ft silty to sandy limestone	8
Chilson Member (largely S_2 sandstone):	
8. Sandstone, pale- to moderate-reddish-brown, very fine-grained, slightly calcareous; bedding and color very irregular; contains abundant pellets as much as 1 in. in diameter of tan siltstone, chert, and dolomitic limestone	17
7. Largely covered; scattered exposures of red sandstone, tan siltstone, medium-gray to maroon claystone	17
6. Sandstone, moderate-yellowish-orange to light-reddish-brown, conspicuously crossbedded in lower 10 ft; upper part moderate yellowish orange, fine grained, well sorted, not distinctly crossbedded	32
5. Partly covered; probably largely moderate-yellowish-orange fine-grained sandstone with a few thin mudstone beds	80
4. Covered	26

Stratigraphic section of Inyan Kara Group measured at Red Gulch in the SW¼SE¼ sec. 29, T. 8 S., R. 5 E.—Continued

	Feet
Lakota Formation—Continued	
Chilson Member—Continued	
3. Sandstone, moderate-yellowish-orange, fine-grained, well-sorted, indistinctly crossbedded; forms ledge	16
2. Covered; some evidence of medium-gray to olive-gray mudstone	29
1. Sandstone, moderate-yellowish-orange, fine-grained, well-sorted, indistinctly crossbedded; base not exposed	22+
Total thickness of Chilson Member measured	239+
Total thickness of Lakota Formation measured	317+

Lithologic log of U.S. Atomic Energy Comm. diamond drill hole SHR–2, SE¼NE¼ sec. 19, T. 8 S., R. 5 E.

	Feet
Fall River Formation, in part (top not present):	
Upper unit:	
32. Mudstone, medium-gray, micaceous, carbonaceous; badly chewed by drilling	10.0
31. Sandstone S_6, dark-yellowish-orange, fine-grained, moderately well-sorted; subangular to subround grains; contains abundant mica, scattered specks of carbonaceous material, iron-oxide stain associated with clay; few thin claystone seams broken and largely lost by drilling	3.5
30. Mudstone, olive- to yellowish-gray; fine mica and carbonaceous material; fissile at top and bottom	14.5
Middle unit:	
29. Sandstone, grayish-orange to very pale orange, fine-grained, well-sorted; moderate mica, iron-oxide stain associated with clay grains, scattered clay galls, and specks of carbonaceous material; lower part yellowish gray to light olive gray, silty, grades into siltstone	10.5
28. Mudstone, light-olive-gray to yellowish-gray; silty at top; locally contains abundant mica and fine carbonaceous material; upper part contains a highly calcareous fine-grained to very fine grained 2½-ft-thick sandstone with scattered specks of carbonaceous material	22.0
27. Mudstone, yellowish-gray to olive-gray, micaceous; abundant dark sand grains	2.2
26. Sandstone, light-gray, very fine grained; abundant mica and carbonaceous material	1.0
25. Mudstone, medium-light-gray to light-olive-gray, fissile; lower half is massive, highly carbonaceous, and contains small pyrite concretions	4.8
24. Sandstone, yellowish-gray, fine-grained; abundant mica and carbonaceous fragments and specks	1.5
23. Mudstone, medium-light-gray, fissile, micaceous; contains scattered fragments and specks of carbonaceous material in upper part	4.0

Lithologic log of U.S. Atomic Energy Comm. diamond drill hole SHR-2, SE¼NE¼ sec. 19, T. 8 S., R. 5 E.—Continued

	Feet
Fall River Formation, in part (top not present)—Continued	
Middle unit—Continued	
22. Sandstone, light-gray, micaceous; contains scattered fragments of pyritic carbonaceous material	0.5
21. Mudstone, light-olive-gray; contains sparse mica, abundant fragments of pyritic carbonaceous material; locally becomes dark gray and more carbonaceous	10.5
20. Sandstone S_5, pale-grayish-orange to light-brownish-gray, fine-grained, highly micaceous; contains local seams of hematite and abundant fragments of carbonaceous material; argillaceous in lower part	59.0
Thickness of Fall River Formation measured	144.0
Lakota Formation:	
Fuson Member:	
19. Mudstone, pale-yellowish-gray, very sandy, massive, cohesive; forms good core; contains irregular streaks of clean clay; lower foot has abundant clay pellets and is very sandy	12.0
18. Sandstone, white, fine-grained, well-sorted; some interstitial clay; calcareous	4.0
17. Claystone, variegated moderate-yellowish-green to grayish-red; sandy; middle part grades into clayey sandstone	29.0
16. Sandstone to sandy claystone, light-greenish-gray, locally pyritic, calcareous	3.0
15. Mudstone, variegated grayish-olive to olive-gray; ranges from claystone to siltstone; massive; locally pyritic	28.5
Total thickness of Fuson Member	76.5
Minnewaste Limestone Member:	
14. Sandstone, mottled yellowish-gray to light-gray, some pale-red, fine-grained, highly calcareous, hard	1.0
Total thickness of Minnewaste Limestone Member	1.0
Chilson Member (largely S_2 sandstone):	
13. Sandstone, mottled reddish-orange, fine-grained, well-sorted, firm, moderately calcareous	7.5
12. Siltstone to very fine grained sandstone, medium-gray; sparse very fine grained mica	3.5
11. Sandstone, moderate-reddish-orange, fine grained to very fine grained; contains splotches of interstitial green clay; moderately calcareous	7.5
10. Mudstone, light-olive-gray, slightly silty; contains pyrite cubes; massive; hard; makes good core; lower contact gradational	2.6
9. Siltstone, medium-olive-gray, carbonaceous, irregularly laminated; contains stringers of fine-grained sandstone	1.8
8. Sandstone, moderate-orange-pink to pale-reddish-orange, fine-grained, well-sorted; contains abundant white clay grains; locally calcareous; massive; locally grades into light-gray siltstone	63.6
7. Mudstone, light-olive-gray, silty, massive, badly broken	10.0

Lithologic log of U.S. Atomic Energy Comm. diamond drill hole SHR-2, SE¼NE¼ sec. 19, T. 8 S., R. 5 E.—Continued

Lakota Formation—Continued

Chilson Member—Continued

	Feet
6. Sandstone, grayish-yellow, fine-grained, well-sorted, clean; near base becames coarser and more argillaceous and color changes to light yellowish orange mottled with grayish red	22.0
5. Sandstone, medium-light-gray to light-brownish-gray; very fine grained to siltstone; argillaceous; grades downward into silty mudstone	14.0
4. Sandstone, very pale orange to yellowish-gray, fine-grained to very fine grained, well-sorted, clean; abundant white clay grains; locally mottled with red iron-oxide stain; contains two medium-gray shale splits; base contains streaks of gray siltstone and carbonaceous fragments	195.0
3. Mudstone, grayish-black; grades from claystone to fine-grained sandstone; contains carbonaceous material and disseminated fine-grained pyrite; local intense reddish-brown to yellowish-green iron-oxide stain	10.0
2. Sandstone, yellowish-gray, fine-grained to very fine grained, argillaceous	11.0
Total thickness of Chilson Member	348.5
Total thickness of Lakota Formation	426.0
Total thickness of Inyan Kara Group measured	570.0
Unkpapa Sandstone, in part:	
1. Sandstone, light-gray, very fine grained, slightly argillaceous	50.0

Stratigraphic section of lower part of Lakota Formation measured southeast of Flagpole Mountain in the NW¼ sec. 3, T. 9 S., R. 5 E., and the adjacent SE¼ sec. 33, T. 8 S., R. 5 E.

[Measured by E. V. Post]

Lakota Formation:

Minnewaste Limestone Member:

	Feet
11. Limestone, medium-gray, sandy; grades into limy sandstone; beds about 2 ft. thick; weathers hackly	12
Chilson Member (largely S_2 sandstone):	
10. Sandstone, yellowish-orange, fine-grained; weathers rounded	15
9. Mudstone, light-gray to light-greenish-gray; predominantly claystone; some yellowish-gray argillaceous siltstone; locally calcareous; top 2 ft. reddish-brown to yellowish-orange siltstone	20
8. Sandstone, yellowish-orange, fine-grained; crossbedded with intricate scour-and-fill structures; silicified logs abundant; thickens abruptly southwestward and interfingers with overlying mudstone	15
7. Mudstone; lower part medium-gray moderately calcareous silty claystone to clean claystone; upper part medium- to light-gray noncalcareous argillaceous siltstone	20
6. Sandstone, pale-yellowish-orange, fine-grained to very fine grained; unit composed mainly of 4 thick beds of sandstone which are internally cross bedded	60

Stratigraphic section of lower part of Lakota Formation measured southeast of Flagpole Mountain in the NW¼ sec. 3, T. 9 S., R. 5 E. and the adjacent SE¼ sec. 33, T. 8 S., R. 5 E.—Continued

Lakota Formation—Continued

Chilson Member—Continued

	Feet
5. Mudstone; unit largely covered; 5 ft. of brownish-gray sparsely carbonaceous clay shale at base overlain by less than 5 ft. of tabular-bedded light-gray fine-grained sandstone; upper part of unit is moderate-yellowish-gray to moderate-gray calcareous mudstone which breaks with an irregular fracture	25
4. Sandstone, pale-yellowish-orange, very fine grained to fine-grained, well-sorted; contains scattered small irregular patches of white to light-greenish-gray interstitial clay; lower and middle parts of unit consist of large lenses of crossbedded sandstone which are separated laterally by thin lenses of gray to grayish-red claystone. Bedding at top of unit more tabular and uniform	160
3. Largely covered; probably greenish-gray silty claystone containing thin tabular-bedded very fine grained light-gray sandstone	35
2. Sandstone, grayish-yellow, very fine grained; yellowish iron stain in streaks parallel bedding; thin tabular beds 1–3 ft thick, becoming more massive in top half of unit	60
Thickness of Chilson Member	410
Partial thickness of Lakota Formation	422

Unkpapa Sandstone (in part):

1. Sandstone, pale-pink, fine-grained; weathers to rounded, somewhat cavernous cliffs; thickness probably not greater than 50 ft.

Stratigraphic section of part of the Lakota Formation measured southeast of Flagpole Mountain in the NE¼ sec. 3, T. 9 S., R. 5 E.

[Measured by E. V. Post]

Lakota Formation (in part):

Chilson Member (largely S_2 sandstone):

	Feet
9. Sandstone, dark-yellowish-orange, fine-grained, well-sorted, crossbedded; local concentrations of golf-ball-sized carbonate concretions; top of unit eroded	45
8. Mudstone, greenish-gray; sandy claystone to argillaceous siltstone	8
7. Sandstone, dark-yellow-orange (moderate reddish brown in basal 10 ft), fine-gained, well-sorted, crossbedded; local concentrations of golf-ball-sized carbonate concretions	40
6. Mudstone; ranges from greenish-gray to moderate-gray sandy clay to medium-gray and dusky-yellow siltstone	35

Stratigraphic section of part of the Lakota Formation measured southeast of Flagpole Mountain in the NE¼ sec. 3, T. 9 S., R. 5 E.—Continued

	Feet
Lakota Formation—Continued	
Chilson Member—Continued	
5. Conglomerate; matrix is moderate reddish-orange to grayish-yellow fine-grained to very fine grained sandstone which contains flakes, galls, and irregular fragments of mottled pale-greenish-yellow to pale-red siltstone. Locally the sandstone forms irregular discontinuous resistant ledges containing thin streaks of siltstone fragments. The fragments weather out of the more resistant sandstone ledges leaving a pock-marked surface; top 25 ft largely sandstone with few thin conglomerate beds	40
4. Mudstone; grades from brownish-gray clay shale through varicolored sandy clay to clayey siltstone	29
3. Siltstone, dark-brownish-gray, highly carbonaceous, laminated to massive; top 1–2 ft grades into carbonaceous clay shale; more massive siltstone contains polished well-rounded siliceous pebbles and pebbles of clean fine-grained sandstone surrounded by carbonaceous material; unit generally forms a thin irregular ledge	8
2. Sandstone, white, very fine grained, silty to clayey; 2 ft of laminated highly carbonaceous siltstone at base; thin seams of olive clay; locally contains abundant fragments of charred wood; top grades into varicolored sandy mudstone and yellowish friable very fine grained sandstone	20
1. Sandstone, light-gray, yellowish-gray-weathering, fine-grained to very fine grained, crossbedded to massive; consists of irregular lenses of sandstone; thickness variable, as unit fills small scours cut in underlying Unkpapa Sandstone	20
Partial thickness of Chilson Member of Lakota Formation	245
Unkpapa Sandstone, not measured.	

SKULL CREEK SHALE

The Skull Creek Shale is the lowermost unit of a series of marine shales and sandstones between the Fall River Formation and the Greenhorn Limestone. This group of rocks was called the Graneros Shale by Darton (1901a, p. 532), who incorrectly correlated it with Gilbert's (1896) Graneros Shale of eastern Colorado. (See Waagé, 1959, p. 22.) The Graneros of the Black Hills region was subsequently subdivided, and the Skull Creek Shale first named (as a member of the Graneros Shale) by Collier (1922).

The Skull Creek Shale occurs in several parts of the Cascade Springs quadrangle and is best exposed in the area between Coffee Flat and Sorghum Flat. It also occurs west of Cascade Creek, northwest and southeast of Red Gulch, and in the southeast corner of the quadrangle.

The thickness is difficult to measure because of the general softness, low dip, and indefinite upper contact of the formation; however, 250 feet is a good average for the thickness within this quadrangle.

Most of the Skull Creek consists of medium- to dark-gray marine shale. There are a few lenses and beds of yellowish-gray calcareous sandstone, and about 100 feet from the base of the formation is a 3-inch-thick bed of medium-brown to yellowish-brown cone-in-cone limestone. In many places the lower 15 feet of the formation contains scattered brownish-gray calcareous and ferruginous siltstone concretions and abundant selenite crystals.

The basal contact with the Fall River Formation is generally gradational upward through several feet of laminated carbonaceous siltstone to dark-gray shale. The contact is commonly mapped at the top of the uppermost sandstone in the Fall River, which is at the base of the gradational sequence. This is one of the best exposed contacts in the quadrangle. It may be seen west of Cascade Creek in sec. 31, T. 8 S., R. 5 E.; along the road from Coffee Flat to Rocky Ford in sec. 1, T. 9 S., R. 4 E.; along the Cheyenne River in sec. 15, T. 9 S., R. 4 E.; and in sec. 16, T. 9 S., R. 5 E., south of Angostura Reservoir. The upper contact of the Skull Creek Shale is difficult to map accurately for reasons discussed in the section on the Mowry Shale.

West of Coffee Flat, a few sandstone dikes have been mapped in the Skull Creek Shale. At least one crosses the upper contact with the Mowry Shale. Most of the dikes are found in the Mowry, however; and they will be discussed with that formation.

The Skull Creek is not abundantly fossiliferous, and little attempt was made to search for fossils. However, the pelecypod *Inoceramus bellvuensis* Reeside was found in a small thinly bedded lens of dark-grayish-brown calcareous sandstone about 150 feet up from the base of the formation just east of Rocky Ford in sec. 12, T. 9 S., R. 4 E. The formation is considered to be of Early Cretaceous age (Cobban and Reeside, 1952).

MOWRY SHALE

The Mowry Shale was considered by Cobban and Reeside (1952) to be the youngest formation of Early Cretaceous age in the Black Hills. The formation was named by Darton (1904) for a type area on the east side of the Bighorn Mountains, Wyo.

The Mowry Shale is neither widely exposed nor well exposed in the Cascade Springs quadrangle. Its thickness is difficult to measure, but it appears to average about 150 feet. The Mowry is best exposed south of Coffee Flat, where it contains abundant irregular masses and dikes of sandstone. Other exposures are found east and west of Red Gulch and along Little Tepee Creek in the southeastern part of the quadrangle. Stands of pine trees, which appear to grow preferentially on the Mowry, indicate the general distribution of the Mowry.

Although the Mowry in the southeastern Black Hills is not characteristically siliceous as is the Mowry Shale of northeastern Wyoming (Rubey, 1929, p. 155), there are subtle differences in the lithology of the Skull Creek, Mowry, and Belle Fourche Shales. The Mowry Shale is a medium-light-gray or brownish-gray shale in contrast to the dark-gray or grayish-black of the Skull Creek and Belle Fourche. (See fig. 91.) In general, the Mowry splits into larger flakes (1 in. or more in diam.) than the adjacent units, and it appears to be more thinly fissile. Thin sandstone beds and sandstone masses and dikes are common in the Mowry; they are rare in the Skull Creek and Belle Fourche Shales.

The contact between the Mowry and Skull Creek Shales is difficult to map accurately in the Cascade Springs area because of the atypical nature of the Mowry and because of the absence of the Newcastle Sandstone which separates the two formations in other parts of the Black Hills region. The contact is mapped in places at the base of a 15-foot-thick zone of interlaminated carbonaceous siltstone and dark-gray shale, which may represent the interval of the Newcastle Sandstone in this area. This siltstone unit is best exposed in bluffs along the Cheyenne River in the center of sec. 12, T. 9 S., R. 4 E. Elsewhere, the

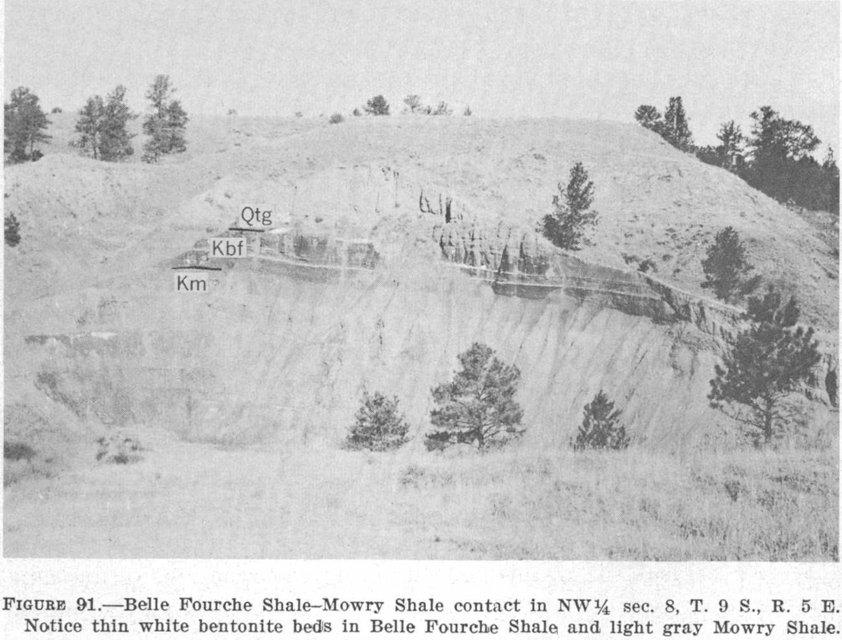

FIGURE 91.—Belle Fourche Shale–Mowry Shale contact in NW¼ sec. 8, T. 9 S., R. 5 E. Notice thin white bentonite beds in Belle Fourche Shale and light gray Mowry Shale. Qtg, terrace gravel; Kbf, Belle Fourche Shale; Km, Mowry Shale.

contact was mapped beneath a thin calcareous sandstone bed which overlies a layer of calcareous concretions. This sandstone and concretion sequence correlates with a similar interval noted about 15 feet stratigraphically above the Newcastle in the southwest corner of the Flint Hill quadrangle.

The upper contact of the Mowry Shale with the Belle Fourche Shale is not quite so difficult to map as the basal contact. It is commonly mapped at a color change beneath several thin bentonites which are about 10 feet below a zone of large dark-reddish-brown manganosiderite concretions (fig. 91).

SANDSTONE DIKES

Sandstone dikes and masses are common in the Mowry Shale in the southern Black Hills and are especially abundant in the area south of Coffee Flat in the Cascade Springs quadrangle.

The dikes in this area were studied by W. B. Bryan, whose observations and conclusions are summarized as follows: Sandstone masses and dikes are very fine grained, micaceous, and locally slightly carbonaceous, and contain fish scales and moderate amounts of interstitial silt and clay. The masses and dikes extend to within 15 feet of the top of the Mowry Shale, and some dikes extend down as far as the middle of the Skull Creek Shale. The sandstone masses commonly occur within 30–50 feet of the top of the Mowry and are as much as 45 feet high and 40 feet wide; in places they appear to be lens shaped and thin laterally into the surrounding shale. Other boundaries of the same mass may be vertical and very abrupt, showing slickensides. The masses are generally thin-bedded or crossbedded near the top and grade downward into massive sandstone. Disturbed bedding is occasionally seen. The sandstone dikes are a few inches to several feet wide and as much as one-fourth mile long. In outcrop on a relatively flat surface, many of them resemble low stone walls. They are cut into blocks the size of paving bricks by bedding planes and vertical joints. The sandstone either shows shear fractures which resulted from vertical compression, or the dike is intricately buckled or folded. Dikes which are connected to sandstone masses commonly join the masses parallel to and adjacent to the straight vertical boundaries of the masses, and they thin out downward from the sandstone bodies. Few dikes extend upward from the sandstone masses.

It is postulated that the sandstone masses were originally deposited as lenses of marine sandstone; movement of the surrounding shales, either as a result of submarine slumping, compaction, or tectonic movement, or possibly a combination of all three, sheared the masses into separate blocks with one or more vertical boundaries. Sand derived from these masses was in some places dragged into shear fractures by the movement of the enclosing shale; more commonly, the sand was sifted into open tension fractures and produced the bedding and cross-lamination now seen in the dikes.

The lack of lithologic similarity with the Fall River Sandstone, the absence of any dikes in close proximity to Fall River Sandstone, and the downward thinning of the sandstone dikes make it extremely unlikely that the sand was derived from the underlying rocks, as has been suggested by Darton (1901a), Russell (1927), and Grace (1952).

CRETACEOUS SYSTEM, UPPER CRETACEOUS SERIES

BELLE FOURCHE SHALE

The Belle Fourche Shale was named by Collier (1922) for an exposure along the Belle Fourche River in Crook County, Wyo. It is the lowermost formation of Late Cretaceous age in the Black Hills region (Cobban and Reeside, 1952). The formation occurs in the south-central part of the Cascade Springs quadrangle, where it supports only a meager growth of short grass on a well-gullied terrain. The thickness of the Belle Fourche is as difficult to measure as that of the Skull Creek and Mowry Shales; it appears to average about 200 feet.

The base of the Belle Fourche Shale is best exposed south of Angostura Reservoir in the SW¼ sec. 9, T. 9 S., R. 5 E., and also just east of Little Tepee Creek in the western part of sec. 16, T. 9 S., R. 5 E., where the beds dip about 45° W. Here the contact was mapped at a 6-inch-thick tough medium-gray siltstone that is about 5 feet stratigraphically beneath a 2-inch-thick bentonite bed and 12 feet beneath the base of a conspicuous 70-foot-thick zone of large manganosiderite concretions. This manganosiderite concretion zone is widespread and is generally considered to be characteristic of the lower part of the Belle Fourche Shale. The zone is exposed in the southeastern part of sec. 7, T. 9 S., R. 5 E., but the contact with the Mowry is obscure in this area. In general, dark-gray shale below the zone of manganosiderite concretions is mapped as Belle Fourche, and light-gray shale as Mowry. (See fig. 91.)

Much of the Belle Fourche is dark-gray shale; 115 feet above the base it contains a zone of yellowish calcareous cone-in-cone concretions. The upper contact with the Greenhorn Formation was mapped at the base of the Orman Lake Limestone Member of the Greenhorn Formation by G. B. Gott and D. E. Wolcott of the Geological Survey.

GREENHORN FORMATION

The Greenhorn Limestone was named by Gilbert (1896, p. 564) for exposures in the vicinity of Pueblo, Colo., and the name was extended by Darton (1901a, p. 533) to equivalent rocks in the Black Hills region. The formation is exposed in the south-central part of the Cascade Springs quadrangle, where it forms a prominent cuesta or hogback.

Two distinct units have been mapped in the Greenhorn Formation: a lower olive-gray to yellowish-brown calcareous shale unit about 225 feet thick and an upper slabby limestone unit about 15–25 feet thick.

The basal contact with the Belle Fourche Shale was mapped by G. B. Gott and D. E. Wolcott of the Geological Survey at the base of a thin grayish-yellow limestone considered to be equivalent to the Orman Lake Limestone Member, which generally is accepted as the base of the Greenhorn Formation in this area. (See Petsch, 1949; Cobban, 1951.)

The shale above this limestone is commonly olive gray, yellowish gray, or yellowish brown and is partly calcareous. It includes a few thin grayish-yellow shaly limestones and calcareous sandstones and was included with the Belle Fourche Shale on preliminary geologic maps of the quandrangle (Post, 1959a, b; Post and Cuppels, 1959a, b; Post and Lane, 1959a, b).

The top of the formation is mapped at the approximate top of the ledge-forming slabby limestone. The Greenhorn is gradational with the overlying Carlile Shale, as Darton (1901a, p. 533) stated, "through 6 to 8 feet of passage beds."

The following measured section gives a general description of the upper part of the Greenhorn Formation in this area.

Partial section of Greenhorn Formation measured in the NW¼NE¼ sec. 17, T. 9 S., R. 5 E.

[Measured by E. V. Post and C. L. Rogers]

Greenhorn Formation:	Feet
5. Limestone, yellowish-gray to pale-yellowish-orange, silty; in beds 6 in. thick alternating with very calcareous yellowish-gray laminated siltstone; *Inoceramus labiatus* abundant; top 5 ft flaky, weathers into gentle slope; lower part slabby, forms prominent cuesta	15
4. Shale, dark-yellowish-brown to olive-gray, calcareous; includes 1 ft of fine-grained yellowish-orange calcareous sandstone 12 ft up and a 2-in.-thick pale-gray bentonite 22½ ft up	31
3. Shale, olive-gray to yellowish-brown, calcareous; includes 4-in.-thick light- to medium-gray calcareous fine-grained sandstone 1½ ft up from base and at top a 6-in.-thick dark-gray silty concretionary discontinuous limestone containing pelecypod fragments	4.5

Partial section of Greenhorn Formation measured in the NW¼NE¼ sec. 17, T. 9 S., R. 5 E.—Continued

	Feet
Greenhorn Formation—Continued	
2. Sandstone, yellowish-gray, very calcareous; contains pelecypod(?) fragments; grades into siltstone	0.5
1. Shale, olive-gray to yellowish-brown, calcareous; includes 2 in. of pale-gray bentonite 2 in. up from base and 3 in. of very limy hard fossiliferous sandstone 23 ft up from base	28
Partial thickness of Greenhorn Formation; base not exposed	79.0

CARLILE SHALE

Darton (1901a, p. 533) applied the term Carlile Shale to rocks in the Black Hills that he considered equivalents of Gilbert's (1896, p. 565) Carlile Shale of southern Colorado. The Carlile consists of three members in the Black Hills. They are, oldest to youngest: the lower unnamed member, chiefly gray noncalcareous shale; the Turner Sandy Member, yellow-gray sandstone and gray shale; and the Sage Breaks Member, gray shale and limestone concretions.

Only the lower two members are exposed in the Cascade Springs quadrangle. Exposures are poor because of a Quaternary sand cover in the south-central part of the quadrangle (pl. 29). Better exposures, which were studied in the Heppner quadrangle adjacent to the south, are described below. The fossils were identified by W. A. Cobban of the Geological Survey.

Stratigraphic section of Carlilie Shale measured in NW¼ sec. 28, T. 9 S., R. 5 E., Heppner quadrangle

[Measured by E. V. Post]

	Feet
Niobrara Formation:	
Poorly fissile dusky-yellow calcareous shale; not measured.	
Carlile Shale:	
Sage Breaks Shale Member:	
Shale, medium-gray, poorly fissile; single layer of septarian limestone concretions in middle	19
Shale, medium-gray, poorly fissile; contains abundant yellowish-gray septarian limestone concretions, especially at base and top	21
Shale, medium-gray, poorly fissile; base marked by single layer of yellowish-gray septarian limestone concretions	17
Total thickness of Sage Breaks Shale Member	57
Turner Sandy Member:	
Shale, mostly covered; includes 2 thin platy sandstones at 16 ft and 22 ft down from top, and a 6-in.-thick medium-gray medium-grained blocky-weathering sandstone 5 ft up from base	44
Sandstone, yellowish-gray, fine-grained, platy-weathering; includes 1 in. of yellowish cone-in-cone limestone near top; sandstone contains abundant carbonaceous fragments at top	5
Total thickness of Turner Sandy Member	49

Stratigraphic section of Carlile Shale measured in NW¼ sec. 28, T. 9 S., R. 5 E., Heppner quadrangle—Continued

	Feet
Niobrara Formation—Continued	
Lower unnamed member:	
Shale, dark-gray, noncalcareous, partly covered	18
Shale containing yellowish-gray platy-weathering limy siltstone concretions; concretions contain *Inoceramus cuvieri* Sowerby, *Collignoniceras woollgari* (Mantell), and *Scaphites larvaeformis* Meek and Hayden	7
Largely covered; noncalcareous shale in upper part, calcareous in lower part; contact with Greenhorn Formation indefinite	123
Total thickness of lower unnamed member	148
Total thickness of Carlile Shale	254
Greenhorn Formation, not measured.	

QUATERNARY SYSTEM

LANDSLIDE DEBRIS

Landslide debris, where present in the Cascade Springs quadrangle, forms a very distinctive topography. The largest area of landslide debris is in upper Falls Canyon in the extreme northwest corner of the quadrangle, where rocks of the Inyan Kara Group, Sundance Formation, and Unkpapa Sandstone are involved in slumps as much as ¾ mile long and ½ mile wide.

The slumping probably took place at a time when the streams that cut the canyons were carrying a maximum amount of water, a condition that permitted rapid undercutting of the shales and mudstones. Another large landslide area ¾ mile long and ¼ mile wide, is between State Highway 87 and the hogback ridge in sec. 29, T. 8 S., R. 5 E., just south of Cascade Springs. Here the Skull Creek Shale has apparently slid down the steeply dipping bedding surface at the top of the Fall River Formation. Blocks of silicified Fall River sandstone are scattered over much of this slide area. The landslide debris is extremely variable in thickness, perhaps reaching a maximum of 400 feet in Falls Canyon.

TERRACE GRAVEL

The remnants of several stream terraces along the Cheyenne River, Cascade Creek, and Falls Canyon are marked by relatively small patches of silt, sand, and gravel. The two largest of these terrace gravel deposits are west of Coffee Flat and north of Angostura Reservoir. The matrix of the gravel is commonly a loamy silt or silty sand.

The composition of the fragments in the gravel varies, depending on the source of the materials; the fragments consist mainly of chert, quartz, quartzite, ironstone, other igneous and metamorphic rocks, and fresh feldspar. Terraces along Cascade Creek include abundant slabs of Minnekahta Limestone and Lakota sandstone crisscrossed by silicified shear fractures; these rocks indicate the derivation of that material from the northeast side of the hogback at Cascade Springs. Fragments of silicified logs and sandstone in the gravel on the west side of Falls Canyon indicate a relatively local source for that terrace deposit.

The thickness of most deposits is difficult to measure accurately because of the tendency of the gravel to wash down over the underlying bedrock. The average terrace gravel deposits appear to be 5–15 feet thick; some may be locally as much as 50 feet thick.

One deposit mapped as terrace gravel on the west side of Alabaugh Canyon in the NW¼ sec. 20, T. 8 S., R. 5 E., is similar to the conglomerate in Fall River Canyon at Hot Springs. This deposit is about 5 feet thick and consists of a moderately well cemented conglomerate of subangular slabs of Minnekahta Limestone in a calcareous sandstone matrix. It is overlain by unconsolidated alluvial gravel consisting of blocks of Minnekahta Limestone in a red silty matrix probably derived from the Spearfish Formation.

WINDBLOWN SAND

Four areas in the southern part of the Cascade Springs quadrangle are covered by sand that appears to have been surficially modified by prevailing northwesterly wind. Each of these areas has a northwesterly grain marked by parallel longitudinal ridges and depressions. One area in the southwest corner of the quadrangle includes two conspicuous blowouts and associated blowout dunes. The sand in each of these areas tends to wash down the slopes and thus creates the impression that the deposit is thicker than it actually is. The sand attains its maximum thickness of 100 feet and its coarsest grain size in the NE¼ sec. 20, T. 9 S., R. 5 E.

Darton (Darton and Smith, 1904) claimed that the sand was derived from the adjacent alluvial deposits of the Cheyenne River, which are "upstream" in the prevailing wind direction. Nevertheless, the material shows none of the sorting characteristics of known dune sands. Mechanical analyses of nine supposed "dune sands" from the southern Black Hills showed an average coefficient of sorting of 1.64 as compared with 1.19 for fluviatile sandstones of the Inyan Kara Group and only 1.14 for dune sand collected for comparison at Sand Dunes National Monument, Colo.

This relatively poorer sorting, coupled with the fact that the sand is generally found on higher divides south of the Cheyenne River, gives the impression that these sand deposits are remants of older alluvial terrace deposits not yet completely dissected by the Cheyenne River or its tributaries. These sands may actually be older than any of the alluvial or landslide deposits associated with the present drainage system.

ALLUVIUM

Deposits of alluvial silt, sand, and gravel are extensive along the Cheyenne River and the major stream valleys. The composition of the alluvium generally reflects the character of the source rock. The alluvium along the Cheyenne River is a composite of many types; alluvium in streams draining the Inyan Kara rocks is predominantly sandy, and some canyons such as Alabaugh Canyon are floored with red silt derived from the Spearfish Formation. Red Gulch gets its name from the red silty alluvium that is derived dominantly from the Spearfish Formation.

The thickness of the alluvial deposits is extremely variable. Gravel 29 feet thick was reported in a water well drilled in 1955 on Coffee Flat in the NE¼ sec. 6, T. 9 S., R. 5 E. The streams in Buck Canyon and Falls Canyon have gullied through as much as 40 feet of alluvium, and the stream in Red Gulch has cut through alluvium ranging from 35 to 90 feet in thickness.

Discontinuous layers of calcareous tufa are interbedded with the silty alluvium in the banks of Cascade Creek. The tufa apparently precipitated from the limy waters of Cascade Springs and formed molds around the vegetation growing in the stream. This material is known locally as "fossil moss rock."

STRUCTURAL GEOLOGY

The Cascade Springs quadrangle is at the extreme south end of the Black Hills uplift. The general domal character of the uplift is modified in the southern Black Hills by two asymmetric southward-plunging anticlines. The easternmost of these, the Cascade anticline, forms the major structural feature of this quadrangle (pl. 29). The anticline has 1,635 feet of structural relief near Cascade Springs.

The axis of the Cascade anticline trends about S. 10° E. in the northeast quarter of the quadrangle, turns S. 40° E. for about 3 miles, and then trends about S. 7° W. in the southeastern part of the quadrangle.

The crest of the anticline in the vicinity of Angostura Reservoir is poorly defined. Southeast of Flagpole Mountain the structure bifurcates; one fork trends about S. 7° W., and a second fork trends southeastward through the southwestern part of the Angostura Reservoir quadrangle (Connor, 1963, p. 119). The S. 7° W. direction appears to be the main trend of the anticlinal axis.

Dip on the east flank of the anticline averages 5° SE. Immediately west of the axis the dip steepens abruptly and reaches a maximum of about 70° SW. in the hogback ridge in the vicinity of Cascade Springs. Some beds of sandstone in the Fall River Formation immediately east of the Brainerd Indian Training School are overturned to the west, but this is apparently the result of creep rather than tectonics. The axis of the fold plunges about 300 feet per mile, or a little greater than 3° S. The westerly dip flattens abruptly in the extremely narrow trough of the Coffee Flat syncline, and the rocks dip an average of about 3° SE. on the east flank of the Chilson anticline in the west half of the quadrangle.

The more competent rocks, especially the thick sandstones of the Inyan Kara Group, are closely jointed in many places. Most joints trend N. 20°–40° W. and dip nearly vertically, although a set of minor joints trends about N. 70° E. Closely spaced joints are particularly conspicuous in the S_4 and S_5 sandstones, which have the appearance of columnar-jointed lava flows.

No large faults have been mapped in the Cascade Springs quadrangle. A series of small step faults with less than 1 foot of displacement were noted in thin sandstone of the Fall River Formation at Cascade Springs. These faults apparently relieved the stress developed in the more competent rocks as the dip of the strata changed from horizontal to 60° W. in less than 100 feet laterally.

Sandstones of both the Fall River and Lakota Formations in the hogback ridge at Cascade Springs are crisscrossed by small silicified shear fractures that weather into a network of tiny ridges on the rock surface.

A local angular unconformity, probably the result of penecontemporaneous deformation, was noted in the lower part of the Fall River Formation in the SW¼NW¼ sec. 2, T. 9 S., R. 4 E.

ECONOMIC GEOLOGY

URANIUM DEPOSITS

FALL RIVER FORMATION

Uranium minerals have been found in the Fall River Formation at two localities in the Cascade Springs quadrangle. The smaller of the two deposits is at the top of the cliff south of Angostura Reservoir in the south-central part of sec. 10, T. 9 S., R. 5 E. Here, yellow uranium minerals occur in a carbonaceous sandstone near the top of the lower unit of the Fall River Formation. A grab sample of mineralized rock from this locality assayed 0.39 percent U_3O_8 and 0.29 percent V_2O_5. The limited extent of the radioactivity anomaly suggests that the deposit is small.

CANYON LODE DEPOSIT

The larger of the two uranium deposits in the Fall River Formation is the Canyon Lode deposit on the east side of Cedar Canyon in the SE¼ sec. 25, T. 8 S., R. 4 E. Five mining claims were located here in November 1954, by Everett and Marie Hill and by Francis Michaud and Melvin Hanson. These claims were all assigned in November 1955 to the Big Sioux Uranium and Mineral Co., Inc., which explored the property in 1956.

At the Canyon Lode deposit black highly radioactive uranium minerals and yellow uranium minerals are concentrated in a band 2 inches thick in a thin sandstone about 10 feet above the base of the Fall River Formation. This sandstone is part of a 75-foot-thick sequence of thin carbonaceous sandstones, laminated carbonaceous siltstones, and mudstones. These rocks contain abundant pyritic concretions and black manganese oxides. Much of the sandstone sparkles because of secondary silica overgrowths on the quartz grains.

A grab sample of ore collected at this deposit assayed 1.04 percent U_3O_8 and 0.88 percent V_2O_5. A 2-foot channel sample cut vertically across the "ore" zone assayed 0.09 percent U_3O_8 and 0.27 percent V_2O_5.

Plate 31 shows the relations of the major rock units at the Canyon Lode, surface radioactivity, and the results of radiometric probing of some of the exploratory drill holes with a Geiger-Mueller-type hole probe. The radiometry indicates that there is a highly radioactive unit about 2 feet thick extending southeastward through the center of the deposit. The correlation between radiometric readings and uranium content of the rock is unknown, but the sample of rock containing 1.04 percent U_3O_8 described above was obtained from the surface at hole B, in which radioactivity at the surface was 0.5 milliroentgen per hour.

SPEARFISH FORMATION

Anomalous radioactivity was noted in the Spearfish Formation at two places. The radioactivity appeared to be associated with a 1½-foot-thick dark-gray to black mudstone that is approximately 54 feet above the base of the formation and just below the lowermost gypsum bed. The radioactivity ranged from 2 to 90 times background and appeared to be relatively limited in extent. The black mudstone as a whole was not anomalously radioactive.

Radioactivity as much as 35 times background was noted at a bleached and structurally disturbed zone in the Spearfish Formation on the south side of State Highway 87 in the SW¼SE¼ sec. 20, T. 8 S., R. 5 E. (fig. 87). This disturbed zone is approximately 15 feet wide and extends vertically up the face of the roadcut. Bedding in the zone is obliterated, and the rock consists of a mass of disoriented fragments of siltstone, gypsum, and black mudstone. The siltstone, which is the major constituent, has been bleached to a moderate greenish gray from the normal reddish brown of the Spearfish Formation. The black mudstone fragments have been derived from the 1½-foot-thick unit described in the preceding paragraph.

The highest radioactivity was recorded at fragments of black mudstone, some of which are coated with an unidentified yellowish-green fluorescent mineral. Both the black mudstone and the yellowish material give a positive flux test for uranium. Fragments of this highly radioactive mudstone mixed with bleached siltstone assayed 0.37 percent U_3O_8 and less than 0.1 percent V_2O_5.

The character of this disturbed zone, its proximity to the hot springs at Cascade Springs, and the presence of caverns in the gypsum at the top of the roadcut just east of this zone suggest that the structural disturbance and bleaching were caused by a hot spring similar to those now active at Cascade Springs. If this is true, spring water may be the source of the uranium at this locality. Water from Cascade Springs contains 5.7 micrograms of uranium per liter (table 7).

The black mudstone is overlain by a white very fine grained sandstone 1–2 feet thick in the NE¼SE¼ sec. 29, T. 8 S., R. 5 E. Both the mudstone and the sandstone are irregularly impregnated with splotches of malachite; radioactivity of the mudstone is as much as 90 times background. Results of analyses of samples of this material are given in table 6.

TABLE 6.—*Analyses, in percent, of mudstone from Spearfish Formation, NE¼SE¼ sec. 29, T. 8 S., R. 5 E.*

[Analyses for eU by C. G. Angelo, for U_3O_8 by E. J. Fennelly and H. H. Lipp, for V_2O_5 by J. S. Wahlberg and for Cu by W. D. Goss]

Laboratory No.	Field No.	Material	eU	U_3O_8	V_2O_5	Cu
252529	L–47–2	Black mudstone	0.11	0.12	<0.1	----------
252530	L–47–3	Olive-gray mudstone	.027	.015	<.1	0.55

PROSPECTING

A great amount of information has been gathered in recent years on the source, movement, and deposition of uranium in various types of deposits. Much of this has been summarized by McKelvey, Everhart, and Garrels (1956). They noted that, although the ultimate source of uranium in sandstone is debatable, it is generally agreed that the uranium was transported in aqueous solutions not far out of chemical equilibrium with the enclosing rocks, that the uraniferous solutions migrated along fractures and permeable beds to the site of deposition, and that the uranium was precipitated from solution by reduction commonly caused by the presence of decaying organic material. Applying these principles to the known uranium deposits and geology in the Cascade Springs quadrangle enables one to suggest certain guidelines for future uranium prospecting in the area.

The principal means of vertical access for uranium-bearing ground water in the quadrangle appears to have been through fractured rock along the crest of the Cascade anticline. The small concentrations of uranium in the Spearfish Formation at Cascade Springs are evidence that uraniferous waters have risen along the crest of the anticline.

The most favorable routes for horizontal migration of uranium-bearing ground water are through the permeable sandstones of the Inyan Kara Group. The many uranium deposits in the S_1, S_4, and S_5 sandstones of the Inyan Kara Group in the Edgemont mining district to the west are evidence that uranium-bearing waters did, in fact, move through these sandstones.

The S_1 sandstone does not occur in the Cascade Springs quadrangle, and the S_2 standstone, although widespread, does not contain uranium deposits. The absence of sufficient carbonaceous material in sandstone S_2 to produce a reducing environment in which uranium would be precipitated from solution probably accounts for the lack of uranium in this unit.

The S_4 sandstone occurs in the western part of the quadrangle, but it contains no known uranium. It is, however, the host rock for some of the largest deposits in the southern Black Hills a few miles to the west. It is conceivable that uraniferous solutions migrated through this sandstone but met no reducing environment in which uranium would precipitate. If such an environment existed farther downdip, then the extension of the S_4 sandstone southeastward from where it is covered by alluvium in sec. 36, T. 8 S., R. 4 E., might be favorable ground for exploration. Prospecting adjacent to carbonate-cemented parts of sandstone S_4 might be particularly fruitful, as suggested by Gott (1956). Carbonate nodules and manganese stain were noted in S_4 sandstone in the lower part of Wildcat Canyon, west of the Cedar Canyon Lode.

The S_5 sandstone of the Fall River Formation has apparently carried uranium-bearing ground water. Uranium appears to have been deposited in the carbonaceous rocks of the lower unit of the Fall River near where the S_5 sandstone pinches out. Thus, the lower part of the Fall River Formation near the margins of the S_5 sandstone is favorable ground for additional exploration.

Although ore-grade analyses of uranium have been obtained from samples of Spearfish black mudstone, the Spearfish Formation is not considered a likely source for the commercial production of uranium. The only known potential host rock for uranium in the Spearfish is the black mudstone, and its thinness appears to preclude the formation of a commercially significant deposit.

GYPSUM

Gypsum is abundant in the Spearfish Formation. On the east side of the Cascade anticline, the gypsum beds dip gently and are widely exposed at the ground surface, a condition making them readily amenable to strip mining. An analysis of gypsum from near Cascade Springs is given by Darton and Smith (1904, p. 10). It is doubtful that gypsum in this area will be utilized in the near future, inasmuch as the gypsum beds are comparatively thin and are separated by thin siltstone beds and because the material is relatively far from any market.

LIMESTONE

Minnekahta Limestone was quarried in Sheps Canyon in the SW¼ sec. 16, T. 8 S., R. 5 E., for use as coarse concrete aggregate in the construction of Angostura Dam on the Cheyenne River in the Angostura Reservoir quadrangle (Killin, 1951). The limestone was considered for use as riprap on the earth abutment of the dam, but the thin parting and close jointing of the rock precluded the production of sufficiently large blocks of rock. The Minnekahta Limestone has been quarried just north of the Cascade Springs quadrangle and crushed for use as road metal and surfacing material on State Highway 87. The Minnekahta is not suitable for use in the cement industry because of its high magnesia content, as shown by the analysis given by Darton and Smith (1904, p. 3).

SAND AND GRAVEL

Sand and gravel are abundant in the alluvium and the higher level terrace gravels along the Cheyenne River. This material has been used extensively in building gravel roads in the area. Much of the sand and gravel is not suitable for concrete aggregate, as pointed out by Killin (1951), because of the high admixture of silt and clay, and the presence of reactive materials such as opal, chert, and fragments of acid volcanic glass. Alluvial sand along the Cheyenne River was used as fine concrete aggregate in the construction of Angostura Dam, but it required washing out silt and clay and using low-alkali cements.

WATER

Water is scarce in the Cascade Springs quadrangle: the Cheyenne River has a very low flow during much of the year, and only two streams in the quadrangle are perennial—Cascade Creek, which is fed by springs that issue from the Minnekahta Limestone at Cascade Springs, and the stream in Red Gulch, which is fed by Bridal Veil Spring that issues from the Spearfish Formation.

The springs at Cascade Springs have an approximate flow of about 25 cubic feet per second, and the water temperature is about 72° F. An analysis of water from these springs is given in table 7. The temperature and high calcium sulfate content of this spring water suggest that the water rises through breccia pipes along a zone of weakness near the crest of the Cascade anticline from the Minnelusa Formation of Pennsylvanian and Permian age where anhydrite is being dissolved at depth (Braddock, 1956, p. 11; 1957, p. 213; 1963, p. 221, 258; Bowles and Braddock, 1963; Braddock and Bowles, 1963).

Springs also occur near the crest of the Cascade anticline northwest of Hot Springs, and collapse structures probably resulting from the solution of rocks at depth have been noted in the Minnekahta Limestone east of the anticlinal crest and west of State Highway 87 in the southeastern part of the Minnekahta NE quadrangle.

Water from Cascade Springs is used for irrigation in corn and alfalfa fields along the north side of the Cheyenne River from Wildcat Canyon to Little Tepee Creek. Its suitability for such use can be

TABLE 7.—*Analysis of water from Cascade Springs*

[Laboratory sample 2250, collected Nov. 1, 1957, by D. E. Wolcott and C. E. Price; analyzed by B. P. Robinson]

Constituent	*Parts per million*	*Equivalent parts per million*	*Constituent*	*Parts per million*	*Equivalent parts per million*
SiO_2	22		B	.19	
Al	.2		HCO_3	235	3.85
Fe	.03		CO_3	0	.00
Mn	.00		SO_4	1540	32.06
Ca	568	28.34	Cl	62	1.75
Mg	92	7.57	F	.9	.05
Na	54	2.35	NO_3	.6	.01
K	6.2	.16	PO_4	.00	
Li	.00				

Dissolved solids, residue on evaporation at 180° C ppm	2,530
Specific conductance micromhos at 25° C	2,700
pH	7.0
Beta-gamma activity micromicrocuries per liter	76
Radium do	0.9
Uranium micrograms per liter	5.7

judged by reference to a report by the staff of the U.S. Salinity Laboratory (1954, p. 69).

Two other springs have been noted in the quadrangle, both of which are utilized for livestock water. These are in the NW¼NE¼ sec. 24, T. 8 S., R. 4 E., and at the mouth of Hell Canyon in the NE¼NW¼ sec. 35, T. 8 S., R. 4 E. Both issue from the top of the Fuson Member of the Lakota Formation just below the S_5 sandstone of the Fall River Formation. The interbedded carbonaceous sandstone and siltstone unit of the Fall River Formation is not present at either locality.

A well for agricultural purposes was drilled in 1955 on Coffee Flat in the NE¼ sec. 6, T. 9 S., R. 5 E., for Mr. Ralph McClure. The well is 245 feet deep, and apparently it recovers water from the lower 50 feet of the Fall River Formation. The high sulfate content suggests that this water circulates from the Minnelusa up into the Fall River Formation, rather than being derived entirely from local recharge of the Fall River. An analysis of water from this well, supplied by Mr. McClure, is given in table 8.

TABLE 8.—*Analysis of water from well in NE¼ sec. 6, T. 9 S., R. 5 E.*

Constituent	*Parts per million*	*Constituent*	*Parts per million*
$CaSO_4$	1,190	$CaHCO_3$	85
$MgSO_4$	821	NaCl	20
Na_2SO_4	975	Total	3,091

OIL AND GAS

A small amount of oil has been produced from sandstone of the Pennsylvanian and Permian Minnelusa Formation in the Barker dome in the northwestern part of the Edgemont NE quadrangle (Gott and Schnabel, 1963, p. 186; Gott, 1964). Similar structural features in the Cascade Springs area may contain oil or gas. Although there is as much as 350 feet of closure on the Cascade anticline north of the Cascade Springs quadrangle (Wolcott and others, 1962), the apparent free circulation of ground water from the Minnelusa Formation to the surface along the crest of the anticline seems to preclude the possibility of oil being trapped in the Minnelusa in this area.

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