Geology of the Angostura Reservoir Quadrangle Fall River County South Dakota

GEOLOGICAL SURVEY BULLETIN 1063-D

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

Geology of the Angostura Reservoir Quadrangle Fall River County South Dakota

By JON J. CONNOR

GEOLOGY AND URANIUM DEPOSITS OF THE SOUTHERN BLACK HILLS

GEOLOGICAL SURVEY BULLETIN 1063-D

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

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1963

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

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

CONTENTS

ILLUSTRATIONS

TABLE

GEOLOGY OF THE ANGOSTURA RESERVOIR QUADRANGLE, FALL RIVER COUNTY, SOUTH DAKOTA

By Jon J. Connor

ABSTRACT

The Angostura Reservoir quadrangle is in the northeast part of Fall River County, S. Dak., a few miles south of the town of Hot Springs. About 2,600 feet of sedimentary rocks are exposed in the quadrangle. The oldest exposed rocks consist of 150 feet of siltstones, shales, and sandstones of the Lak and Redwater shale members of the Sundance formation. Overlying the Sundance is the brightly colored Unkpapa sandstone which consists of 215 feet of massive-weathering sandstone and siltstone. Both the Sundance and Unkpapa are of Late Jurassic age. A disconformity separates the Unkpapa from 570 feet of continental sandstones, siltstones, claystones and limestones which make up the Inyan Kara group of Early Cretaceous age. The Inyan Kara group is divided into the Lakota formation and the overlying Fall River formation, both of which contain commercial deposits of uranium in the Edgemont mining district, about 15 miles to the west. The Lakota formation is subdivided into three members which are, in ascending order: the Chilson member, chiefly sandstone and silty claystone; the Minnewaste limestone member; and the Fuson member, chiefly siltstone and claystone. The contact of the Lakota formation with the overlying Fall River formation is marked by a regional disconformity. The Fall River formation is a thin blanket-like deposit consisting in its lower part of thin-bedded carbonaceous siltstone and sandstone and in its upper part of red-weathering lenticular sandstones and siltstones. Five large elongate bodies of prominently exposed channel-fill sandstones cut into the lower part of the formation. Overlying the Fall River formation is about 1,660 feet of marine shale and limestone. In ascending order, the rocks are: the Skull Creek and Mowry shales of Early Cretaceous age and the Belle Fourche shale, Greenhorn formation, Carlile shale, Niobrara formation, and Pierre shale of Late Cretaceous age. Separated from these shales by an angular unconformity is the basal 10 feet of the Chadron(?) formation of Tertiary(?) age, a terrestrial conglomeratic sandstone. Quaternary deposits consist of a few slump blocks, many stream-laid terrace deposits, extensive wind-blown sand and silt, and small deposits of alluvium. The quadrangle is on the gently dipping east flank of the Cascade anticline, and the structural attitude of the rocks is generally homoclinal with an average dip of 3° E. or SE. Imposed upon this gentle structure are many structural swells and furrows. A northeastward-

oriented fault of 15-feet displacement was observed in the northwestern part of the quadrangle. Deposits of aggregate, bentonite and building stone have not been exploited.

INTRODUCTION

The Angostura Reservoir quadrangle (pl. 11) consists of about 55 square miles on the southeast edge of the Black Hills in Fall River County, S. Dak. The northern boundary of the quadrangle is 3 miles

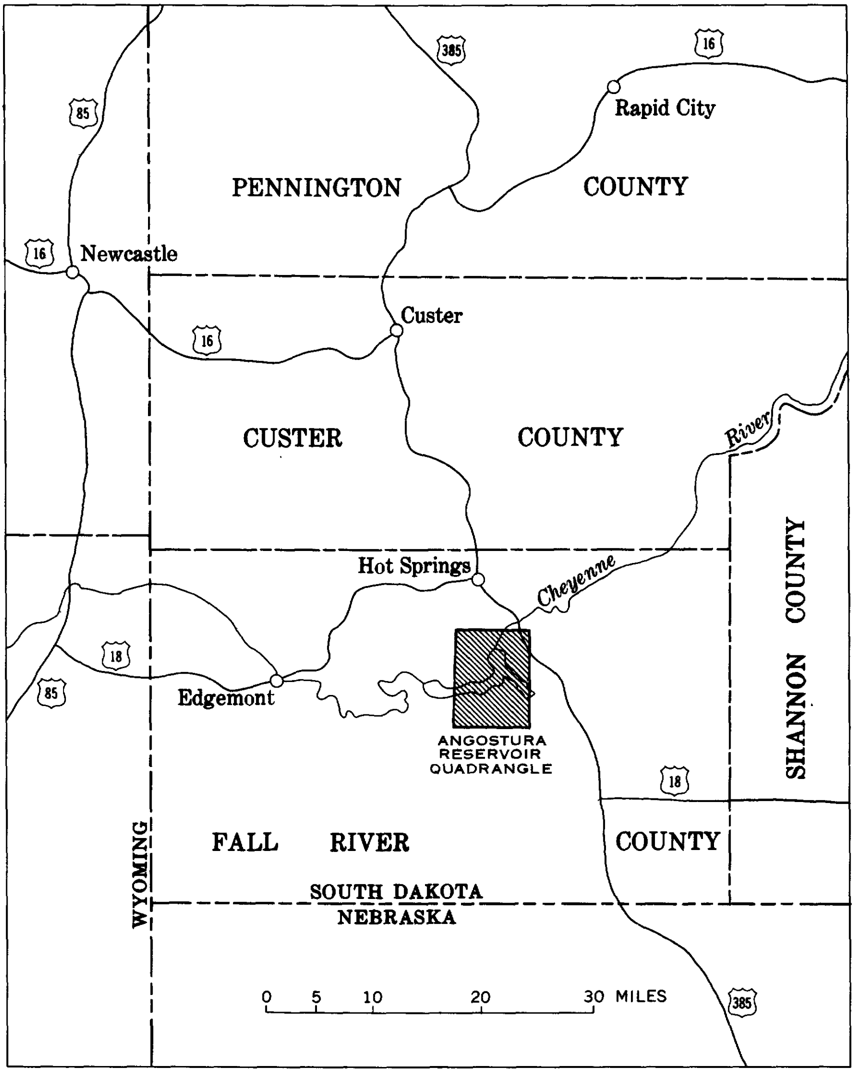

FIGURE 16.—Index map showing location of the Angostura Reservoir quadrangle, Fall River County, S. Dak.

south of the town of Hot Springs (fig. 16). The principal geographic feature of the quadrangle is the Angostura Reservoir that was built as part of the U.S. Bureau of Reclamation's Missouri River Basin Project to provide water for irrigation. The reservoir has a normal capacity of 160,000 acre-feet.

The reservoir divides the quadrangle into two physiographic divisions: to the west and northwest is the Dakota hogback which encircles the Black Hills; to the east and southeast are subdued gently rolling hills and valleys of the Missouri Plateau. Topographic relief is about 1,300 feet.

The Cheyenne River is the only perennial stream in the quadrangle; all other drainage is intermittent except for a few small springs in the canyons that supply water for livestock.

The Angostura Reservoir quadrangle is included in the 30-minute Oelrichs quadrangle mapped by Darton (1902). More recently, geologists of the South Dakota Geological Survey have included parts of the quadrangle in reconnaissance studies of bentonite deposits and oil structures (Spivey, 1940, and Rothrock, 1949).

The quadrangle is one of a group of fourteen 7½-minute quadrangles that have been mapped by the U.S. Geological Survey in a study of the geology and mineral resources of the southern Black Hills. The work was done on behalf of the Division of Raw Materials of the U.S. Atomic Energy Commission. The fieldwork was done in the summer of 1957. The west half of the quadrangle was mapped at a scale of 1:7,200 and the east half at 1:20,000. Final compilation of the data was done at a scale of 1:20,000. Thanks are due Carl M. Wentworth, Jr., whose assistance in the field was greatly appreciated.

STRATIGRAPHY

GENERAL FEATURES

About 2,600 feet of sedimentary rocks, ranging in age from Late Jurassic to Oligocene(?), are exposed in the Angostura Reservoir quadrangle. These rocks are locally covered by thin discontinuous deposits of unconsolidated silt, sand, and gravel of Quaternary age. Sandstone and shale are the predominant rock types but claystone, siltstone, and limestone are locally present in large quantities. Conglomerate is rare. Table 1 briefly describes the stratigraphic units exposed in the quadrangle.

TABLE 1.—*Generalized geologic section of the Angostura Reservoir quadrangle*

System	Series	Group	Formation	Member	Smaller units mapped	Brief description	Thickness (feet)
Quaternary	Recent		Alluvium			Silt and sand, locally gravel.	0–20
	Recent and Pleistocene		Windblown sand and silt.			Poorly sorted, locally contains colluvium and alluvium.	0–25
			Terrace deposits		Terrace deposits laid down by tributary drainage.	Angular to subangular fragments of sandstone, shale, and limestone.	0–20
					Terrace deposits laid down by Cheyenne River.	Well-rounded to subrounded fragments of sandstone, quartz, igneous and metamorphic rocks.	0–50
			Landslides			Mostly slump blocks; rare earth flows and one rockfall.	0–100
			— Unconformity —				
Tertiary(?)	Oligocene(?)	White River(?)	Chadron(?)			Brown conglomeratic sandstone.	10
			— Unconformity —				
	Upper Cretaceous		Pierre shale	Sharon Springs		Black fossiliferous shale including abundant flat ferruginous and spherical white limestone concretions; contains a 5-ft-thick basal bentonite, a distinctive zone of septarian concretions 70 ft above the base (marker bed P–1), and a distinctive zone of cone-in-cone concretions 80 ft above the base (marker bed P–2).	[1] 120
				Gammon ferruginous		Black unfossiliferous shale.	110
			Niobrara			Light gray marly shale, rarely exposed.	300
			Carlile shale	Sage Breaks		Gray shale containing abundant septarian concretions.	60
				Turner sandy		Gray interbedded shale, sandstone, and carbonaceous siltstone, containing a thin prominent sandstone bed 60 ft above the base (marker bed C–2), and a distinctive zone of septarian concretions 100 ft above the base (marker bed C–3).	145

Cretaceous				Unnamed shale		Gray shale, calcareous at base containing a thin prominent limestone bed 90 ft above the base (marker bed C-1).	140
			Greenhorn		Upper	Gray rim-forming thin-bedded limestone.	50
					Lower	Gray interbedded shale and limestone, poorly exposed, containing a 3-ft-thick bentonite bed 45 ft above the base.	225
			Belle Fourche shale			Gray shale containing abundant ferruginous concretions.	150
	Lower Cretaceous		Mowry shale			Gray shale containing sandstone both as thin beds and vertical dikes.	125
			Skull Creek shale			Gray clayey shale, rarely exposed.	235
		Inyan Kara	Fall River		Upper	Brown sandstone interbedded with red or gray siltstone.	140–150
					S_5 sandstones	Brown cliff-forming channel sandstones.	
					Lower	Gray interbedded sandstone and siltstone.	
			— Disconformity —				
			Lakota	Fuson	Mudstone	Variegated slope-forming interbedded siltstone, claystone, and sandstone, rarely exposed.	75–175
					Sandstone	Brown to white thin ledge-forming sandstone.	
				Minnewaste limestone		Gray, thin-bedded limestone; locally contains thin carbonaceous siltstone.	0–30
				Chilson	S_2 sandstones	Orange and white rim-forming sandstone.	175–325
					Mudstone	Gray-green slope-forming interbedded claystone, siltstone, and thin sandstone; rare limestone and shale; poorly exposed.	
			— Disconformity —				
Jurassic	Upper Jurassic		Unkpapa sandstone		Siltstone	Red to white slope-forming structureless siltstone; poorly exposed, locally absent.	150–275
					Sandstone	Red to white cliff-forming massive-weathering sandstone.	
			Sundance	Redwater shale		Gray to green interbedded shale and sandstone.	130
				Lak		Red to white interbedded sandstone and siltstone.	[1] 20

[1] Exposed thickness.

JURASSIC ROCKS

SUNDANCE FORMATION

The Sundance formation was originally defined by Darton (1899a, p. 387) and later subdivided by Imlay (1947, p. 246) into five members. In ascending order these members are: the Canyon Springs sandstone, Stockade Beaver shale, Hulett sandstone, Lak member, and Redwater shale. Only the Lak and Redwater shale members crop out in the Angostura Reservoir quadrangle.

Lak member.—The Lak member crops out in the western parts of Red and Sheps Canyons and is composed of mottled red and white poorly bedded very fine grained sandstone and siltstone. The red color of the Lak affords an easy means of distinguishing it from the overlying gray-green shale and sandstone of the Redwater shale member. A maximum thickness of 20 feet is exposed in the quadrangle. The contact between the Lak and the Redwater in rare exposures appears to be gradational and is placed at the top of the highest red bed. Imlay (1947, p. 233) considers the contact to be disconformable. The red color of the Lak suggests a terrestrial origin but the presence of a few beds similar to those of the Redwater suggests that the Lak member may be in part marine.

Redwater shale member.—The Redwater shale member crops out in the western parts of Wall, Red, and Sheps Canyons and consists of gray to green thin interbedded calcareous fossiliferous shales and crossbedded glauconitic micaceous sandstones. Broken belemnites are commonly found scattered about on weathered slopes. In Red Canyon 130 feet of Redwater was measured.

A 4-foot-thick bed of red friable siltstone is present at the top of the Redwater member. This bed is transitional with the underlying green shales and is in sharp contact with the everlying cliff-forming Unkpapa sandstone. Although this formational contact is sharp in the Angostura Reservoir quadrangle, Imlay (1947, p. 234) states that regionally the contact of the Redwater member with the overlying Morrison formation or Unkpapa sandstone is transitional. The member is marine in origin.

UNKPAPA SANDSTONE

The Unkpapa sandstone, a formation present only along the southeast edge of the Black Hills, was defined by Darton (1899a, p. 387). In the Angostura Reservoir quadrangle the formation crops out in the western parts of all the major canyons, and is easily distinguished by its massive appearance and bright colors. Two lithologic units were mapped in the formation; a sandstone at the base and a siltstone of local extent at the top. These units will be referred to as the sandstone unit and siltstone unit, respectively. The Unkpapa ranges in thickness from 150 to 275 feet and averages about 215 feet.

No fossils have been found in the Unkpapa and its age remains uncertain. Imlay (1947, p. 246) states that the Unkpapa is most probably a facies of the Morrison formation and he places it in the Jurassic.

Sandstone unit.—The sandstone unit is fine grained to very fine grained, poorly sorted, white to red, and commonly weathers to a massive vertical cliff. Joints are uncommon and those observed were not well displayed. The unit is exposed in lower parts of the canyon walls in the western part of the quadrangle.

The sandstone unit averages about 125 feet in thickness. In the center of the N½ sec. 14, T. 8 S., R. 5 E., 150 feet was measured and in the NE¼SW¼ sec. 23, T. 8 S., R. 5 E., 125 feet was measured.

The contact between the sandstone unit and the overlying siltstone unit is commonly sharp and planar. One exposure of the contact in Wall Canyon near the center of sec. 12, T 8 S., R 5 E., however, does show the sandstone unit laterally grading into the siltstone unit.

The sandstone unit is probably of terrestrial origin. Thin bedding, small crossbeds, and symmetrical ripple marks observed near the base of the unit suggest that at least the basal part of the unit is a stream or lake deposit. A few faint crossbeds observed in the center and upper part of the unit are long and sweeping and suggest an eolian deposit.

Siltstone unit.—The siltstone unit of the Unkpapa sandstone is massive, soft, and poorly sorted. It commonly weathers to steep slopes, and exposures locally have a knobby surface. The unit rarely displays sedimentary structures or fossils. The siltstone is red or white like the underlying sandstone, but the contact is easily found because of the differences in weathering.

The siltstone unit ranges from 0 to about 120 feet in thickness and averages about 90 feet. Forty feet of the unit was measured in the center of the N½ sec. 14, T. 8 S., R. 5 E., and 95 feet was measured in the NE¼SW¼ sec. 23, T. 8 S., R. 5 E.

In Adams and Sheps Canyons the siltstone pinches out along a line about half a mile east of the west edge of the quadrangle, leaving the Chilson member of the Lakota formation lying disconformably on the sandstone unit. The local absence of the siltstone unit may possibly have resulted from localized deep scouring of the Unkpapa sandstone preceding deposition of the overlying Chilson member, but figure 17 shows that the line of pinch out has no obvious relation to the change in thickness of the Chilson member.

Data are insufficient to determine the cause of the pinch out, but it may be due to either pre-Lakota deformation that resulted in localized

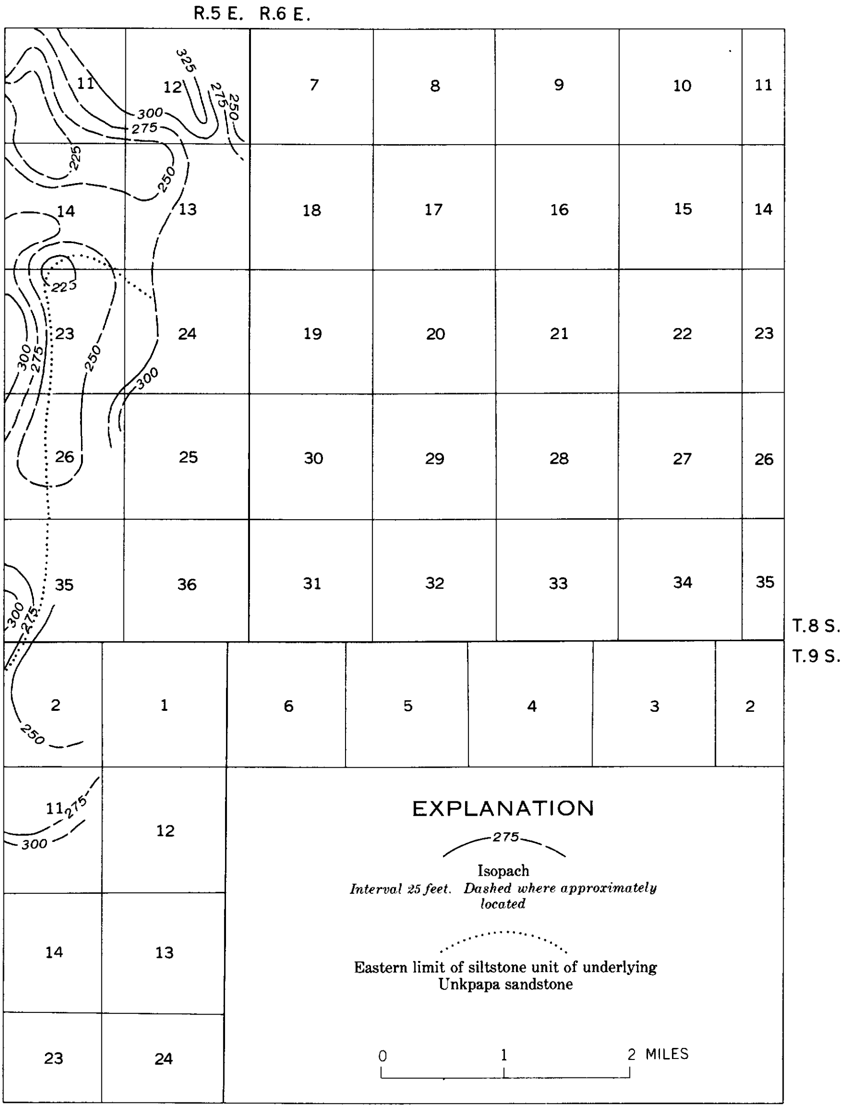

Figure 17.—Isopach map of the Chilson member of the Lakota formation in the Angostura Reservoir quadrangle.

erosion of the Unkpapa or, more probably, to an initial thinness or nondeposition of the siltstone unit.

The depositional environment of the siltstone unit is obscure, but fine grain size and rarity of sedimentary structure suggest that the unit may be, at least in part, an ancient loess.

LOWER CRETACEOUS NONMARINE ROCKS

INYAN KARA GROUP

NOMENCLATURE

The formations of the Inyan Kara group were originally defined by Darton (1899a, p. 387; 1901, p. 526, 529, 530) and included in ascending order: the Lakota sandstone, Minnewaste limestone, Fuson shale, and Dakota sandstone. In 1928 Russell (p. 136) substituted the name Fall River formation for the Dakota sandstone of Darton. Later Rubey (1930, p. 5), working in the northwestern Black Hills, introduced the name Inyan Kara group to include the Lakota, Fuson, and Fall River formations (the Minnewaste limestone is absent in that part of the Black Hills). Waagé (1959, p. 32) revised the nomenclature of the Inyan Kara group and retained the names Fall River and Lakota. He redefined the Fall River formation to include at the base a variable thickness of beds which Darton had placed in the Fuson. He redefined the Lakota formation to include as members the Minnewaste limestone and Fuson shale of Darton with the restriction that the name Fuson be used only in those areas where the Minnewaste limestone is present. Subsequently, Post and Bell (1961) defined the Chilson member of the Lakota formation to include that sequence of rocks Darton called Lakota.

The discovery in 1951 of commercial uranium deposits in sandstones of the Inyan Kara group in the southern Black Hills led to detailed study of the stratigraphy of the group. This detailed mapping resulted in an informal subdivision of the group into many lithologic units. The key lithologic units of the Inyan Kara group are the thicker and more prominent intervals of sandstone which are separated by intervals of finer grained rocks generally referred to as mudstone. Six zones of sandstone of regional significance in the group have been mapped in the southern part of the Black Hills and have been informally numbered in ascending order, S_1 through S_6. In the Angostura Reservoir quadrangle, sandstones equivalent to the S_2 zone are recognized in the Chilson member of the Lakota formation and sandstones equivalent to the S_5 zone are recognized in the Fall River formation.

LAKOTA FORMATION

The Lakota formation is composed predominantly of sandstone, siltstone, and claystone. Limestone, conglomerate, and shale are sparse. The formation is prominently exposed in the canyon walls in the western part of the quadrangle and locally underlies the grass-covered canyon divides. The formation is subdivided into three members which are, in ascending order: the Chilson, Minnewaste limestone, and Fuson.

The geologic map indicates a formational thickness ranging from about 375 to 475 feet. Adding the average thicknesses of the three members gives a thickness for the formation of 430 feet.

The age of the Lakota formation is probably Early Cretaceous, although Waagé (1959, p. 52) states that regionally "all that can be said with relative certainty is that the sequence of continental beds * * * between the Sundance and Fall River formations is of Jurassic age in its lower part and Early Cretaceous in its upper part."

The formation disconformably overlies the Unkpapa sandstone and disconformably underlies the Fall River formation. The disconformity between the Lakota and Fall River formations is recognized throughout the central Great Plains (Waagé, 1959, p. 13).

CHILSON MEMBER

The Chilson member of the Lakota formation is exposed in all the canyon walls in the western half of the quadrangle and weathers to a steep rugged cliff-and-slope profile. The member is composed of lenticular rim-forming sandstones, and slope-forming siltstones and claystones (grouped as mudstone on pl. 11). The S_2 sandstones interfinger with and locally truncate the mudstones. Shale, limestone, and conglomerate are minor constituents of the member.

The Chilson member varies from 225 to 325 feet in thickness but averages about 300 feet (fig. 17).

Measured section 1 is typical of the Chilson member in the Angostura Reservoir quadrangle. The section was measured on the southward-facing canyon wall in the N½NE¼SW¼ sec. 23, T. 8 S., R. 5 E. The line of section trends eastward.

Measured Section 1. Chilson member of the Lakota formation, N½NE¼SW¼ sec. 23, T. 8 S., R. 5 E.

	Thickness (feet)
Lakota formation:	
Minnewaste limestone member:	
12. Limestone rubble, gray, dense, structureless	2.0
Total Minnewaste limestone member	2.0
Chilson member:	
11. Sandstone, very poorly exposed, pale-orange, very poorly sorted, slightly calcareous, lenticular, strongly crossbedded, ledge-forming. Interbedded with lenticular siltstone and claystone which locally contains nodules of calcium carbonate cement about 1 in. in diameter	69.0
10. Claystone, gray-green, silty, friable, slope-forming	9.5
9. Sandstone, orange, very poorly sorted, slightly calcareous, strongly crossbedded, cliff-forming	20.0
8. Claystone, like unit 10	10.0
7. Sandstone, like unit 9	69.0

Measured section 1. Chilson member of the Lakota formation; N½NE¼SW¼ sec. 23, T. 8 S., R. 5 E.—Continued

	Thickness (feet)
Lakota formation—Continued	
Chilson member—Continued	
6. Claystone, gray-green, silty, calcareous, friable, slope-forming. Contains thin white limestone beds averaging 1 in. in thickness	43.0
5. Sandstone, pale-yellow, very silty, poorly bedded; contains many lenses of siltstone pebble conglomerate; forms ledge	5.0
4. Claystone, gray-green, noncalcareous, friable; forms slope	12.0
3. Sandstone, like unit 5	35.0
Total Chilson member (rounded)	273.0
Total Lakota formation exposed (rounded)	275.0
Disconformity.	
Unkpapa sandstone:	
2. Siltstone, white, noncalcareous, friable, structureless, slope-forming	94.5
1. Sandstone, white, noncalcareous, massive, contains many iron nodules; forms cliff. Contact with underlying Redwater shale member of Sundance formation not exposed	125.5
Total Unkpapa sandstone	220

Section 1 illustrates the heterogeneity of the Chilson member. Individual sandstone or mudstone lenses pinch and swell abruptly.

Individual S_2 sandstone lenses are generally fine grained and average 20 to 25 feet in thickness although locally a few are about 50 feet thick. They are abundantly crossbedded, exhibit both trough and planar crossbeds, and are poorly sorted, well jointed, in part calcareous, and rarely quartzitic or conglomeratic. They commonly weather to cliffs or ledges.

Calcium carbonate cement is erratically distributed in the S_2 sandstone lenses. Normally the cement is sparsely distributed in the pore space of the rock and the cemented rock is porous and friable. Locally, the cement fills the entire pore space of the sandstone and produces a very hard resistant rock. Thoroughly cemented sandstone weathers into nodules that give the rock a knobby or warty appearance. The nodules are commonly about 1 inch in diameter.

Carbonaceous material was not observed in the S_2 sandstone lenses except as scattered flakes in the basal lenses. The occurrence of carbon particles in a few of these basal sandstones suggests that, locally, the basal few feet of the Chilson member may be equivalent to a prominent carbon-bearing channel sandstone of the Chilson which is recognized west of the Angostura Reservoir quadrangle (fig. 18).

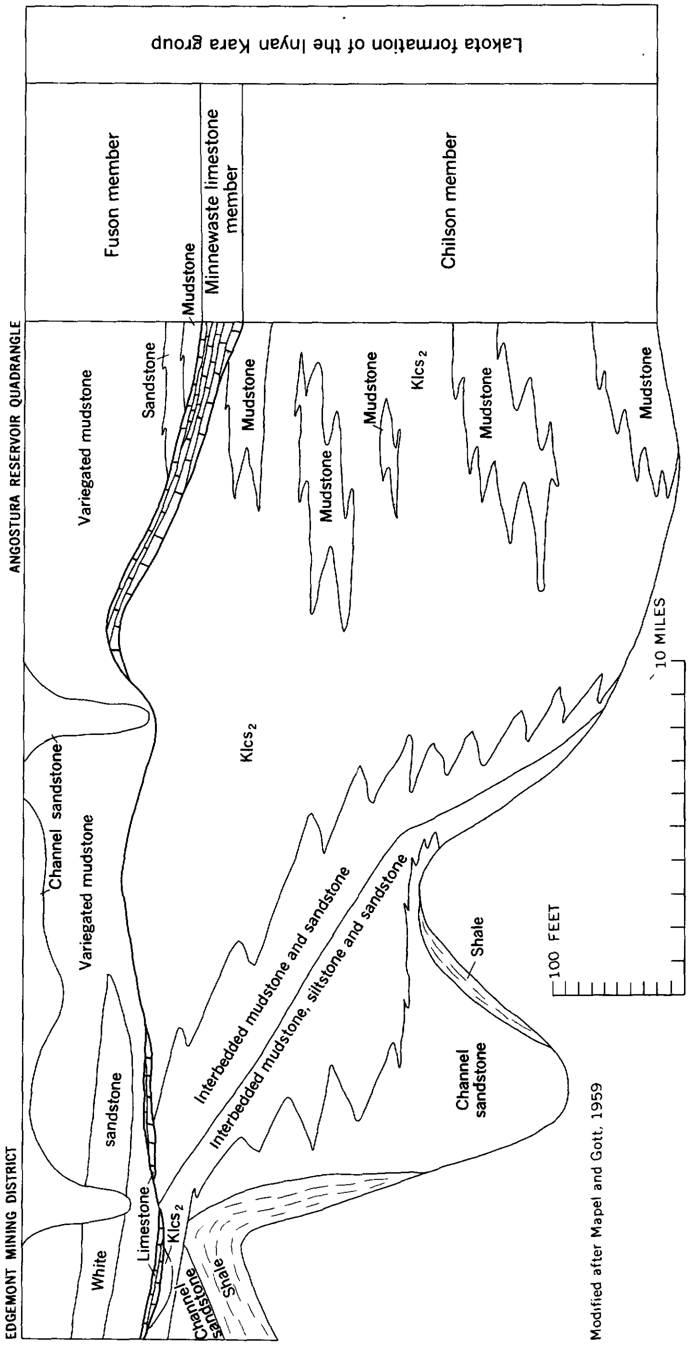

FIGURE 18.—Cross section showing relation of lithologic units of the Lakota formation exposed in the Angostura Reservoir quadrangle to units exposed in the Edgemont mining district.

In the E½ sec. 2, T. 9 S., R. 5 E., 20 feet of brown slightly carbonaceous silty shale is present at the base of the Chilson member. This shale may be equivalent to a basal carbonaceous shale unit which has been recognized to the west (fig. 18). This is the only occurrence of shale in the Chilson member in the Angostura Reservoir quadrangle.

Fossil wood, dinosaur bones, and fresh-water pelecypods have been found in the S_2 sandstone lenses in the Angostura Reservoir quadrangle. Some of the fossil wood has been replaced by silica or hematite. Two pelecypods, found in Green Canyon about 200 feet below the Minnewaste limestone member, were identified by J. B. Reeside, Jr., of the Geological Survey, as *Unio* sp. (written communication, 1958). Of these fossils he says:

> These shells have much the size and shape of that called by Meek *Margaritana nebrascensis*, from the Dakota sandstone at the type locality near Sioux City, Iowa, but there is no other definite record of the species and I hesitate to refer these to it. They certainly seem * * * to be a nonmarine form and I use * * * a very generalized name for such shells. Such shells in the living fauna are fluviatile in habitat.

The lenticular mudstones of the Chilson member generally weather to debris-laden slopes that separate the S_2 sandstone ledges. The mudstone units as a group are distinctive and resemble one another in color, weathering habit, and variety of composition. They are composed predominantly of gray-green, silty, friable claystone but include variable amounts of white to gray siltstone, white fine-grained limestone, and thin white sandstone. These sandstones do not differ appreciably from the thinner parts of the large rim-forming S_2 sandstones of the member and in many places probably are the lateral extensions of S_2 sandstones.

The mudstones are irregularly distributed throughout the Chilson member both vertically and laterally. These mudstones are commonly subordinate to the sandstone and may make up as little as 10 percent of the member. In parts of Wall Canyon, however, the mudstone is commonly equal to or greater than the sandstone content. Measured section 2 illustrates the uncommon predominance of mudstone in the Chilson member. The section was measured on the southward-facing canyon wall in the E½SE¼NW¼ sec. 12, T. 8 S., R. 5 E. The line of section trends northwest.

649663 O—63——3

Measured section 2. Chilson member of the Lakota formation, E½SE¼NW¼ sec. 12, T. 8 S., R. 5 E.

	Thickness (feet)
Lakota formation:	
Minnewaste limestone member:	
16. Limestone, gray, dense, sandy; caps dip slope; contains vugs filled with calcite	5
Total Minnewaste limestone member	5
Chilson member:	
15. Claystone, gray-green, silty, calcareous, friable; forms slope	4
14. Sandstone, orange, fine-grained, calcareous, crossbedded; forms ledge	16
13. Siltstone, gray-green and red, argillaceous, calcareous, friable; forms slope	8
12. Sandstone, like unit 14; contains rare siltstone pebbles	11.5
11. Siltstone, poorly exposed, gray-green, argillaceous, noncalcareous; forms slope	22.5
10. Sandstone, white, fine-grained, locally conglomeratic, silty, calcareous, crossbedded; forms cliff	29.5
9. Claystone, gray-green, locally variegated, in part very silty, locally calcareous, friable; forms slope. Contains abundant ostracodes and many thin white silty sandstone ledges. Locally carbonaceous near middle	108.5
8. Sandstone, white, medium-grained, calcareous, thin-bedded, porous; forms ledge	4
7. Claystone, gray-green, silty, calcareous, friable, locally carbonaceous; forms slope	45
6. Sandstone, white, very fine grained, noncalcareous, crossbedded; forms ledge	4
5. Claystone, poorly exposed, gray-green and red, silty, noncalcareous, friable, locally carbonaceous; forms slope	30
4. Sandstone, like unit 6	4
3. Claystone, like unit 5. Lowest carbonaceous material in section is 11 ft. above base	44
2. Claystone, mottled red and white, very silty, slightly calcareous, friable; forms steep slope	12.5
Total Chilson member (rounded)	344
Total Lakota formation exposed (rounded)	349
Disconformity.	
Unkpapa sandstone:	
1. Siltstone, red, slightly calcareous, friable; forms steep slope exposed in creek bed	30
Total Unkpapa sandstone exposed	30

The sequence of interbedded mudstone and thin sandstone, described in units 2 through 9 of measured section 2, rapidly thins in adjacent areas. Field evidence does not indicate whether the thinning is due to intertonguing with or truncation by S_2 sandstones.

Ostracodes found near the middle of unit 9 in section 2 were identified by I. G. Sohn of the Geological Survey (written communication, 1958) as *Pseudocypridina* spp., and "*Metacypris*" spp. Sohn also identified *Pseudocypridina* spp., *Cypridea longispina* Peck, 1941, and "*Metacypris*" spp. in a sample of gray silty claystone collected about 150 feet below the top of the Chilson member in the center of the NE¼ sec. 12, T. 8 S., R. 5 E. The ostracode-bearing parts of the mudstones are generally carbonaceous, calcareous, and bedded. Other fossils found in the mudstones of the measured section consist of two small gastropods collected from near the middle of unit 9 and a few small fish teeth found in a silty claystone about 30 feet above the base of the member (I. G. Sohn, written communication, 1958).

The contact between the Chilson member and the underlying Unkpapa sandstone in the Angostura Reservoir quadrangle is marked by a disconformity. The disconformity is well exposed in Sheps Canyon where basal S_2 sandstones rest on the Unkpapa. Other exposures, notably those in the northwest corner of the quadrangle, display a contact of basal mudstones of the Chilson member resting on the Unkpapa. These basal beds have a varied composition including variegated claystone and siltstone, carbonaceous siltstone, thin sandstones, thin gray limestones, and lenses of conglomerate. The contact of the Chilson member with the overlying Minnewaste limestone member is conformable.

The bulk of the rocks that make up the Chilson member were probably deposited by an aggrading stream system. The lenticular shape of the sandstones suggests that they were deposited in stream channels. The abundance of trough-type crossbedding and the presence of petrified wood and fresh-water pelecypods also indicate a fluviatile origin for the sandstones. The presence of ostracodes, fine grain size, and occasional thin bedding of the mudstones indicate a quiet-water environment of deposition. The interfingering of the mudstones with the sandstones suggests that the mudstones were deposited largely on flood plains, although some may have been deposited in shallow lakes or swamps.

MINNEWASTE LIMESTONE MEMBER

The Minnewaste limestone member of the Lakota formation consists of thin, tabular lenses of light-gray, dense, structureless limestone locally interbedded with thin carbonaceous siltstones and thin, very calcareous, structureless sandstones. The member is resistant to erosion and commonly underlies smooth, sparsely vegetated dipslopes. It weathers to a thin, prominent ledge where exposed in canyon walls.

The type section of the Minnewaste limestone as defined by Darton (1901, p. 529) is at the falls of the Cheyenne River in the S½ sec. 20,

T. 8 S., R. 6 E., now under the water of Angostura Reservoir. Section 3 was measured on the north side of the creek bed in the southernmost canyon in the E½SE¼NE¼ sec. 7, T. 8 S., R. 6 E. The line of section trends north.

Measured section 3. Minnewaste limestone member of the Lakota formation, E½ SE¼ NE¼ sec. 7, T. 8 S., R. 6 E.

	Thickness (feet)
Lakota formation:	
Fuson member:	
6. Claystone, gray, friable; forms slope. Contains small lenses of calcareous oolites and underlies sparsely vegetated flat	5.5
Total Fuson member exposed	5.5
Minnewaste limestone member:	
5. Limestone, light-brown, structureless, sandy	4
4. Limestone, gray, structureless, relatively pure. Intertongues with unit 3	4.5
3. Limestone, light-gray, dense, structureless; includes thin calcareous sandstones	20
Total Minnewaste limestone member (rounded)	29
Chilson member:	
2. Siltstone, light-yellow, poorly sorted, calcareous, friable. Becomes carbonaceous 100 ft to east	.5
1. Siltstone, poorly exposed, light-gray, sandy, locally calcareous, friable; forms steep slopes	15.3
Total Chilson member exposed (rounded)	16
Total Lakota formation exposed (rounded)	50

The limestone lenses of the member are generally very fine grained, in part lithographic, and contain relatively large amounts of subangular to well-rounded quartz sand grains. Many of the quartz grains are frosted. The limestones also contain minor amounts of chert, hematite, and clay-sized material. The calcium carbonate content of 18 samples ranged from 50 to nearly 100 percent and averaged about 85 percent.

The carbonaceous siltstone forms relatively small lenses distributed vertically throughout the member but restricted geographically to the easternmost exposures. The lenses are poorly bedded, locally cross-laminated, and commonly calcareous.

The Minnewaste limestone member ranges from 0 to 30 feet in thickness but averages about 20 feet and generally thickens southeastward. It is locally absent in the SE¼ sec. 11, T. 8 S., R. 5 E., probably because of nondeposition.

The upper and lower contacts of the member are difficult to define, principally because exposures of these contacts are rare. The Minnewaste limestone member may intertongue locally with the underlying Chilson member, but many exposures exhibit a sharp contact of limestone on sandstone. The lower contact was placed so as to exclude any gray limestone from the upper part of the Chilson member of the Lakota formation. The member is overlain by a basal Fuson gray silty claystone which contains many small pods of calcareous oolites and a few nodules of barite or dense gray limestone.

Fossils are rare in the member, but a few poorly preserved remains were found in sandy limestone lenses near the top of the member in the NE¼SE¼NE¼ sec. 19, T. 8 S., R. 6 E., and the center of sec. 7, T. 8 S., R. 6 E. Preston E. Cloud, Jr., of the Geological Survey, states (written communication, 1958) that these specimens are:

> * * * as yet unsolved problematica. Tentatively I am inclined to the opinion * * * that they belong to the fresh-water sponge family Spongillidae, a presently widespread group that lives in * * * fresh water. Living spongillids ordinarily attach to a hard substance like a rock or drifting log, but may grow even on soft mud. They are generally photopositive; most common in waters less than two meters deep and not recorded below about 50 meters.

I. G. Sohn (written communication, 1958) identified a detrital Paleozoic fusulinid in a sample of carbonaceous siltstone taken from the member in the NW¼ SE¼ NE¼ sec. 7, T. 8 S., R. 6 E.

The limestones of the member were evidently deposited in one, or possibly more, shallow fresh-water lakes, and the carbonaceous siltstones and thin sandstones may have been deposited in swamps or streams near the lake margins.

FUSON MEMBER

The Fuson member of the Lakota formation in the Angostura Reservoir quadrangle consists of variegated claystone, siltstone, and minor amounts of sandstone. The member is present in all the canyons in the western part of the quadrangle and commonly weathers to a steep grass-covered slope between the prominent limestone ledge of the Minnewaste limestone member and the cliff- or ledge-forming sandstones of the overlying Fall River formation.

The member is composed principally of mudstone, as shown in plate 11, but near the base is a thin ledge-forming sandstone.

The mudstone of the Fuson member consists of variegated generally noncalcareous lenses of siltstone, claystone, and sandstone. Siltstone is probably the predominant rock type. The three rock types are similar in their rarity of sedimentary structure and their tendency to weather to grass-covered slopes.

The crossbedded, ledge-forming sandstone near the base of the member stands in marked contrast to the generally structureless beds composing the bulk of the Fuson. The sandstone is white to brown, poorly sorted, and in part calcareous. It is discontinuous and attains a maximum thickness of 10 feet near the mouth of Green Canyon.

Polished siliceous pebbles and cobbles are scattered indiscriminately through the claystone lenses of the Fuson member. The origin of these polished stones is unknown. A distinctive thin bed of white claystone that contains sparse bands of gray chert, locally crops out about 100 feet above the base of the member and is useful in locating the rarely exposed contact between the Lakota and Fall River formations. Joints are rare in the member, and those observed were poorly defined.

Measured section 4 illustrates the nature of the Fuson member in the Angostura Reservoir quadrangle. The section was measured on the northward-facing slope of Adams Canyon in the W½SE¼ sec. 24, T. 8 S., R. 5 E. The line of section trends south.

Measured section 4. Fuson member of the Lakota formation, W½SE¼ sec. 24, T. 8 S., R. 5 E

	Thickness (feet)
Lakota formation:	
Fuson member:	
8. Claystone, light-gray to light-blue, silty; forms slope. Contains 0.5-ft-thick white medium-grained ledge-forming sandstone 29 ft above base	37
7. Sandstone, white, structureless, very friable; forms slope	14.5
6. Claystone, very poorly exposed, variegated, silty; forms slope	25
5. Sandstone, pale-orange, very fine grained, silty, blocky, crossbedded; forms ledge	8
4. Claystone, gray, silty, structureless, friable; forms slope. Contains small lenses of calcareous oolites near base. Contact with Minnewaste limestone member not exposed	21.5
Total Fuson member	106
Minnewaste limestone member:	
3. Limestone, gray, poorly exposed	10
Total Minnewaste limestone member	10
Chilson member:	
2. Covered interval, probably mudstone	30
1. Sandstone, pale-orange, medium-grained; forms ledge	30
Total Chilson member exposed	60
Total Lakota formation exposed	176

The Fuson member ranges from 75 to 175 feet in thickness and averages about 110 feet (fig. 19). The variation in thickness may be due, at least in part, to gentle pre-Fall River folding and later erosion.

Fossils are rare in the Fuson member, and those found in the Angostura Reservoir quadrangle consist of a few ostracodes. The ostracodes were found in the basal gray siltstone of the member at several

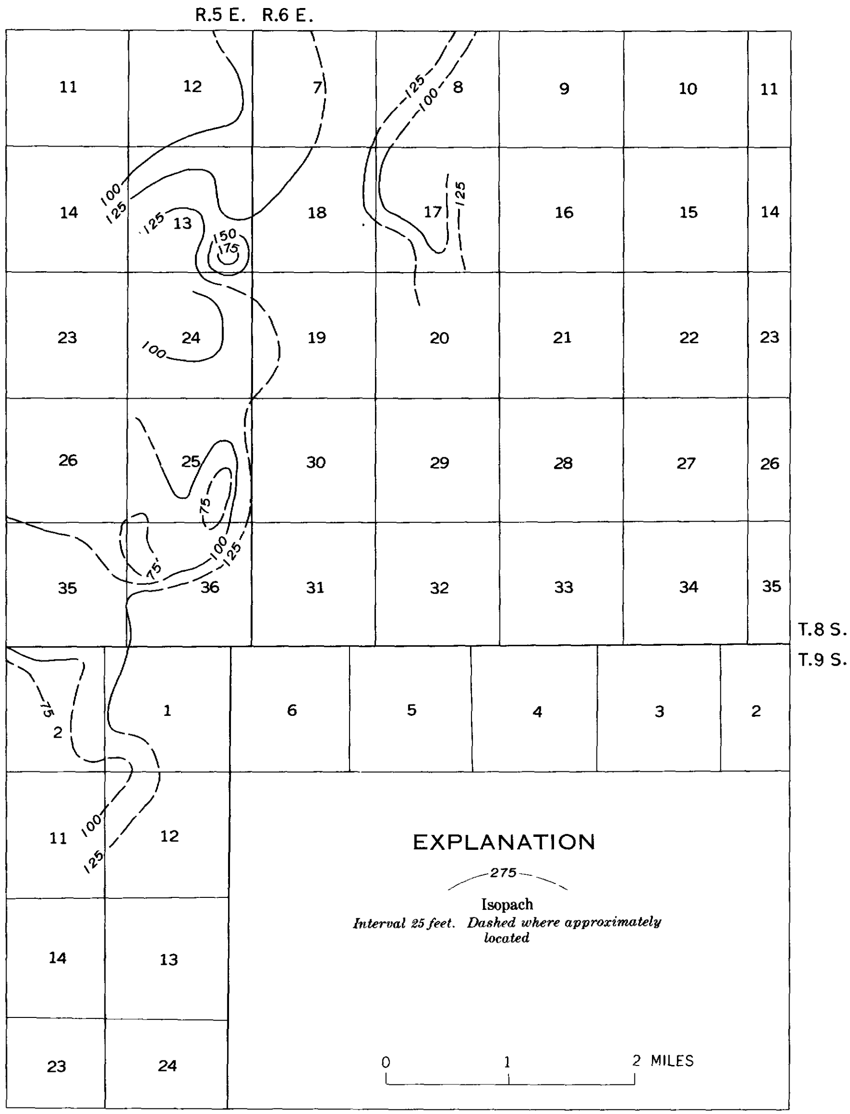

Figure 19.—Isopach map of the Fuson member of the Lakota formation in the Angostura Reservoir quadrangle.

localities and were identified by I. G. Sohn (written communication, 1958) as *Mongolianella?* spp. and an indeterminable genus.

The depositional environment of the member is puzzling, but the fine grain size and scarcity of sedimentary structures suggest that some of it may have been deposited as loess. Parts of the member may be lacustrine. The crossbedded sandstone near the base was evidently deposited by a stream.

FALL RIVER FORMATION

The Fall River formation consists of light-brown, medium- to coarse-grained, cliff-forming sandstone, and less well-exposed, slope-forming siltstone and fine-grained sandstone. Conglomerate and quartzite are rare. The coarse-grained sandstones are well jointed, crossbedded, and locally contain ripple marks and abundant iron nodules. Calcium carbonate cement is generally lacking, and as a consequence the sandstones are highly porous. The formation is commonly gray in the lower parts and red in the upper. It is 140 to 150 feet thick.

The formation caps most of the intercanyon divides in the western part of the quadrangle, and its contact with the overlying Skull Creek shale generally marks the boundary between the Black Hills and Missouri Plateau physiographic divisions.

The contact of the formation with the underlying Fuson member of the Lakota formation is rarely exposed. Where it has been observed, it is sharp and unmistakable, being a planar boundary between bedded siltstone or sandstone above and nonbedded gray claystone below.

The Fall River formation is transitional with the overlying Skull Creek shale, and the contact was placed so as to exclude as much sandstone as possible from the Skull Creek. Locally this contact can be easily recognized by the break in slope where the resistant upper sandstone beds of the Fall River formation dip under the soft shales. Parts of the contact are obscured by high-level terrace deposits of the Cheyenne River, and other parts are covered by the waters of the reservoir. Around the base of Tepee Mountain in the southwest corner of the quadrangle, the contact is particularly difficult to establish. It was placed at the top of a transitional unit about 20 feet thick that consists of slope-forming, thin, interbedded, carbonaceous sandstone, siltstone, and black shale identical to the overlying Skull Creek.

The Fall River formation in the Angostura Reservoir quadrangle consists (pl. 11) of a lower unit of interbedded sandstone and siltstone; a middle unit of large discontinuous sandstones; and an undivided middle and upper unit of interbedded sandstone and mudstone. The undivided middle and upper unit will be referred to as the upper part of the formation throughout the text description. The upper part correlates with the middle and upper units of the Fall River formation in adjoining quadrangles. Mudstones laterally equivalent to the S_5 sandstones will be included in the undivided middle and upper unit in this report.

Measured section 5 illustrates the general nature of the Fall River formation in the Angostura Reservoir quadrangle. The section was measured along the bottom of Knappie Canyon in the S½NE¼SE¼ sec. 8, T. 8 S., R. 6 E., and up the southward-facing canyon walls in the NW¼NW¼SW¼ sec. 9, T. 8 S., R. 6 E., at the confluence of Knappie Canyon with the Cheyenne River. The line of section trends east.

Measured section 5. Fall River formation, along bottom of Knappie Canyon

	Thickness (feet)
Fall River formation:	
Undivided middle and upper unit:	
5. Sandstone, white, noncalcareous, massive, well-jointed, micaceous, cliff-forming; forms dipslope	14.5
4. Sandstone, light-brown to gray, noncalcareous, thin-bedded, ripple marked, locally crossbedded, interbedded with red to dark-gray cross-laminated locally carbonaceous siltstone	74.0
Lower unit:	
3. Siltstone, light-gray, thin-bedded to laminated, locally carbonaceous, cross-laminated, interbedded with white very fined grained tabular sandstone	49.5
2. Siltstone, dark-gray, very carbonaceous, laminated	5.0
Total Fall River formation	143
Disconformity.	
Lakota formation:	
Fuson member:	
1. Claystone, light-gray, noncalcareous, structureless	2
Total Fuson member exposed	2
Total Lakota formation exposed	2

The middle unit of the Fall River formation is not present at the above locality but it is well exposed 1 mile up Knappie Canyon. There it attains a maximum thickness of 40 feet and displaces all but 10 feet of the lower unit.

The depositional environment of the Fall River formation is difficult to determine. The generally fine grain size, good sorting, and thin bedding indicate deposition on a surface of low relief, and the abundance of cross-stratification indicates deposition from moving water, probably streams. C. M. Wentworth, Jr., found a fossil near the center of sec. 2, T. 9 S., R. 5 E., in a talus block believed to be derived from a sandstone of the upper unit of the formation. It was identified as *Chimaerotheca* sp. by J. B. Reeside, Jr., who states (written communication, 1958):

> This fossil is part of the egg case of a chimaeroid fish, shark-like forms that sometimes entered fresh or brackish water to spawn. They extend in age from Devonian to Recent, but are nowhere common.

This fossil indicates that at least part of the formation was deposited in or near marine waters. Waagé (1959, p. 63) states that the "Fall

River and its equivalents are the initial deposits of the transgressive Cretaceous sea," and interprets the depositional environment of the formation as marginal marine, chiefly tidal flat.

LOWER UNIT

The lower unit of the Fall River formation consists of noncalcareous locally carbonaceous, thin, interbedded, cross-laminated siltstone, and thin very fine grained sandstone. In the area between Adams and Green Canyons a few tabular, white, coarse-grained, strongly cross-bedded ledge-forming sandstones are present.

The unit commonly underlies steep, sparsely vegetated slopes. It is generally light gray owing to the presence of a small amount of carbonaceous material. The carbon occurs as thin, wispy films on the cross-laminae of the siltstones and is so finely comminuted that discrete carbon particles are not visible. No carbonaceous remains were observed in the sandstone beds of the unit. Bedding planes and cross-laminae are locally iron stained, and iron oxide nodules of irregular shapes and sizes are sparsely distributed throughout the unit.

Although the base of the unit is marked by a regional disconformity (Waagé, 1959, p. 13), there is no evidence in the Angostura Reservoir quadrangle to indicate that the older Inyan Kara rocks have been reworked and redeposited as part of the lower unit. The lower unit maintains a thickness of about 50 feet throughout the quadrangle where it has not been eroded prior to deposition of the overlying rocks.

S_5 SANDSTONES

At and near the base of the upper unit of the Fall River formation are five prominent sandstone bodies that constitute the middle unit of the formation. These S_5 sandstone bodies are light brown, medium to coarse grained, generally noncalcareous, crossbedded, and well jointed. The thick parts commonly weather to cliffs. Muscovite is sparsely distributed throughout the sandstone bodies, and spherical iron oxide nodules are locally abundant. Conglomerate is rare, even along the basal contacts, and bedding is generally obscure.

The S_5 sandstones are sinuous, lenticular bodies elongated in a northwest direction. They range from 0 to 50 feet in thickness and are about half a mile wide. Their areal distribution as inferred from outcrops is shown in figure 20.

The northernmost S_5 sandstone lens is continuous with a prominent sandstone in Fall River Canyon to the north known locally as the Quarry sandstone (Waagé, 1959, p. 58). The northernmost S_5 sandstone will be referred to in this report as the Quarry sandstone. The Quarry sandstone ranges from 0 to 40 feet in thickness in this quad-

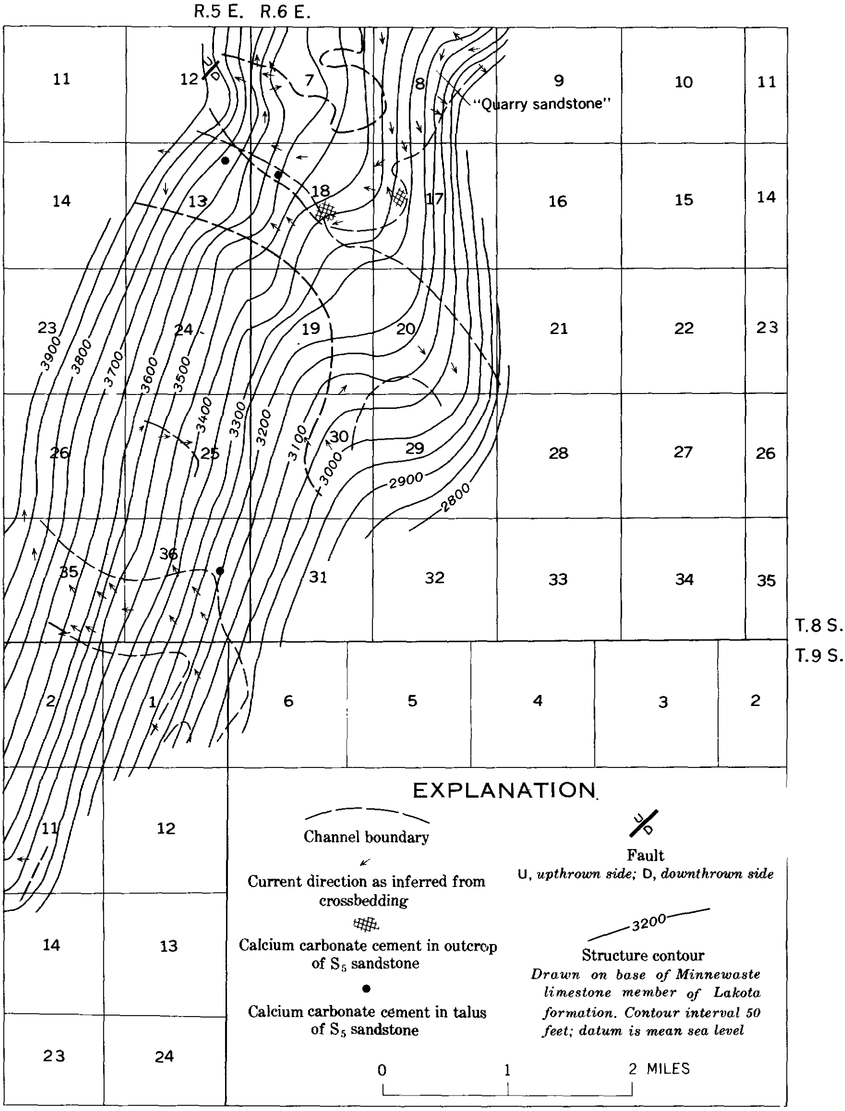

FIGURE 20.—**Approximate lateral limits of the channels in which the S_5 sandstones were deposited in the Angostura Reservoir quadrangle.**

rangle and lies directly below the upper unit of the Fall River formation in a channel scoured into the lower unit. In the E½ sec. 18 and W½ sec. 17, T. 8 S., R. 6 E., the lens contains nodules of calcium carbonate cement, the only S_5 sandstone in the quadrangle that does so.

The middle lens of the three well-defined S_5 sandstones is stratigraphically higher than the Quarry sandstone. It lies entirely within the upper part of the Fall River formation, although, locally, its base is as close as 5 feet to the top of the lower unit. The lens is relatively thin, attaining a maximum thickness of 25 feet in the center of sec. 20, T. 8 S., R. 6 E. In sec. 18, T. 8 S., R 6 E., the lens lies above the Quarry sandstone, but field relations indicate that the two lenses probably have never been in contact.

The southernmost well-defined S_5 sandstone lens lies below the upper part of the Fall River formation, as does the Quarry sandstone to the north, but the top of the lens is as much as 30 feet above the lower unit in places. In this respect, the lens is similar to both the middle well-defined S_5 sandstone, which lies totally within the upper part of the formation, and the Quarry sandstone, which lies totally below the upper part. The lens reaches a maximum thickness of 40 feet in the S½ sec. 36, T. 8 S., R. 5 E., but averages about 20 feet.

Two small remnants of the cliff-forming S_5 sandstone unit are exposed in sec. 25, T. 8 S., R. 5 E., and sec. 11, T. 9 S., R. 5 E. These remnants lie directly below the upper part of the Fall River formation in channels scoured into the lower unit and are here considered to be part of the S_5 sandstone system. Their lateral limits and longitudinal extents are obscure. The lens in sec. 25 attains a maximum thickness of 20 feet and that in sec. 11 attains 50 feet. These sandstones occupy the same stratigraphic position as the Quarry sandstone and at one time may have been physically continuous with it. The S_5 sandstones are channel deposits.

UPPER UNIT

The upper part of the Fall River formation consists of interbedded, lenticular, generally noncalcareous sandstones, siltstones, and silty claystones. The unit is about 90 feet thick and generally weathers to a pale-red soil. It contains scattered carbonaceous material, including a few logs.

The sandstones of the upper part are similar to the underlying S_5 sandstones but are less extensive and contain a large amount of iron oxide cement. Some of the iron oxide is present in the sandstones as nodules but most of it is concentrated along bedding planes and joint surfaces. Near the top of the unit, the sandstone becomes thin bedded and displays a few ripple marks. The siltstones of the upper part are generally cross-laminated and black or red, depending on the proportion of carbonaceous material to red iron oxides.

LOWER AND UPPER CRETACEOUS MARINE ROCKS

Overlying the Inyan Kara rocks is a sequence of marine shales about 1,660 feet thick. They generally weather to sparsely vegetated rolling hills and valleys and underlie the Missouri Plateau physiographic division of the quandrangle. They are overlain by extensive deposits of windblown sand and silt and stream-laid sand and gravel.

The individual formations and smaller units shown on the geologic map crop out in narrow, sinuous northward-trending bands. Thin resistant limestones and sandstones are distributed through the shale section and locally weather to northward-striking cuestas or low escarpments.

The bulk of the shale section is noncalcareous and dark gray. Distinctive zones of limestone or very calcareous shale together with sandstone beds and prominent zones of concretions serve as useful markers for subdivision of the formations, and for interpretation of geologic structure.

The lower 510 feet of the shale section is generally unfossiliferous. The upper 1,150 feet of the section contains many fossiliferous zones. Mollusks and fish remains are the most common fossils. A few of the formations are so uniform vertically that no detailed sections are described.

In ascending order the Skull Creek and Mowry shales are Early Cretaceous in age and have a combined thickness of about 360 feet; the overlying Belle Fourche, Greenhorn, Carlile, Niobrara and Pierre formations are Late Cretaceous in age and have a combined thickness of about 1,300 feet exposed in the quadrangle.

SKULL CREEK SHALE

The Skull Creek shale member was defined by Collier (1922, p. 79) as the lowest member of Darton's Graneros formation of Late Cretaceous age. Reeside (1944) later raised the Skull Creek to formational rank and placed it in the Lower Cretaceous.

The Skull Creek is dark gray, noncalcareous, clayey, and rarely exposed. A few light-yellow cone-in-cone concretions and many thin lenses of dark-brown, ferruginous, calcareous siltstones occur throughout the formation, particularly near the base. Glauconitic siltstone was observed locally. A thickness of 235 feet was measured in the NE¼ sec. 20, T. 8 S., R. 6 E.

The base of the formation is transitional to the underlying Fall River formation, and the top of the formation apparently is transitional to the overlying Mowry shale, although scarcity of exposures makes the top boundary hard to determine.

MOWRY SHALE

Darton (1904, p. 400) defined the Mowry shale member of the Graneros formation, and Reeside (1944) later elevated the member to formational rank.

The Mowry is a dark-gray shale about 125 feet thick and contains many sandstone dikes ranging in thickness from a few inches to as much as 6 feet. All the dikes observed are vertical or nearly vertical; most of them occur in sec. 23, T. 9 S., R. 5 E., on the gentler southwest limb of a southeastward-plunging syncline. Many of the dikes in this swarm have their long dimensions nearly normal to the axis of the syncline. This orientation suggests that the sandstone dikes fill vertical tension fractures that may have been generated by the folding of the strata.

Bentonite is common in the Mowry shale but it occurs in thin beds that rarely crop out. The shale is noncalcareous throughout, although the included sandstones are locally calcareous.

The boundaries of the Mowry shale are difficult to define because of poor exposures, and because the unit is rather atypical in the quadrangle. The shale forms low hills, supports vegetation, and locally contains many sandstone dikes, but it lacks the characteristic fish scales, silvery gray color, and porcelaneous hardness so common on the west flank of the Black Hills.

The base of the Mowry was placed at the base of a thin, discontinuous, locally carbonaceous sandstone characterized by large ripple marks and very thin bedding. This sandstone may be equivalent to the Newcastle sandstone (Hancock, 1920, p. 40) that forms a prominent ledge between the Skull Creek and Mowry shales near Newcastle, Wyo. Other sandstones are present locally in the Mowry, but none are as thick or as extensive as the basal one. The Mowry is transitional to the overlying Belle Fourche shale.

BELLE FOURCHE SHALE

Collier (1922, p. 83) originally defined the Belle Fourche shale as the top member of Darton's Graneros formation, and Reeside (1944) elevated the member to formational rank. The Belle Fourche shale is the lowest Upper Cretaceous formation in the quadrangle and consists of dark-gray, clayey, noncalcareous shale about 150 feet thick. It is characterized by the presence of large dark-brown, flat, ferruginous concretions, particularly near the base. The concretions are commonly 6 to 8 feet wide and 1 to 2 feet thick. Fish scales are relatively more common in the Belle Fourche shale than in the underlying Mowry shale, and a zone of light-yellow cone-in-cone concretions occurs 20 to 40 feet below the top of the shale—a useful guide in locating the upper contact.

Exposures of the shale are poor, but the basal contact was placed so as to exclude any sandstone lenses from the formation, leaving nearly all of the ferruginous concretions in the Belle Fourche. The upper contact was placed at the base of the lowest limestone in the overlying Greenhorn formation.

GREENHORN FORMATION

Gilbert (1896, p. 564) defined the Greenhorn limestone from exposures in southeastern Colorado, and Darton (1901, p. 533) recognized the formation in the Black Hills as a distinctive thin rim-forming limestone. Collier (1922, p. 84), working near the northwestern rim of the Black Hills, included in the Greenhorn formation a sequence of interbedded calcareous shales and thin limestones, considered by many as part of the Belle Fourche, that lie below the Greenhorn limestone rim. Petsch (1949, p. 9), working in the northern Black Hills, correlated a thin fossiliferous limestone, which he called the Orman Lake limestone, with the base of Collier's Greenhorn formation. Petsch, however included this limestone and the overlying shales in the Belle Fourche member of the Graneros formation as Darton had done before him. Cobban (1951, p. 2183), working in the northern Black Hills, recognized four units in the Greenhorn formation and put the base of the formation at the base of the limestone now named the Orman Lake limestone member.

In the Angostura Reservoir quadrangle, the base of the Greenhorn formation was placed so as to exclude all limestones from the Belle Fourche shale. Two units were mapped in the formation. The lower unit is a shale, about 225 feet thick, and may correlate in general with Cobban's lower three units of the Greenhorn formation to the north. The upper unit, about 50 feet thick, is identical to Darton's entire Greenhorn limestone. The basal limestone referred to in this report to mark the contact between the Belle Fourche and the Greenhorn may not be continuous or even represent a single horizon. The basal contact, as here defined for the Angostura Reservoir quadrangle, probably does not vary more than 20 feet vertically.

The shale unit of the Greenhorn formation is poorly exposed and consists of interbedded thin fossiliferous limestone; dark-gray noncalcareous shales; and light-brown calcareous shales. The dark-gray noncalcareous shales are common near the base of the unit and gradually decrease in abundance upward, giving way to the light-brown calcareous shales and limestones. A bed of bentonite 3 feet thick crops out about 45 feet above the base of the unit. Fossil bones found in the NE¼ sec. 20 T. 9 S., R. 6 E., about 180 feet above the base of the unit, were identified by D. H. Dunkle of the Geological Survey (written communication, 1958) as trunk vertebrae of the ichthyodectid fish *Xiphactinus*.

The contact between the shale and limestone units of the Greenhorn formation is transitional. The limestone unit weathers to a conspicuous low cuesta trending north across the eastern half of the quadrangle. It consists of thin, tabular, white limestone lenses interbedded with minor amounts of gray marly shale. The limestone beds contain abundant remains of *Inoceramus labiatus*.

The contact of the Greenhorn formation with the overlying Carlile shale is transitional. Although the limestone unit includes only about 30 feet of prominent limestone, its topographic expression suggests a total thickness of 50 feet, and this figure was arbitrarily accepted. The transition zone between the Greenhorn formation and the Carlile shale is about 60 feet thick and displays an upward decrease in calcium carbonate content. Of this transition zone, the basal 20 feet was placed in the Greenhorn formation and the remainder was placed in the Carlile shale.

CARLILE SHALE

The Carlile shale was named by Gilbert (1896, p. 564) for exposures in southeastern Colorado, and Darton (1901, p. 533) introduced the name into the Black Hills. Rubey (1930, p. 4) subdivided the Carlile shale into an upper Turner sandy member and a lower shale member that he did not name. He recognized two members of the overlying Niobrara formation and named the lower one Sage Breaks, now considered to be the upper member of the Carlile shale (Cobban, 1951, p. 2187).

The Carlile is a gray, generally noncalcareous shale containing minor amounts of sandstone, siltstone, and limestone, and many limestone concretions, particularly near the top.

Measured section 6 is typical of the Carlile shale in the Angostura Reservoir quadrangle. The section was measured in the N½SW¼ sec. 34, T. 8 S., R. 6 E. The line of section trends east.

Measured section 6. Carlile shale; typical sequence from N½SW¼ sec. 34, T. 8 S., R. 6 E.

	Thickness (feet)
Carlile shale:	
Sage Breaks member:	
13. Shale, dark-gray, clayey, noncalcareous; contains abundant large, light-gray, nearly spherical septarian limestone concretions having white and brown calcite in the vugs	60
Total Sage Breaks member	60
Turner sandy member:	
12. Shale, dark-gray, noncalcareous, poorly fissile; contains interbedded shaly siltstone lenses	43

Measured section 6. Carlile shale; typical sequence from N½SW¼ sec. 34, T. 8 S., R. 6 E.—Continued

	Thickness (feet)
Carlile shale—Continued	
Turner sandy member—Continued	
11. Shale, like unit 12 but containing zone of large, light-brown, nearly spherical, septarian limestone concretions having brown calcite in the vugs (marker bed C–3)	5
10. Shale, dark-gray, noncalcareous, poorly fissile; contains interbedded, structureless, carbonaceous siltstone	32.5
9. Sandstone, light-brown, very fine grained, calcareous, ripple-marked (marker bed C–2)	2
8. Shale, dark-gray, clayey, noncalcareous, interlaminated with light-gray very fine grained, noncalcareous sandstone	49.5
7. Sandstone, like unit 9 but not as prominent	2
6. Shale, like unit 8	11.5
Total Turner sandy member (rounded)	146
Unnamed member:	
5. Shale, dark-gray, slightly silty, noncalcareous; weathers into splinters	47.5
4. Limestone, light-gray, very fossiliferous (marker bed C–1)	.5
3. Shale, poorly exposed, light-gray, clayey, calcareous near base, noncalcareous near top; contains abundant light-gray fossiliferous limestone concretions near top	91.5
Total unnamed member (rounded)	140
Total Carlile shale	345
Transitional contact.	
Greenhorn formation:	
2. Shale, light-gray, marly; contains interbedded limestone	20
1. Limestone, white, tabular; contains abundant remains of *Inoceramus labiatus;* interbedded with minor amounts of light-gray calcareous shale	27.5
Total Greenhorn formation exposed (rounded)	48

Unnamed member.—The unnamed member of the Carlile shale consists of light-gray calcareous shale at the base grading to dark-gray hard splintery shale at the top. The member is about 140 feet thick. Ninety feet above the base of the member is a thin limestone marker bed that is helpful in determining geologic structure (unit 4 in measured section 6). The bed is shown on plate 11 and is designated C–1. The marker bed is everywhere underlain by a zone of distinctive light-gray fossiliferous limestone concretions.

Turner sandy member.—The Turner sandy member consists of interbedded and interlaminated noncalcareous dark-gray shale, fine-grained sandstone, and carbonaceous siltstone. The member is about 145 feet thick. Two conspicuous marker beds in the member were mapped as an aid in determining geologic structure. The stratigraphically lower marker bed is a thin, rim-forming sandstone (unit 9 in measured section 6) similar to the one near the base. It is designated C–2 on plate 11. The upper marker bed (labeled C–3 on pl. 11) is a zone of large, nearly spherical, light-brown septarian limestone concretions containing vugs filled with brown calcite (unit 11 in measured section 6).

The contact of the Turner sandy member with the unnamed member below is poorly exposed and, in mapping, the base of a thin, discontinuous, calcareous, ripple-marked sandstone ledge (unit 7 in measured section 6) was used as the basal contact.

Sage Breaks member.—The Sage Breaks member of the Carlile formation consists of about 60 feet of dark-gray, noncalcareous, clayey shale containing abundant light-gray septarian concretions that have both white and brown calcite in the vugs.

The base of the member was placed so as to include all the light-gray concretions. This horizon roughly coincides with the change from sandy shale below to nonsandy shale above. The top of the member was placed so as to exclude any calcareous shale.

NIOBRARA FORMATION

The Niobrara formation was defined by Meek and Hayden (1861, p. 419) from exposures along the Missouri River. The formation is rarely exposed in the Angostura Reservoir quadrangle, but where observed, is principally a gray to white, soft marl or chalk, which weathers to a pale-orange color. It is about 300 feet thick and contains many thin beds of bentonite. A few light-gray, small, spherical, dense, limestone concretions were found near the base.

The basal contact of the Niobrara is sharp and consists of light-gray, calcareous shale above dark-gray, noncalcareous shale. A thin band of black, phosphatic nodules is commonly found along this contact. The formation apparently intertongues with the overlying Pierre shale, and the contact was placed at the top of the highest calcareous shale in the section.

PIERRE SHALE

The Pierre shale was defined by Meek and Hayden (1861, p. 419). About 230 feet of the Pierre is exposed in the Angostura Reservoir quadrangle and consists of black noncalcareous, bentonitic, concretion-bearing shale. The Gammon ferruginous member, defined by Rubey (1930, p. 4), is the basal member of the Pierre. The overlying Sharon Springs member, defined by Elias (1931) and first recognized in South Dakota by Searight (1938, p. 137), is only partly represented.

Section 7 was measured in the SE¼SE¼ sec. 34, T. 8 S., R. 6 E. The line of section trends east.

Measured section 7. Pierre shale, SE¼SE¼ sec. 34, T. 8 S., R. 6 E.

	Thickness (feet)
Pierre shale:	
Sharon Springs member:	
8. Shale, dark-gray, noncalcareous, poorly fissile; contains many small, flat, dark-brown ferruginous concretions and scattered large, light-yellow, cone-in-cone limestone concretions; overlain disconformably by about 10 ft. of windblown sand and silt of Quaternary age	30.5
7. Shale, like unit 8; contains zone of large, light-yellow, cone-in-cone limestone concretions (marker bed P–2)	3.0
6. Shale, dark-gray, noncalcareous, fissile; contains abundant fish remains	10.0
5. Shale, like unit 6; contains zone of large, light-gray nearly spherical, septarian limestone concretions (marker bed P–1)	5.0
4. Shale, like unit 6; contains abundant, small, white spherical, fossiliferous limestone concretions	64.5
3. Bentonite ("Ardmore"), light-yellow, rarely exposed	5.0
Total Sharon Springs member exposed	118.0
Gammon ferruginous member:	
2. Shale, dark-gray, noncalcareous, fissile; contains rare purplish siltstone concretions near base	110.5
Total Gammon ferruginous member (rounded)	111
Total Pierre shale exposed (rounded)	229
Niobrara formation:	
1. Shale, light-gray, calcareous, poorly exposed in creek bed	10
Total Niobrara formation exposed	10

Gammon ferruginous member.—The Gammon ferruginous member is about 110 feet thick and consists of black fissile generally unfossiliferous shale that contains rare purplish siltstone concretions near the base. The member is transitional with the underlying Niobrara formation. The upper contact was placed at the base of a 5-foot bed of a light yellow bentonite, which Spivey (1940, p. 3) called the Ardmore bentonite (unit 3 in measured section 7).

Sharon Springs member.—The Sharon Springs member is a black fissile shale, similar to the underlying Gammon ferruginous member, and contains distinctive concretionary zones and commonly weathers to a subdued cuesta. About 120 feet of the member is exposed in the quadrangle.

The lower 70 feet of the Sharon Springs member contains fish remains and many small spherical limestone concretions. These concretions are dark gray on fresh surfaces but generally weather to white. Exposures of the member are commonly littered with small fragments of these concretions. Fossils found in the concretions were identified as *Pteria nebrascana* (Evans and Shumard), *Pholadomya* sp., and *Baculites* cf. *B. aquilaensis* Reeside by W. A. Cobban (written communication, 1957).

The upper 35 feet of Sharon Springs exposed in the quadrangle is black generally unfossiliferous shale containing abundant small ferruginous concretions and sparse cone-in-cone limestone concretions.

Two marker beds in the member were mapped as an aid in determining geologic structure. The stratigraphically lower marker bed is a zone of large septarian limestone concretions (unit 5 in measured section 7). It is designated P–1 on plate 11. The upper marker bed is a zone of yellow cone-in-cone limestone concretions (unit 7). It is the lowest occurrence of cone-in-cone concretions in the Pierre shale and is designated P–2 on plate 11.

TERTIARY(?) ROCKS

CHADRON(?) FORMATION

A thin veneer of rarely exposed hematitic, conglomeratic, soft sandstone, which lies in angular disconformity upon the Niobrara and Pierre formations in secs. 3, 11, and 14, T. 9 S., R. 6 E., is probably the basal part of the Chadron formation of Oligocene age. Darton, who in 1899 defined the Chadron formation (1899b, p. 736), wrote later that the base of the formation east of the Black Hills is commonly conglomeratic (Darton, 1901, p. 543). The Chadron(?) in the Angostura Reservoir quadrangle ranges from 0 to 10 feet in thickness and consists predominantly of subangular quartz grains associated with varying amounts of feldspar and weathered mica, and minor amounts of weathered igneous and metamorphic rocks. The altitude of the erosional surface at the base of the Chadron(?) is about 3,200 to 3,250 feet.

QUATERNARY DEPOSITS

LANDSLIDES

Landslides in the Angostura Reservoir quadrangle involve movement of relatively small volumes of rock and consist chiefly of slump blocks. They are present in the western parts of Wall and Red Canyons, along the steep slopes above the reservoir in sec. 9, T. 9 S., R. 6 E., and along the banks of the Cheyenne River near the north edge of the quadrangle.

The four landslides in Wall Canyon are slumps and consist of coherent blocks of the cliff-forming S_2 sandstones of the Chilson member of the Lakota formation that have slid downward and rotated backward on mudstones in the member.

The four landslides in Red Canyon consist chiefly of poorly defined blocks of Redwater or Unkpapa that apparently have not slid very far. Backward rotation of the blocks of the massive Unkpapa sandstone is difficult to prove; these landslides may be very small earth flows.

Two landslides are present in sec. 9, T. 9 S., R. 6 E., and both involve movement of coherent blocks of the limestone unit of the Greenhorn formation. The east block is a well-defined slump that has a backward rotation of about 85° to the horizontal. The west block has an apparent forward rotation of about 80° to the horizontal and is a small rockfall.

The slump block on the west bank of the Cheyenne River in the SE¼ sec. 8, T. 8 S., R. 6 E., consists of a small block of the upper unit of the Fall River formation that has been displaced vertically about 10 feet. The south bank of the Cheyenne River in sec. 9, T. 8 S., R. 6 E., is virtually a continuous landslide consisting chiefly of small slumps and earth flows. The sliding occurs in the Skull Creek and Mowry shales.

TERRACE DEPOSITS

Thin deposits of unconsolidated sand and gravel cover many stream-cut terraces at different altitudes throughout the Angostura Reservoir quadrangle. The terrace deposits are subdivided into those deposited by the main stream of the Cheyenne River and those deposited by its tributaries.

The terrace deposits laid down by the Cheyenne River contain abundant well-rounded quartz and sandstone fragments, sparse igneous- and metamorphic-rock fragments, and rare limestone fragments. Sand- and silt-sized material comprises the bulk of the deposits although a few, notably those along the west side of the reservoir, contain enongh cobble- and boulder-sized material to warrant the term "gravel."

The terrace deposits laid down by drainage tributary to the Cheyenne River are composed largely of sandstone, shale, or limestone, depending upon the type of rock present in the area being drained. Igneous- and metamorphic-rock debris is not present in these deposits except near the mouth of Red Caynon where the canyon drainage has reworked terrace deposits of the Cheyenne River.

The terrace deposits lie from 10 to 300 feet above the bed of the Cheyenne River but are not readily divisible into distinct levels of deposition.

WINDBLOWN SAND AND SILT

Eolian deposits are plentiful in the quadrangle, particularly in the eastern half. They are not well sorted, nor do they make distinctive landforms, except for shallow blowouts in secs. 14, 15, 16, 34 and 35, T. 8 S., R. 6 E. The windblown material is chiefly a thin mantle 3 to 5 feet deep that locally includes appreciable alluvium and colluvium. The thickest deposits of eolian sand are about 25 feet thick and occur in the center of sec. 7, the NW¼ sec. 8, and the S½ sec. 9, T. 9 S., R. 6 E. The eolian mantle is relatively stable at present and is being actively eroded by headward stream erosion.

ALLUVIUM

The alluvium is generally fine grained, except along the Cheyenne River where it may locally consist of gravel, and may include appreciable colluvium in the creek beds of the tributary drainage.

STRUCTURAL GEOLOGY

REGIONAL SETTING

The Black Hills region is a domal uplift, elongated to the south and northwest, having about 9,000 feet of structural relief and a relatively flat top and steep sides (Darton, 1902, p. 5). The structure at the south end of the Black Hills is complicated by three major southward plunging anticlines. The eastermost of these major anticlines, called the Cascade anticline, is an asymmetrical structure having a steep dip on its western limb and a shallow dip on its eastern limb (Rothrock, 1949, p. 39). The Angostura Reservoir quadrangle lies on the low-dipping eastern flank of the Cascade anticline. Northeast of the Cascade anticline is a similar but much smaller anticline, called the Dudley anticline (D. E. Wolcott, written communication, 1958), which plunges to the south and dies out in the northern part of the Angostura Reservoir quadrangle (fig. 21).

STRUCTURE OF THE ANGOSTURA RESERVOIR QUADRANGLE

The major structure of the Angostura Reservoir quadrangle is a homocline having a regional dip of about 3° E. or SE. Imposed upon this gentle homocline are many swells and furrows of small extent and low relief. The total structural relief of the quadrangle is about 3,100 feet.

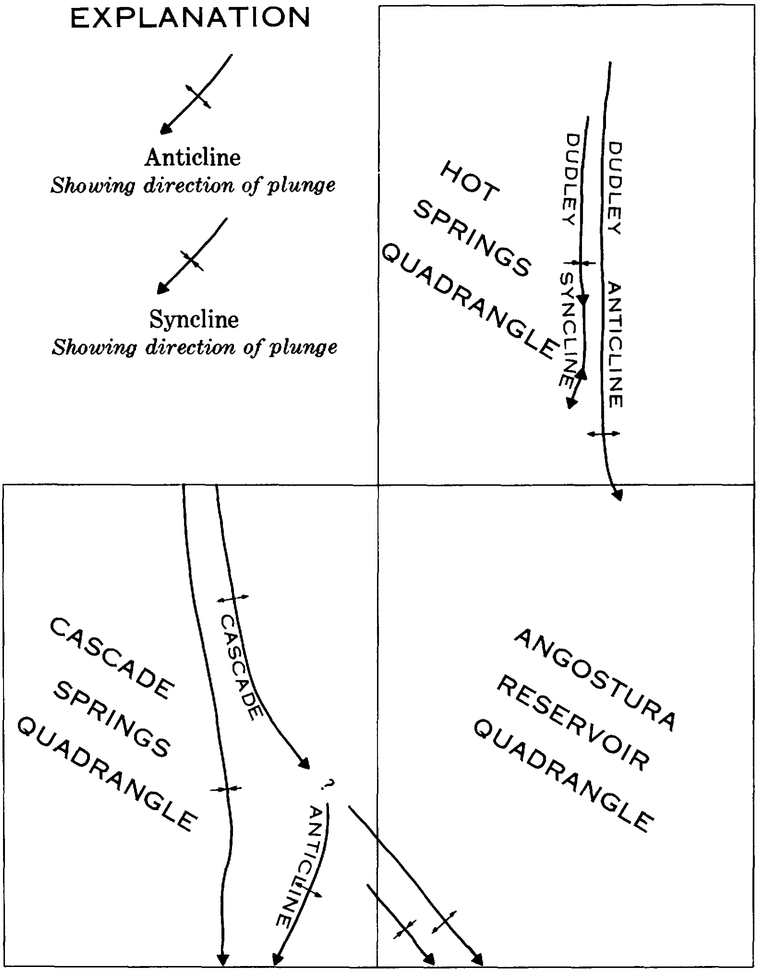

FIGURE 21.—Major structural features in and adjacent to the Angostura Reservoir quadrangle. Data in Hot Springs quadrangle from D. E. Wolcott (written communication, 1958); data in Cascade Springs quadrangle from E. V. Post (written communication, 1958).

A southeastward-plunging anticline and adjacent syncline in the southwest corner of the quadrangle form a monocline of low relief and contain the steepest dips of any structure in the quadrangle. A glance at the regional structure as interpreted by Darton and Smith (1904) clearly shows this structure to be a bifurcation of the Cascade anticline, and it is probably a true tectonic feature caused by the same forces that produced the Cascade anticline.

In the central and northwestern part of the quadrangle, many small flexures interrupt the homoclinal attitude of the rocks. The origin of these flexures is obscure. Widespread solution of gypsum beds in the Minnelusa formation has caused abundant slumping and structural anomalies adjacent to those areas where the Minnelusa crops out (C. G. Bowles and D. E. Wolcott, written communication, 1958). The flexures in the northwestern part of the quadrangle may possibly be due to solution of soluble beds in the Minnelusa which lie about 1,000 to 1,500 feet below the surface. If the flexures seen at the surface are to be attributed to solution of the Minnelusa and subsequent crenulation of the overlying beds, a solution mechanism must be available; but nothing is known of water or other fluid movement at this depth.

Possibly the flexures are truly tectonic features of small magnitude resulting from the same stress conditions that produced the northward-trending Cascade and Dudley anticlines.

Joints are numerous in the sandstones of the Inyan Kara group but are relatively uncommon in the competent rocks underlying and overlying the Inyan Kara group. The joints are vertical, well displayed and generally trend northwest.

The only observed fault in the quadrangle is in the NE¼ sec. 12, T. 8 S., R. 5 E., in Wall Canyon. It strikes N. 50° E. and has a vertical displacement of 15 feet. The south side has dropped relative to the north side, and the fault dies out to the northeast in the Fuson member of the Lakota formation and to the southwest in the siltstone unit of the Unkpapa sandstone. A few thin vertical veins of chalcedony, oriented parallel to the fault, are present in the variegated mudstones at the base of the Lakota formation in the center of sec. 12, T. 8 S., R. 5 E. in Wall Canyon, and are probably genetically related to the fault.

The structure of the quadrangle was formed in Laramide time as a result of the Black Hills uplift. Minor structural deformation probably occurred in the quadrangle prior to deposition of the Fall River and Lakota formations resulting in the discomformities present at the base of these formations. Gott and Schnabel (1962) demonstrate significant, though small, folding prior to deposition of the Fall River in the Edgemont NE quadrangle about 20 miles to the west.

ECONOMIC GEOLOGY

URANIUM

Commercial uranium deposits have been found in four lithologic units of the Inyan Kara group in the Edgemont mining district, about 15 miles west of the Angostura Reservoir quadrangle (Gott and Schnabel, 1962). The four units are the S_1, S_4, and S_5 sandstones and a unit of interbedded carbonaceous siltstone and sandstone at the base of the Fall River formation (referred to in this report as the lower unit of the Fall River). The S_1 and S_4 sandstones have not been recognized in the Angostura Reservoir quadrangle, whereas the S_5 and the underlying siltstone and sandstone unit are recognized but have no known occurrences of uranium within the quadrangle.

Prospecting for deposits of uranium in the Angostura Reservoir quadrangle should probably be limited to those areas where the S_5 sandstones of the Fall River formation are present. Gott and Schnabel (1962) believe that these channel sandstones, together with the S_1 and S_4 sandstones of the Lakota formation, are the principal conduits through which uranium- and vanadium-bearing solutions have been distributed in the Edgemont district.

The local presence of calcium carbonate cement in the otherwise noncalcareous S_5 sandstones indicates that carbonate-bearing solutions have migrated through the sandstones. Inasmuch as uranium, in the hexavalent state of oxidation, is believed to be transported most easily in a carbonate solution, the presence of calcium carbonate cement in the sandstones suggests that uranium-bearing carbonate solutions may have moved through them. If a reducing agent, such as carbonaceous matter, is available, the uranium would be reduced to the tetravalent oxidation state and precipitated as uraninite. Therefore, an area favorable for the deposition of uranium may be indicated by calcium carbonate cement in or near a reducing environment (Wilmarth and Gott, 1958, p. 99). Figure 20 shows the occurrence of calcium carbonate cement in the S_5 sandstones in the Angostura Reservoir quadrangle.

The most favorable rocks for localization of uranium seem to be those of the Quarry sandstone or the lower unit of the Fall River in secs. 17 and 18, T. 8 S., R. 6 E.

OIL AND GAS

No oil or gas wells have been drilled in the Angostura Reservoir quadrangle, but many of the wells drilled in adjacent areas, particularly those on the Chilson anticline near Ardmore, S. Dak., have had oil or gas shows (Rothrock, 1949, p. 45).

Of those formations present in the Angostura Reservoir quadrangle, the Pahasapa, Minnelusa, Sundance, Carlile, and Niobrara formations are considered to contain favorable oil or gas zones (Rothrock, 1944, p. 127–129). The Carlile and Niobrara formations may be excluded as potential oil or gas horizons in the quadrangle because of their shallow position and small areal extent. The upper 150 feet of the Sundance formation is exposed in the western part of Red Canyon, but the formation lies beneath 2,500 feet of beds at the east edge of the quadrangle. The Minnelusa formation lies beneath a minimum of about 800 feet of beds near the west edge of the quadrangle but is probably about 3,200 feet deep near the east edge. The Pahasapa limestone probably ranges from 1,700 to 4,000 feet deep in the quadrangle.

A search for structurally controlled oil or gas pools should probably be restricted to the northwestern part of the quadrangle because here the structural irregularities are the greatest. The flexures, having small surficial dimensions, may be shallow and may not exist at depth.

SAND AND GRAVEL

Extensive deposits of Quaternary sand and gravel in the Angostura Reservoir quadrangle are easily accessible. Relatively pure quartzose sand blankets much of the eastern and southeastern parts of the quadrangle to a thickness that rarely exceeds 5 feet. Locally, in secs. 22, 23, 27, and 28, T. 8 S., R. 6 E., and secs. 2, 3, 4, 7, 8, and 9, T. 9 S., R. 6 E., deposits of sand are about 15 feet thick. The sand deposits are generally composed of fine to coarse, rounded to subangular quartz grains. The terrace deposits along the Cheyenne River and around the Angostura Reservoir contain much gravel. The gravel is generally composed of well-rounded fragments of vein quartz although fragments of sandstone, limestone, and granite are common. Nothing is known of the suitability of the sand and gravel for use as aggregate. One deposit of sand in the SW¼ sec. 20, T. 8 S., R. 6 E., now underwater, was used for concrete in the construction of the Angostura Dam (Robb, 1951, p. 8), but the silt and clay were removed and low-alkali cement was used.

BENTONITE

Bentonite is common but rarely exposed in the Cretaceous marine shales of the Angostura Reservoir quadrangle. The bentonite commonly occurs in beds from a fraction of an inch to a few inches thick. Two beds of relatively thick and easily accessible bentonite are present in the shales. The Ardmore bentonite, at the base of the Sharon Springs member of the Pierre shale, is a 5-foot bed of light-yellow bentonite that contains minor amounts of interbedded black shale. It is exposed in the E½ sec. 34, T. 8 S., R. 6 E. Bentonite mined from the Ardmore bed at Ardmore, S. Dak., is used as a water softener (Spivey, 1940, p. 1). The Greenhorn formation contains a 3-foot bed of bentonite about 180 feet above the base. It is exposed in the W½ sec. 10, the SE¼ sec. 21, the E½ sec. 28, and the E½ sec. 33, T. 8 S., R. 6 E., and the SE¼ sec. 4, the W½ sec. 17 and the W½ sec. 20, T. 9 S., R. 6 E. Spivey (1940) discusses in detail the commercial possibilities of bentonite in Fall River County.

BUILDING STONE

S_5 sandstone of the Fall River formation is eminently suitable for use as building stone, although outcrops in the quadrangle are generally inaccessible. The stone weathers to a uniform light-brown color. A large amount of building stone has been mined from the Quarry sandstone at Evans Quarry, a few miles north of the quadrangle in Fall River Canyon. Other Inyan Kara group sandstones and the Unkpapa sandstone are probably less suitable for use as building stone, because they generally are less resistant to weathering than the S_5 sandstone.

REFERENCES CITED

Cobban, W. A., 1951, Colorado shale of central and northwestern Montana and equivalent rocks of Black Hills: Am. Assoc. Petroleum Geologists Bull., v. 35, no. 10, p. 2170–2198.

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

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

——— 1899b, Preliminary report on the geology and water resources of Nebraska west of the one hundred and third meridian: U.S. Geol. Survey 19th Ann. Rept., pt. 4, p. 719–785.

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

——— 1902, Description of the Oelrichs quadrangle [South Dakota-Nebraska]: U.S. Geol. Survey Geol. Atlas, Folio 85.

——— 1904, Comparison of the stratigraphy of the Black Hills, Bighorn Mountains, and Rocky Mountain front range: Geol. Soc. America Bull., v. 15, p. 379–448.

Darton, N. H., and Smith, W. S. T., 1904, Description of the Edgemont quadrangle [South Dakota-Nebraska]: U.S. Geol. Survey Geol. Atlas, Folio 108.

Elias, M. K., 1931, The geology of Wallace County, Kansas: Kansas Geol. Survey Bull. 18, 254 p.

Gilbert, G. K., 1896, The underground water of the Arkansas Valley in eastern Colorado: U.S. Geol. Survey 17th Ann. Rept., pt. 2, p. 551–601.

Gott, G. B., and Schnabel, R. W., 1962, Geology of the Edgemont NE quadrangle, Fall River and Custer Counties, South Dakota: U.S. Geol. Survey Bull. 1063–E, in press.

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

Imlay, R. W., 1947, Marine Jurassic of Black Hills area, South Dakota and Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 31, no. 2, p. 227–273.

Mapel, W. J., and Gott, G. B., 1959, Diagrammatic restored section of the Inyan Kara group, Morrison formation and Unkpapa sandstone on the western side of the Black Hills, Wyoming and South Dakota: U.S. Geol. Survey Mineral Inv. Map MF–218.

Meek, F. B., and Hayden, F. V., 1861, Descriptions of new Lower Silurian (Primordial), Jurassic, Cretaceous, and Tertiary fossils, collected in Nebraska by the exploring expedition under the command of Capt. Wm. F. Raynolds, U.S. Topog. Eng., with some remarks on the rocks from which they were obtained: Philadelphia Acad. Nat. Sci. Proc., v. 13, p. 415–435.

Petsch, B. C., 1949, North part of the Whitewood anticline, [South Dakota]: South Dakota Geol. Survey Rept. Inv. 65.

Post, E. V., and Bell, Henry, 3d, 1961, Chilson member of the Lakota formation in the Black Hills, South Dakota, and Wyoming, *in* Short papers in the geologic and hydrologic sciences, articles 293–435: U.S. Geol. Survey Prof. Paper 424–D, p. D-173–D-178.

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

Robb, G. L., 1951, Final geologic report—Angostura Dam, Cheyenne Division, Missouri River Basin Project, South Dakota: U.S. Bur. Reclamation, Eng. Geology Br. Geology Rept. G–113, 26 p.

Rothrock, E. P., 1944, Mineral resources, pt. 3 *of* A geology of South Dakota: South Dakota Geol. Survey Bull. 15, 255 p.

——— 1949, Structures south of the Black Hills [South Dakota]: South Dakota Geol. Survey Rept. Inv. 62.

Rubey, W. W., 1930, Lithologic studies of fine-grained Upper Cretaceous sedimentary rocks of the Black Hills region: U.S. Geol. Survey Prof. Paper 165–A, p. 1–54.

Russell, W. L., 1928, The origin of artesian pressure: Econ. Geology, v. 23, no. 2, p. 132–157.

Searight, W. V., 1938, The microfauna of the Sully member of the Pierre: Iowa Acad. Sci. Proc., v. 45, p. 135–137.

Spivey, R. S., 1940, Bentonite in southwestern South Dakota: South Dakota Geol. Survey Rept. Inv. 36, 56 p.

Waagé, K. M., 1959, Stratigraphy of the Inyan Kara group in the Black Hills: U.S. Geol. Survey Bull. 1081–B, p. 11–89.

Wilmarth, V. R., and Gott, G. B., 1958, The Runge uranium mine, Fall River County, South Dakota, *in* Geologic investigations of radioactive deposits—Semiannual progress report, Dec. 1, 1957, to May 31, 1958: U.S. Geol. Survey TEI–740, p. 97–99, issued by U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

INDEX

U. S. GOVERNMENT PRINTING OFFICE : 1963 O - 649663