Geology of the Fanny Peak Quadrangle Wyoming-South Dakota

GEOLOGICAL SURVEY BULLETIN 1063-I

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

Brobst, Epstein—GEOLOGY OF THE FANNY PEAK QUADRANGLE, WYOMING-SOUTH DAKOTA—Geological Survey Bulletin 1063-I

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By DONALD A. BROBST *and* JACK B. EPSTEIN

GEOLOGY AND URANIUM DEPOSITS OF THE SOUTHERN BLACK HILLS

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GEOLOGY OF THE FANNY PEAK QUADRANGLE WYOMING-SOUTH DAKOTA

By DONALD A. BROBST and JACK B. EPSTEIN

ABSTRACT

The Fanny Peak quadrangle includes an area of about 50 square miles on the west flank of the Black Hills in parts of Weston County, Wyo., and Custer and Pennington Counties, S. Dak. A stratigraphic section 4,500 feet thick of consolidated sedimentary rocks ranging in age from Early Mississippian to Late Cretaceous is exposed in the quadrangle. The stratigraphy of these rocks in the western Black Hills and in the quadrangle is summarized. Detailed descriptions are given of the stratigraphy of the Minnelusa Formation of Pennsylvanian and Permian age, the Minnekahta Limestone of Permian age, and the Inyan Kara group of Early Cretaceous age.

The Minnelusa Formation consists of four mappable rock units containing sandstone, shale, limestone, dolomite, and, in the upper unit in the subsurface, about 235 feet of anhydrite and gypsum. At the surface, the anhydrite and gypsum have been leached out by ground water, and the remaining rocks have formed a unit of "founder breccia" 250 to 300 feet thick. Four analyses of spring water from the area indicate that the removal of soluble salts from the Minnelusa and other formations is continuing now. The Minnekahta Limestone is a thin-bedded limestone 25 to 40 feet thick that contains folds and faults attributed, in part, to gravity sliding. The Inyan Kara Group consists of a sequence of terrestrial to marginal marine sedimentary rocks having an average thickness of 325 feet.

Deposits of terrace gravel, landslide debris, alluvium, and spring tufa of Quaternary age locally cover the older rocks.

The major structural features are the Black Hills and Fanny Peak monoclines which appear to intersect in the west-central part of the quadrangle. The apparent intersection of the monoclines occurs on the west side of the Black Hills uplift where the northwesterly structural trends of the northern Black Hills meet the northerly structural trends of the southern Black Hills. The monoclines are interpreted as the drape of the sedimentary rocks over faults in the subsurface.

INTRODUCTION

The Fanny Peak quadrangle (lat 43°45′ to 43°52′30″ N. and long 104° to 104°7′30″ W.) includes an area of about 50 square miles on the west flank of the Black Hills in parts of Weston County, Wyo., and Custer and Pennington Counties, S. Dak., (pls. 25, 26

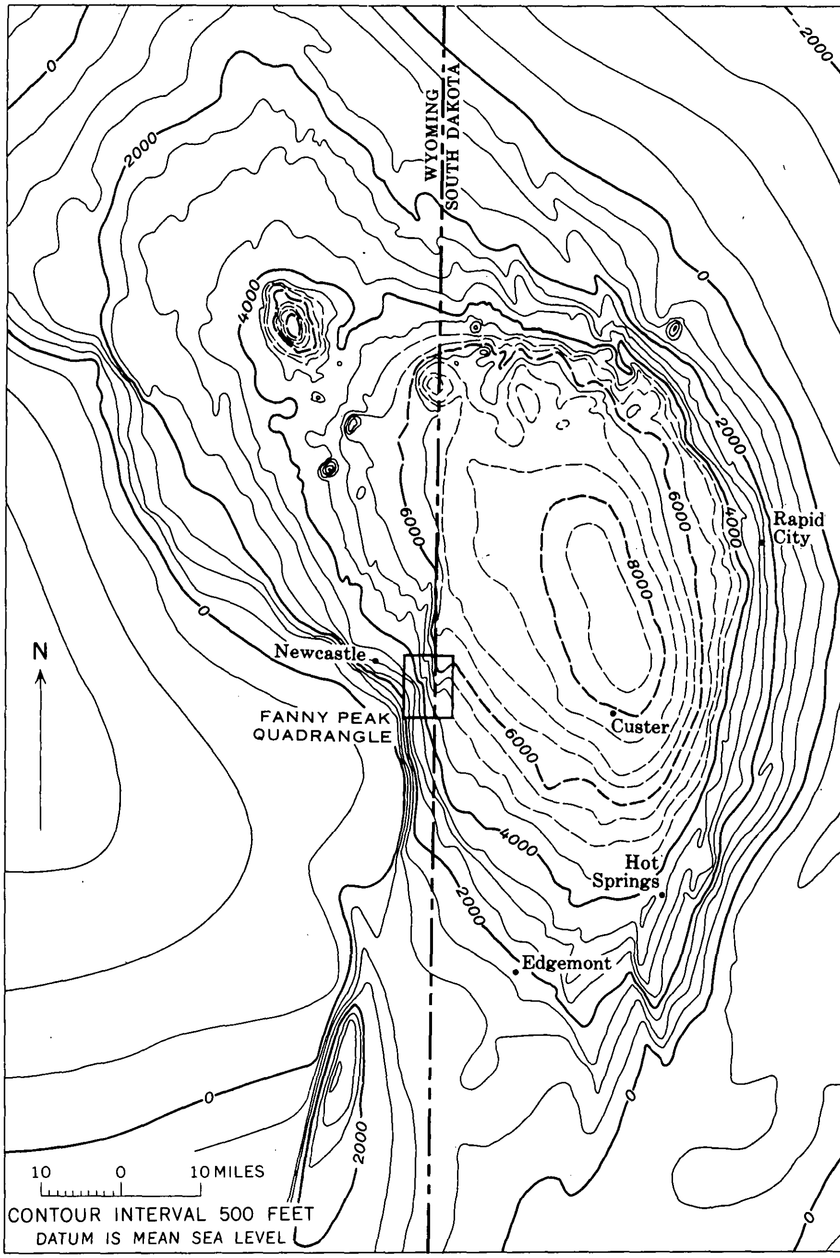

FIGURE 66.—Structure contour map of the Black Hills, S. Dak., and adjacent areas. Contours shown on the top of the Minnekahta Limestone. Broken lines indicate area from which the limestone has been eroded. After Darton (1909, pl. 19).

and fig. 66). The area contains monoclines which form the boundary structures between the Black Hills on the east and the Powder River Basin on the west. The structures continue southward through the Clifton and Dewey quadrangles, Wyoming–South Dakota (pl. 25). A stratigraphic section of about 4,500 feet of consolidated sedimentary rocks of Mississippian to Late Cretaceous age is exposed in the quadrangle.

The highest point in the quadrangle is Fanny Peak, altitude 5,884 feet; the lowest point is on Stockade Beaver Creek where it flows westward out of the quadrangle at an altitude of about 4,260 feet. The quadrangle is drained by Stockade Beaver and Whoopup Creeks. Rainfall of about 15 to 20 inches a year supports growth of grass in most of the area and juniper and ponderosa pine on the monoclinal ridges and on the plateau area of the northeastern quarter of the quadrangle. Stockraising is the chief occupation of the area, although some lumbering is carried on in the plateau area.

The city of Newcastle, Wyo., (population 5,000) 5 miles west of the quadrangle, is the commercial center of the region. The Chicago, Burlington and Quincy Railroad (Omaha, Nebr., to Billings, Mont., branch) passes through Newcastle. U.S. Highway 16 and graveled secondary roads provide easy access to most of the quadrangle.

FIELDWORK AND ACKNOWLEDGMENTS

The mapping in the Fanny Peak quadrangle was sponsored by the Division of Raw Materials of the U.S. Atomic Energy Commission as part of a study of the geology and uranium deposits of the Inyan Kara group in the southern Black Hills.

The fieldwork was done by the authors in 4 months during the summers of 1956 and 1957. The geology was mapped at a scale of 1:20,000. The authors are grateful to the residents of the area and the management of the LAK Ranch for their kind cooperation.

PREVIOUS WORK

Darton (1904) described the geology of the Newcastle area. Since that time many geologists have written on various aspects of the geology of the Black Hills region. Papers dealing with specific features of the local and regional geology are referred to on table 1 and in other appropriate sections of this report; these papers are listed in the references cited at the end of this report.

STRATIGRAPHY

A stratigraphic section consisting of about 4,500 feet of consolidated rocks ranging in age from Early Mississippian to Late Cretaceous, and some surficial deposits of Quaternary age are exposed in the

Fanny Peak quadrangle. The salient features of each unit are summarized in table 1. Some of the units that are poorly exposed and for which no significantly new regional data were obtained are described chiefly in table 1. Other units, particularly the Minnelusa Formation of Pennsylvanian and Permian age, the Minnekahta Limestone of Permian age, and the Inyan Kara Group of Early Cretaceous age, that are well exposed are described in detail in the following pages. Measured sections of these and other formations are presented as a group at the end of the report.

MISSISSIPPIAN SYSTEM

LOWER MISSISSIPPIAN SERIES

PAHASAPA LIMESTONE

The Pahasapa Limestone is the oldest unit exposed in the Fanny Peak quadrangle. Good outcrops are in the valleys just east of the Fanny Peak monocline in secs. 16, 21, and 28, T. 45 N., R. 60 W., Weston County, Wyo. Table 1 summarizes the regional and local stratigraphy of the Pahasapa.

PENNSYLVANIAN AND PERMIAN SYSTEMS

MINNELUSA FORMATION

Darton (1901a, p. 510) redefined the Minnelusa of Winchell (1875, p. 65) to include all the beds between the Pahasapa Limestone and the Opeche Formation. The regional and local stratigraphy of the formation is summarized on table 1.

The Minnelusa Formation is exposed in the northeast quarter of the Fanny Peak quadrangle where it consists of sandstone, limestone, dolomite, shale, and siltstone. Minor amounts of chert occur as thin beds or pods; the bedded chert is black, and the chert pods are multicolored. The rocks change laterally in thickness and composition.

Scattered exposures indicate that the thickness of the formation is about 700 feet, but nowhere is the entire thickness exposed in one place. Subsurface data suggest that the total thickness is about 850 to 900 feet in this area (Foster, 1958, fig. 6, Darton, 1904, p. 3). The difference is explained by the presence of as much as 235 feet of anhydrite and gypsum in the upper 520 feet of the formation in the subsurface (section 5). The anhydrite and gypsum missing at the surface apparently have been removed by solution. The removal of the soluble material resulted in subsequent collapse of the remaining rocks to form the breccia unit at or near the surface. In the subsurface where the anhydrite and gypsum are present, brecciation is not noticeable in the upper part of the Minnelusa.

Geologists of the U.S. Geological Survey studying the stratigraphy of the southern Black Hills in conjunction with the search for uranium minerals have recognized six lithic units in the Minnelusa Formation. In the Fanny Peak quadrangle, however, these six lithic units form four mappable units, each with a generally consistent gross composition (pl. 25). The mappable units are from oldest to youngest: the lower limestone (lithic units 4, 5, and 6, pl. 25), the upper limestone (lithic unit 3, pl. 25), the sandstone (lithic unit 3, pl. 25), and the breccia (lithic units 1 and 2, pl. 25). The lower and upper limestones and the sandstone are best exposed in the canyons adjacent to the Fanny Peak monocline and in Redbird Canyon. The breccia is the best and most widely exposed of the mappable units, especially along the Fanny Peak monocline and in Redbird Canyon.

LOWER LIMESTONE

The lower limestone is about 200 feet thick, and consists chiefly of red, purple, yellow, brown, and gray limestone and dolomite but has some red, gray, and green calcareous shale and mudstone and calcareous sandstone. Chert nodules and pods are common in some beds.

This mappable unit crops out chiefly in the canyons east of the Fanny Peak monocline. Exposures are generally poor and exposures of the entire unit at one place are rare. A nearly complete, but poorly exposed section was measured in the NW¼NE¼ sec. 21, T. 45 N., R. 60 W., Weston County, Wyo. (section 1). Parts of the lower limestone also are described in sections 2 and 4.

The uppermost 40 feet contains abundant gray, purple, and red calcareous shale and some interbeds of limestones as thick as 5 feet. The red shale contains pods of green calcareous shale 1 or 2 inches in diameter. The shale generally is not well exposed, but its red soil makes this interval relatively easy to locate, even on covered slopes. The limestone beds are light gray on a fresh surface and weather to a deep dove gray. (These beds are well exposed on the ridge just north of the trail in the NW¼NW¼ sec. 33, T. 45 N., R. 60 W., Weston County, Wyo.) The limestone contains fusulinids and the brachiopod *Schizophoria* aff. *S. texana* Girty of Middle(?) Pennsylvanian age (unit 14, section 1; identification by J. T. Dutro, Jr.).

The lowermost 25 feet of the lower limestone includes siliceous to sandy limestone containing chert nodules, calcarous white to yellow sandstone some of which is cherty and crossbedded, as well as minor amounts of red shale similar to that at the top of the unit. These lowermost limestone beds are dense and weather to a light-brown or flesh color. Individual beds are about 1 foot thick. The chert nodules, as much as several inches in diameter, are commonly mottled in shades of red and brown.

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The contact between the Minnelusa and the underlying Pahasapa Limestone of Mississippian age generally is not exposed. Poor exposures of this contact are in the steep canyons east of the Fanny Peak monocline and north of Frannie Peak, especially in secs. 28, 21, and 16, T. 45 N., R. 60 W., Weston County, Wyo. (pl. 25). The Pahasapa forms steep to vertical cliffs in the canyons. Above the cliffs is a much gentler, covered slope having small scattered outcrops and rock-debris that contains fragments of fossils of Early Mississippian age for 10 to 20 feet above the top of the cliffs. These fossils indicate that the contact is above the break in slope. Higher on the slope are debris and small scattered outcrops of cherty and sandy limestone and crossbedded sandstone which are assigned to the lowermost part of the Minnelusa. Regional studies in the northern plains indicate that the contact between the Minnelusa and Pahasapa is unconformable (Sloss, 1952, p. 68).

UPPER LIMESTONE

The upper limestone consists chiefly of gray cherty beds of limestone and dolomite, black chert, fine-grained calcareous sandstone, gray to black shale, and dark siltstone. The rocks weather to a yellow to brown plastic soil. This limestone ranges in thickness from about 70 to 80 feet in Redbird and Boles Canyons and thickens westward to about 165 feet in Frannie Peak Canyon. The average thickness is perhaps 80 to 100 feet. Exposures of the unit are most widespread on the ridge between the Fanny Peak monocline and Boles Canyon (pl. 25), where it forms covered slopes having few outcrops. Good vertical continuous exposures are rare; the best are in Frannie Peak Canyon (section 4) and Redbird Canyon (section 2).

Brecciated beds are common in the upper limestone; they commonly grade laterally and vertically into nonbrecciated strata within a few feet or tens of feet in any direction within the bed. Edgewise conglomerate or desiccation breccia was found in Frannie Peak Canyon (unit 38, section 4; fig. 67). The fragments of limestone are a few inches long and less than an inch thick. They are derived from the underlying limestone and incorporated in a sandstone bed. The fragments are fewer and more randomly oriented away from the limestone. This brecciated zone was traced for several hundred feet along the canyon wall to the end of the exposure. One mile east of the Frannie Peak Canyon locality, similar breccia at the same stratigraphic level and with similar rocks suggests that this breccia zone is of considerable lateral extent. The breccia is attributed to desiccation that indicates a minor disconformity.

A single fossil, *Linoproductus* sp., of Pennsylvanian to Permian age (identified by J. T. Dutro, Jr.) was found in a dark cherty bed at an

FIGURE 67.—Desiccation breccia in the upper limestone of the Minnelusa Formation in Frannie Peak Canyon, Weston County, Wyo. Light tabular limestone fragments are randomly oriented in sandstone that overlies the light-colored parent limestone at the bottom of the photograph. Note the limestone pillar on the right.

altitude of 4,900 feet on the west side of Redbird Canyon, SW¼NE¼ sec. 9, T. 3 S., R. 1 E., Custer County, S. Dak.

The base of this unit is placed at the top of the purple, gray, and red calcareous shale sequence that comprises the uppermost part of the lower limestone. As noted previously, this contact is rarely well exposed, but the red soil derived from the shale makes it relatively easy to find, even on covered slopes.

SANDSTONE

The sandstone unit is composed chiefly of yellow fine-grained friable sandstone in beds as much as 40 feet thick and small amounts of limestone and dolomite, calcareous siltstone, red sandstone, and chert. It is 26 feet thick in Frannie Peak Canyon (section 4) and attains a maximum thickness of 170 feet in Redbird Canyon (sections 2 and 3), although the average thickness is about 100 feet. The sandstone is well exposed in both of these canyons; elsewhere various beds are sporadically exposed in small scattered outcrops or as discontinuous ledges as in Boles Canyon and on the ridge between the Fanny Peak monocline and Boles Canyon.

Deltaic crossbedding is common in the sandstones. Abundant ribs of sandstone about one-fourth-inch thick firmly cemented by calcium carbonate crisscross the less firmly cemented sandstone and form boxwork structures on weathered outcrops. These rocks weather to yield a sandy yellow to light-brown soil.

In areas of good exposure, the lower contact of the sandstone unit was mapped at the base of the sequence of abundant sandstone. Elsewhere, the contact was inferred at the base of the exposed sequence of discontinuous ledges. No fossils were found.

BRECCIA

A remarkable interval of brecciated rocks occurs in the upper 250 to 300 feet of the Minnelusa Formation. By Norton's terminology (1917, p. 191), this mappable unit can be called a founder breccia. (See section on "Origin of the Breccia"). The breccia unit is well exposed among the steeply dipping beds along the Fanny Peak monocline, and as gently dipping cap rocks over large areas between Frannie Peak and the eastern boundary of the quadrangle (pl. 25). Brief descriptions of the breccia are given in measured sections 2, 3, 4, and 6.

The rocks of the breccia at the surface include interbedded red, white, and yellow, fine-grained, massive to crossbedded sandstone, red and gray limestone and dolomite, and red, green to dark-gray shale. Chert fragments occur in small amounts. Small masses of opal were found at the summit of Fanny Peak. The rocks are broken and the fragments range in length from less than 1 inch to many tens of feet. The fragments show little abrasion, although some of the blocks of the more friable material are rounded. The matrix is principally fine-grained sand cemented by calcium carbonate.

A 12- to 20-foot sequence of red shale interbedded with some siltstone and sandstone overlies about 35 feet of sandstone and dolomite that form the lowermost part of the breccia (section 5). This sequence of red shale is poorly exposed in the Fanny Peak quadrangle and was not mapped as a unit separate from the breccia. The best exposures are on the north side of the little canyon on the east side of Redbird Canyon in SW¼NW¼ sec. 16, T. 3 S., R. 1 E., Custer County, S. Dak. This sequence of rocks has been called the "red marker" by Thompson and Kirby (1940) and Krampert (1940). Williams (1949) logged the water well on the LAK Ranch in the SE¼NE¼ sec. 6, T. 44 N., R. 60 W., and reports a sticky red shale 31 feet thick beginning at a depth of 640 feet. The discrepancy in thickness probably is explained by the dip of the rocks on the monocline where the well was drilled. The red mudstone called the "red marker" is considered a key unit in the regional correlation of the Minnelusa Formation and is further discussed in the section on regional correlation.

The rocks of the breccia weather red and white, and form red-brown soils. The color boundaries are sharp in places and poorly defined in others. From a distance it appears that the breccia can be divided into an upper white zone and a lower red zone. Fieldwork proved this assumption to be incorrect. In many places the white part is surficial and can be chipped away to reveal red sandstone beneath. Many cobbles of white sandstone are red on the underside. In the subsurface most of the sandstone is red (section 5).

Seven fragments of red and white sandstone were boiled in a 20 percent solution of hydrochloric acid for 1 hour. The mean percentage of soluble material, chiefly calcium carbonate and iron oxide, was 20.5. The amount of cementing material was not related to color difference in the samples.

The units exhibit crude bedding, chaotic structure, and breccia pipes. In the rocks displaying crude bedding, the beds of the same composition are traceable for hundreds of feet, but they are broken and individual pieces are displaced vertically a few inches or feet. This is the most abundant kind of structure in the breccia. Crude bedding is well displayed on the west wall of Redbird Canyon (SW¼ sec. 9, T. 3 S., R. 1 E., Custer County, S. Dak.).

Chaotic structure generally is restricted to a bed or group of beds that form zones as thick as 20 to 30 feet in which the rocks are fragmented and randomly oriented. On the face of exposures the fragments range from gravel size to lozenge-shaped slabs of bedded rock many feet long. These beds or zones may have a lateral extent of several tens to hundreds of feet and are interlayered with rocks exhibiting crude bedding and containing breccia pipes (fig. 68).

The breccia pipes are localized collapse structures that are filled with angular to subrounded fragments of rock of mixed sizes in a sandy matrix cemented by calcium carbonate. Carbonate cement generally is more abundant in the pipes than in the enclosing rocks. The larger blocks commonly are several feet long. Many of the pipes are red at the periphery and white in the middle. The pipes are generally vertical and transgress rocks having crude bedding and chaotic structure (fig. 68). The pipes are circular, tens to several hundred feet in diameter, and attain a known depth of 200 feet. The pipes stand out as protuberances on the canyon walls (fig. 68) or as chimneylike monoliths above the ground-surface (fig. 69), depending on the progress of differential weathering and erosion between the cemented pipe and the less resistant enclosing rocks. The stages of erosion are well displayed in many canyons, especially in Gettys Canyon (sec. 16, T. 3 S., R. 1 E., Custer County, S. Dak.).

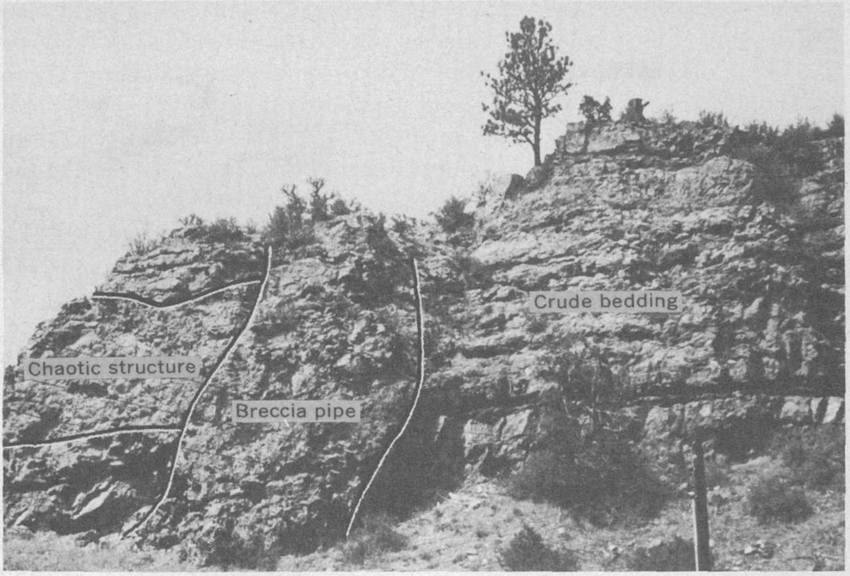

FIGURE 68.—The breccia of the Minnelusa Formation showing crude bedding, chaotic structure, and a breccia pipe in Redbird Canyon, Custer County, S. Dak.

Hundreds of these pipes are exposed in the quadrangle and many of the larger ones are shown on plate 25. Probably a great many more pipes are as yet unexposed.

ORIGIN OF THE BRECCIA

Darton (1901a, 1904, p. 3) described the breccia but did not offer any explanation for its origin. He noted that the Minnelusa is remarkably thicker in the subsurface than in the outcrop, a fact that he termed "interesting and unexpected." Dillé (1930) reported a thickness of 493 feet for the Minnelusa in the northern Black Hills but did not discuss the breccia. P. M. Work (written communication, 1931) believed that the breccia is tectonic, and that it was formed during an uplift that postdated the deposition of the Minnelusa and preceded the deposition of the Opeche. Brady (1931) observed that gypsum in the Minnelusa crops out in the Beulah area of the northwestern Black Hills. Rothrock (1949) stated that anhydrite was leached out of the Minnelusa and a brecciated zone was left in outcrops. Bates (1955) interpreted the breccia as the result of the removal of anhydrite during the deposition of the Minnelusa. Brecciation of the remaining rocks ensued and the blocks were further reworked by wave action.

Denson and Botinelly (1949) believed that the breccia in the upper part of the Hartville Formation, the correlative of part of the Minnelusa in the Hartville uplift, is the result of surface or near-surface collapse of insoluble beds remaining after the leaching out of gypsum in the section. Love, Henbest, and Denson (1953) noticed that gypsum occurs in the outcrop in the red beds overlying the Hartville and concluded that salt probably was present in the Hartville to make the gypsum there more soluble than in the overlying red beds.

As previously noted, exposures of the breccia units of the Minnelusa in the Fanny Peak quadrangle contain no anhydrite and gypsum, but the core recovered from a test hole drilled on contract for the U.S. Geological Survey in the Minnelusa Formation at Pass Creek in the Jewel Cave SW quadrangle (SW¼NE¼ sec. 1, T. 6 S., R. 1 E., Custer County, S. Dak.) indicated that the upper 420 feet of the Minnelusa contained about 235 feet of anhydrite and gypsum (see section 5). The beds of sandstone and limestone in the cores from this hole were not brecciated. If the 235 feet of anhydrite and gypsum

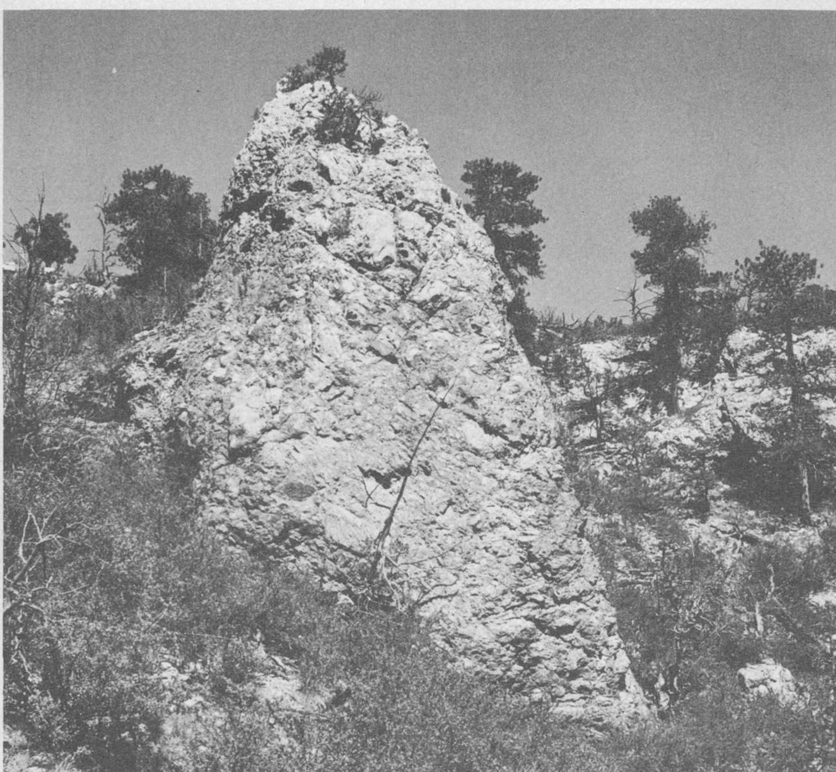

FIGURE 69.—A monolith of breccia pipe in the breccia of the Minnelusa Formation on the north side of Gettys Canyon (sec. 16, T. 3 S., R. 1 E.) Custer County, S. Dak. This pipe rises about 30 feet above the ground surface on the uphill side. Large rock fragments are in a matrix of smaller blocks and sandy material cemented by calcium carbonate.

were restored to the 250 to 300 feet of exposed breccia, the difference between the total subsurface thickness (900 feet) and total exposed thickness (700 feet) of the Minnelusa in the Newcastle region can be explained.

The removal of calcium sulfate and other salts from subsurface is further indicated by analyses of water from springs issuing from the Opeche, Minnekahta, and Spearfish (table 2).

TABLE 2.—*Chemical analyses, in parts per million, of water from four springs in Weston County, Wyo.*

[R. P. Cox and M. J. Fishman, analysts]

Constituent	1	2	3	4
SiO_2	16.0	14.0	13.0	19.0
Al [1]	.2	.4	.1	.4
Fe [1]	.00	.00	.04	.04
Mn [1]	.00	.00	.0	.0
Ca	532.0	472.0	402.0	1,310.0
Mg	83.0	78.0	56.0	246.0
Na	5.4	5.5	3.8	16,500.0
K	2.6	2.6	1.6	19.0
Li	.00	.00	.05	.0
HCO_3	225.0	227.0	190.0	235.0
CO_3	.0	.0	.0	.0
SO_4	1,420.0	1,260.0	1,040.0	3,680.0
Cl	4.0	5.0	1.0	25,000.0
F	.4	.4	.2	.9
NO_3	4.7	3.2	1.4	.0
PO_4	.0	.00	.0	.0
B	.07	.11	.05	2.0
U ... micrograms per liter	.4	11.0	4.7	17.0
Ra ... micromicrocuries per liter	12.0	.2	.1	.7
Total	2,180.0	1,950.0	1,610.0	46,900.0
Residue on Evaporation at 180°C	2,340.0	2,110.0	1,680.0	46,900.0
pH	7.6	7.7	7.5	7.2

Location of springs:
1. SE¼ sec. 31, T. 45 N., R. 60 W.
2. NE¼ sec. 31, T. 45 N., R. 60 W.
3. SW¼ sec. 17, T. 45 N., R. 61 W.
4. NE¼SW¼ sec. 9, T. 46 N., R. 61 W.

[1] In solution at time of analysis.

Northwest of the Fanny Peak quadrangle, in the SW¼ sec. 9, T. 46 N., R. 61 W., near the head of Salt Creek, is a salt spring issuing from the Spearfish Formation. The analysis of this water (table 2, spring 4), indicates that it contains about 4 percent sodium chloride and about 0.5 percent calcium sulfate. The water analysis further indicates that salt, anhydrite, and gypsum are now being removed from the Minnelusa, Opeche, and Spearfish Formations in this vicinity, 6 miles west of the Fanny Peak monocline and the associated fault.

The significance of the presence of sodium chloride in the rocks and ground water should be emphasized. Sodium chloride is extremely soluble in water and would be readily dissolved from the rocks in the early stages of attack by ground water. Furthermore, the solubility of calcium sulfate and of the bicarbonates of calcium and magnesium is increased by the presence of sodium chloride in the solvent. Thus, any sodium chloride in the rocks would be expected to dissolve faster than the sulfate and bicarbonate salts and, as long as the supply of sodium chloride lasted, the rate of solution of the sulfates and bicarbonates would be greater. The analyses on table 2 seem to indicate that the conditions of early stage attack by ground water prevail in the area of the salt spring 6 miles west of the Fanny Peak monocline, and that the conditions of late stage attack by ground water prevail in the Stockade Beaver Creek area adjacent to the Fanny Peak monocline where the supply of sodium chloride has already been depleted. The geological relations and results of these processes are interpreted in the diagrammatic sketch (fig. 70).

The source of the soluble materials in the spring waters is the Spearfish, Opeche, and Minnelusa Formations, as previously stated. It is believed, however, that most of the dissolved material came from the Minnelusa Formation because it is more permeable than either the Spearfish or the Opeche Formations. Within the Minnelusa, ground water may migrate to the anhydrite beds more freely through the adjacent sandstone bed than is possible through the beds of mudstone and siltstone that comprise the bulk of the Spearfish and Opeche Formations. The absence of gypsum in outcrops of the Minnelusa and the occurrence of gypsum in the outcrops of the Spearfish and Opeche Formations support the belief that the mineral constituents of the spring waters were derived chiefly from the Minnelusa Formation.

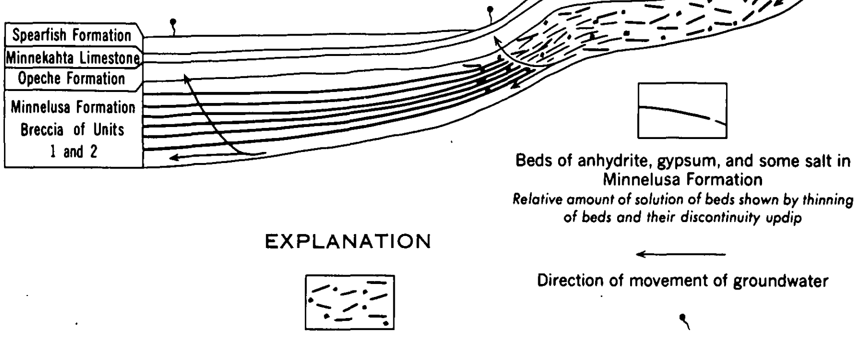

FIGURE 70.—Diagram indicating direction of ground-water movement in the Minnelusa Formation between the Fanny Peak monocline and Salt Creek, and its relation to type of springs issuing from this formation.

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Breccia pipes formed where brecciation was locally intense. The generally vertical attitude of the pipes suggests that they formed along joints or at the intersection of joints, an ideal place for intense solution of intersected beds and lenses of anhydrite and gypsum. The forming of solution chambers was followed by the collapse of overlying and adjacent rocks.

Solution and collapse of the Minnelusa Formation have affected the younger overlying rock. C. G. Bowles (oral communication, 1960) has found fragments of Minnekahta Limestone in breccia pipes in the upper part of the Minnelusa in the Argyl quadrangle, about 25 miles southeast of the Fanny Peak quadrangle. Bowles (oral communication, 1960) also reported red silt similar to that in the Opeche Formation was found in the breccia matrix in the upper part of the Minnelusa in the cores from USGS hole 2 in the Minnekahta quadrangle, about 30 miles southeast of the Fanny Peak quadrangle. He also observed a sag in the Minnekahta Limestone over an exposed breccia pipe in Cold Brook Canyon near Hot Springs, S. Dak. Similar drapes of Minnekahta Limestone over breccia pipes were seen in Hell Canyon, in the Jewel Cave SW quadrangle, by W. A. Braddock (oral communication, 1960). Braddock also found chimneys of breccia in the Spearfish Formation, not far from exposures of gypsum beds in the Spearfish Formation.

Fragments of sandstone from the Canyon Springs Member of the Sundance Formation were found by G. B. Gott (oral communication, 1960) in localized breccia in the upper part of the Spearfish Formation in the Edgemont NE quadrangle, about 25 miles southeast of the Fanny Peak quadrangle. In the same quadrangle, a large collapse structure affects rocks of the Lakota Formation about 1,300 feet above the upper part of the Minnelusa. D. E. Wolcott (oral communication, 1960) reported a similarly large sink structure in the Lakota Formation in the Hot Springs quadrangle.

It is possible that some of the breccia pipes have a base in the Pahasapa caused by solution of the limestone and subsequent collapse. The red shales in the lower limestone of the Minnelusa lack good bedding and appear to be slightly contorted and may have been affected by collapse in the underlying Pahasapa. In Thompson Canyon, about 5 miles north of the quadrangle, brecciation was seen in the Pahasapa. A pipe in the upper and lower limestone of the Minnelusa in Frannie Peak Canyon (SW¼ sec. 33, T. 45 N., R. 60 W.), and one in the lower limestone in the SE¼NW¼ sec. 28, T. 45 N., R. 60 W., possibly have bases in the Pahasapa. Observations in the quadrangle indicate that pipes in the lower part of the Minnelusa are much less abundant than in the breccia in the upper part of the formation, that brecciation is more intense in the upper part of the Minnelusa than in the Pahasapa, and that most of the pipes observed in rocks above the Minnelusa probably have their bases in the breccia of the Minnelusa.

If hydration of anhydrite to gypsum and its solution were not entirely contemporaneous, then a preliminary step to the development of the founder breccia might have been some brecciation caused by the expansion of the anhydrite to gypsum when the latter was penetrated by ground water. An increase in volume of about 40 percent occurs when anhydrite is converted to gypsum by hydration (Bates, 1942, p. 90). Norton (1917, p. 191) termed such a breccia an "expansion breccia." The intensity of such brecciation is unknown because the later brecciation by founder of the remaining insoluble beds is superimposed upon any earlier brecciation, thus masking its effects.

Brecciation of the upper part of the Minnelusa Formation began after the Black Hills were uplifted and the Minnelusa was charged with ground water moving downdip toward the flanks of the uplift. The moving ground waters hydrated the anhydrite to gypsum and then began to remove the latter by solution, although hydration and solution are probably contemporaneous to a great degree. The analyses of the spring waters already given show that solution of gypsum is still going on, resulting in the continuation of brecciation by the foundering of insoluble beds.

The authors conclude that the breccia in the Minnelusa Formation resulted from the removal by ground water of anhydrite or gypsum and some salt and the consequent collapse of the overlying strata. The conclusion is based on the presence of gypsum and anhydrite without breccia at depth, the absence of gypsum and anhydrite in breccia at the surface, and the high amounts of dissolved salts in the spring waters of the area. Norton (1917, p. 191) appropriately called the end product of this process a "founder breccia."

REGIONAL CORRELATION

Regional correlations between the Hartville Formation of Mississippian(?), Pennsylvanian, and Permian age in the Hartville uplift of southeastern Wyoming and the Minnelusa Formation of the Black Hills have been suggested by Condra, Reed, and Scherer (1940; 1950). Condra and Reed (1935) separated the Hartville Formation into six divisions which were later named by Condra, Reed, and Scherer (1940). Love, Henbest, and Denson (1953) summarized the geology of the Hartville Formation; features they described are similar to those of the Minnelusa Formation found during the U.S. Geological Survey's work in the southern Black Hills from 1952 to 1960.

The Minnelusa Formation crops out in large areas around the Precambrian core of the Black Hills (Darton 1909; Darton and Paige, 1925). Only a small part of the total area where the Minnelusa crops out was examined during the Geological Survey's uranium studies in the Southern Black Hills. For this reason, no new formal names are given to the units of the Minnelusa nor is Hartville terminology used in this report. Possible correlations are recognized, however, and the Minnelusa Formation is divisible into six lithic units approximating the six divisions of the Hartville Formation as defined by Condra and Reed (1935). This method is believed to be best for suggesting correlations of rocks in the Black Hills with similar rocks in the Hartville uplift.

C. G. Bowles (oral communication, 1960) has stated that the red marker is of regional extent in the Black Hills, having been found in the Fanny Peak quadrangle, the Pass Creek area, S. Dak., (section 5), the Minnekahta NE quadrangle, S. Dak., in the Argyle quadrangle, northwest of Hot Springs, and in Hot Brook Canyon, near Hot Springs, S. Dak.

Thompson and Kirby (1940) believed that the red mudstone called the red marker can be traced from the Black Hills to the Hartville uplift. They regarded the base of this unit as the systemic boundary between the rocks of Pennsylvanian and Permian age in the Minnelusa Formation. Foster (1958, fig. 6) showed about 400 feet of the Pennsylvanian part of the Minnelusa in the graphic log of the LAK Ranch no. 1 well of the Coronado Petroleum Co., and indicated that he too places the system boundary between the Pennsylvanian and Permian at about the stratigraphic level of the red marker.

In the Fanny Peak quadrangle, the four mappable units of the Minnelusa Formation (pl. 25) are tentatively equated with the six divisions of the Hartville of Condra and Reed (1935) as follows, in ascending order: the lower limestone of lithic units 4, 5, and 6 includes divisions 4, 5, and part of 6; the upper limestone and the sandstone of lithic unit 3 correlate with division 3; and the breccia of lithic units 1 and 2 includes divisions 1 and 2. The base of the red marker is considered the contact of divisions 1 and 2.

PERMIAN SYSTEM

OPECHE FORMATION

The stratigraphy of the Opeche Formation in the western Black Hills and in the Fanny Peak quadrangle is summarized on table 1. Lithologic descriptions are given in measured sections 5, 6, 7, and 8.

MINNEKAHTA LIMESTONE

The Minnekahta Limestone was named and determined to be of Permian age by Darton (1901a, p. 514). The Minnekahta in the

Fanny Peak quadrangle is a gray to purple, laminated, dense to coarsely crystalline slabby limestone that ranges from 25 to 40 feet in thickness. Beds are from less than 1 inch to more than 1 foot thick. The lower 2 to 3 feet and a similar thickness in the middle of the unit contain silty limestone and calcareous siltstone beds which appear as thin dark beds when seen from a distance and weather more rapidly than the more massive limestone between. Pods of chert were found at several places. Microstylolites were seen in thin sections of limestone. A lithologic description is given in measured section 9.

The Minnekahta Limestone is a competent unit that lies between the incompetent and easily eroded Opeche and Spearfish Formations. The Minnekahta, therefore, forms strikingly persistent vertical cliffs in many canyons and strip-surfaces between canyons, particularly in the southeastern part of the quadrangle. In many canyons, the limestone has been undercut; the undercutting is causing slumping of large blocks as great as 100 feet long.

The Minnekahta Limestone contains few fossils. Fragments of crinoid stems were found in float in NE¼ sec. 21, T. 44 N., R. 60 W., Weston County, Wyo. Small impressions that resemble pelecypods were found in the beds of siltstone at many places, but study revealed no organic structures in them.

Part of a fossil ray-finned fish (subclass Actinopterygii) was found in float in Sheldon Canyon. Precise identification was not possible, according to D. H. Dunkle (written communication, 1958), but the fish is of the order Paleoniscoidea or Subholostei. These ray-finned fish were quite abundant during Carboniferous time when extensive morphological change occurred (Romer, 1945, p. 86–96).

Frequent variations in strike and dip over small distances are characteristic of the Minnekahta Limestone. These undulations have a relief as great as 30 feet in a horizontal distance of serveral hundred feet. Previous workers noted these structures. Darton (1901a, p. 515) believed that the variation of attitude is "due to the fact that the formation is relatively hard * * * lying between masses of soft, red shales so that it is free to flex whenever pressure is exerted, the plasticity of the inclosing beds favoring local flexing and warping." E. L. Knaack (written communication, 1936) believed the undulations are due to differential compaction of the Opeche Formation after the deposition of the Minnekahta Limestone and subsequently accentuated by Tertiary diastrophism.

The authors agree that differential compaction of the Opeche is a probable cause of the undulations, but perhaps not the only cause. The foundering of the remaining beds in the upper part of the Minnelusa after the removal of the evaporites could also result in local sagging and warping of the overlying formations. The base of the Minnekahta is only 70 to 120 feet from the top of the breccia unit of the Minnelusa Formation. Gravity sliding of the Minnekahta also may be a cause of the undulations.

GRAVITY SLIDING

Structural features attributed to gravity sliding are found in the Minnekahta Limestone. The Minnekahta is a thin resistant unit between two incompetent formations which act as lubricant; consequently, the limestone could react to the force of gravity by sliding down the regional and local dips. Regional dip here refers to the dips on the flanks of the Black Hills uplift. Local dip here refers to the predominant dip over an area of about 1 square mile.

Two types of gravity sliding were distinguished in the Minnekahta of this quadrangle. The first type results in the buckling of the entire Minnekahta Limestone formation under its own weight where the dip exceeds about 30° and the overlying beds have been removed. The second type results in intraformational folds and faults where lithologically different parts of the unit move differentially with respect to other parts. Billings (1960, p. 368–369) has given a general discussion of the features of gravity sliding.

The first type is common on the monocline east of Stockade Beaver Creek and north of the LAK Reservoir. The stages of development of these structures are shown in figure 71. The beds first buckle slightly then bend and form a cascade fold, and finally rupture and form a slip sheet or small thrust fault whose updip limb overrides the downdip limb. The updip limb generally dips opposite to the downdip limb. The amount of displacement of these slip sheets is not more than about 30 feet and their fault traces are not over 1,000 feet long. A thin zone of breccia is associated with the slip sheets.

The gentle undulations in the Minnekahta described previously may also be partly attributable to gravity sliding. The regional dip, of course, is generally much less than 30° so that the undulations of stage 2 on figure 71 are the end product.

The second type of gravity sliding produces intraformational folds and faults. The Minnekahta contains crystalline limestone and beds of silty limestone and calcareous siltstone. The folds and faults

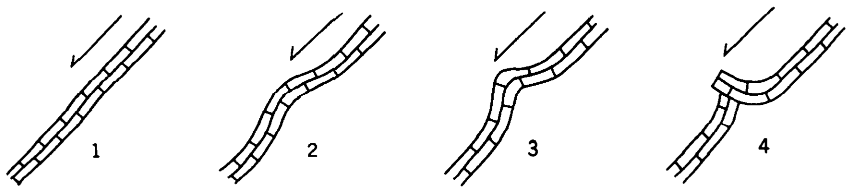

FIGURE 71.—Steps in formation of cascade folds and slip sheets in the Minnekahta Limestone. Flat beds (1), buckle (2), bend and fold (3), small fault (4).

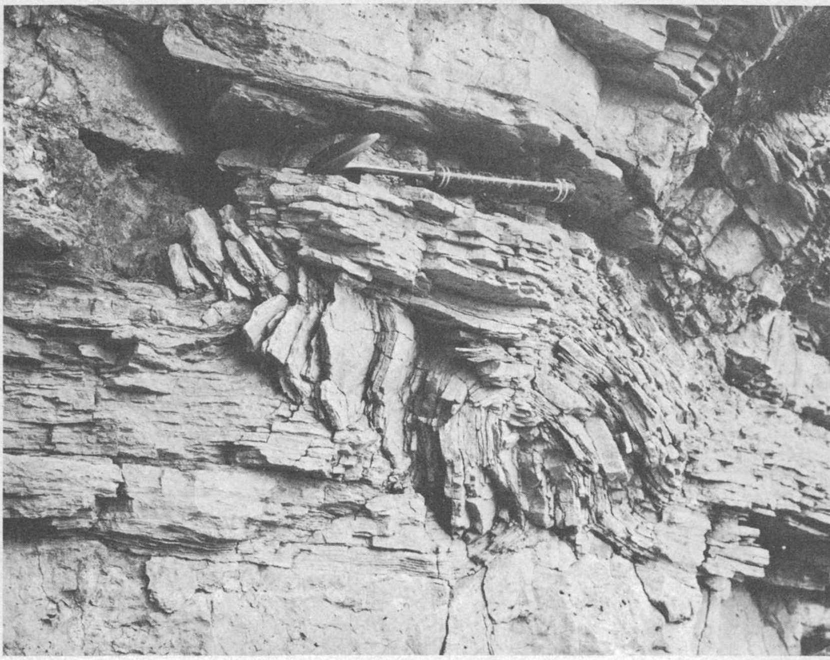

FIGURE 72.—A fold passing into a thrust fault in the Minnekahta Limestone. The fold and fault involve only the thinner more silty beds of the limestone. The photograph was taken in Redbird Canyon.

result from movements of these beds over one another, and although the structures generally cut across the entire formation, in some places they are confined to single beds or groups of beds which form decollements between undisturbed beds above and below (fig 72).

Folds generally are found in the less competent silty beds and pass into thrust faults in the more massive beds of limestone (fig. 72). The faults have displacements of not more than 4 feet and each fold represents a shortening of not more than 3 feet. The horizontal extent of these features could not be determined accurately. In NW¼NE¼ sec. 5, T. 44 N., R. 60 W., Weston County, Wyo., the beds overlying a fold were stripped away and the crest was followed for about 40 feet. The fold probably does not extend for more than 100 feet because its amplitude decreases toward the area of cover.

On the cliffs of Minnekahta Limestone all stages of formation of the folds and faults were seen, including folds with low amplitude, others grading into overturned folds, faulted overturned folds, and thrust faults. Figure 72 shows that the thrust fault in the massive beds follows the projection of the axial plane of the fold. This relationship is in contrast to the usual relationship of thrust faults cutting limbs of folds in areas subjected to regional compression.

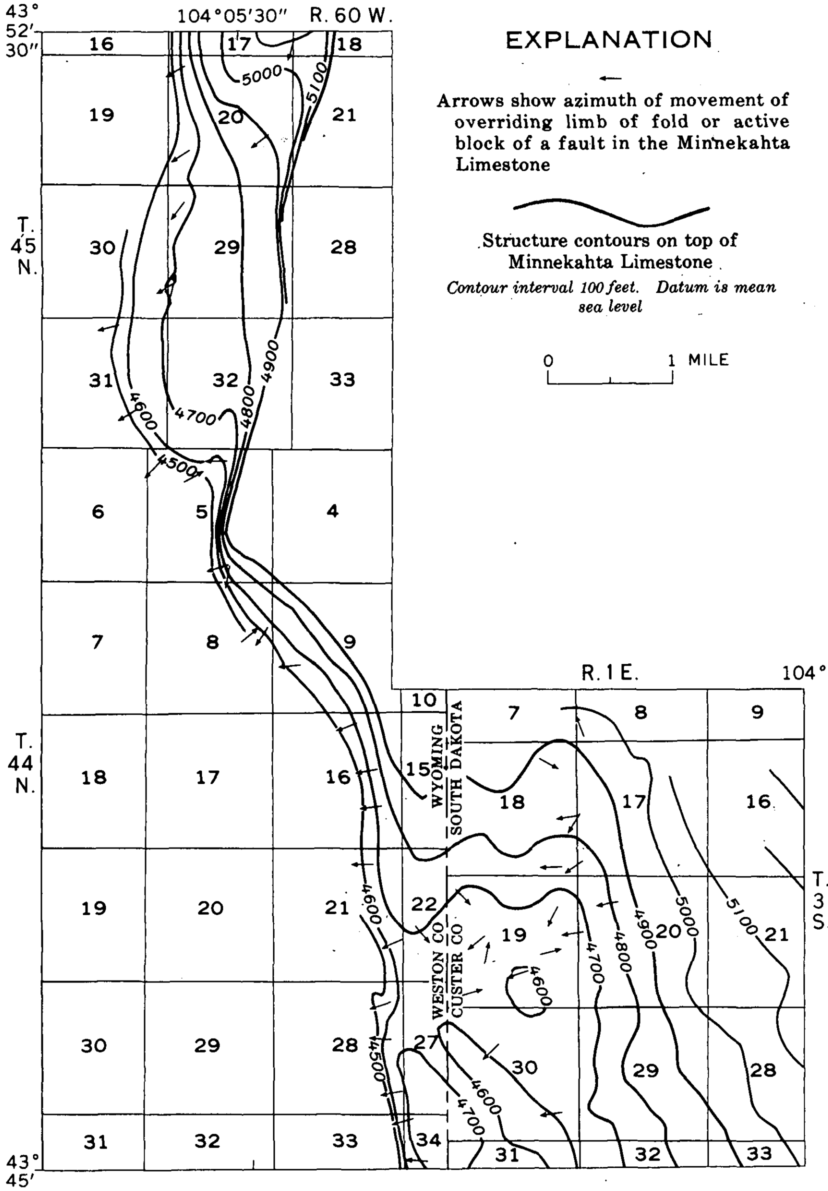

FIGURE 73.—Relation of direction of gravity-sliding features to regional dip of the Minnekahta Limestone, Fanny Peak quadrangle, Wyoming-South Dakota.

The great number of faults and folds, their small size, and their confinement to a thin competent formation between two incompetent units suggest gravity sliding rather than tectonic compressive stress as the cause. If this is true, movement of folds and faults should conform to local directions of dip. Figure 73 is a structure contour map of the areas of exposed Minnekahta Limestone on which are superimposed the azimuth of movement of the overriding limbs of the folds or the active block of a fault. More than 90 percent of the measurements show a movement parallel to strong local dips. Only 7 percent of the measurements indicate movement obliquely to the local dip. Thus, it appears that strong local dip is generally more effective in controlling the direction of movement of the Minnekahta than is the regional dip, provided the local dip is not at too great a variance to the regional dip.

It is estimated that about 100 folds and faults can be seen in a mile of exposed Minnekahta Limestone in cliffs along a canyon wall. If each such feature represents a shortening of about 2 feet, the shortening of the Minnekahta Limestone is about 200 feet per mile, but the range is probably from 25 to 500 feet per mile.

If the hypothesis of gravity sliding is correct, the folds and faults were formed after the uplift of the Black Hills. It is difficult to determine whether sliding began when the overburden was first removed and the Minnekahta breached, or whether it began while the Minnekahta was still buried. If the latter condition prevailed, then tensional fractures probably formed at the crest of the dome and freed the limestone on the limbs of the dome to slide down dip between the confining incompetent beds. Subsurface data are not available to determine whether or not the Minnekahta could slide under confining pressure. Observed cavities formed where the beds have parted in some folds suggest that at least some of the folds could not have formed under thick overburden.

PERMIAN AND TRIASSIC SYSTEMS

SPEARFISH FORMATION

The Spearfish Formation is about 500 feet thick in the Fanny Peak quadrangle, and forms the bedrock of Ferguson Canyon, Lak Draw, and the valley of Stockade Beaver Creek. The regional and the local stratigraphy are both summarized on table 1.

JURASSIC SYSTEM

MIDDLE JURASSIC SERIES

GYPSUM SPRING FORMATION

In the Fanny Peak quadrangle, the Gypsum Spring Formation consists of 4 to 12 feet of impure gypsum. The regional and the local stratigraphy are both summarized on table 1. See also section 10.

UPPER JURASSIC SERIES

SUNDANCE FORMATION

The Sundance Formation consists of green shale, yellow-green and red fine-grained sandstone, and some thin beds of gray limestone. Imlay (1947, p. 232–234) divided the formation into five members totaling a maximum stratigraphic thickness of 475 feet. The members from oldest to youngest are the Canyon Springs Sandstone Member, the Stockade Beaver Shale Member, the Hulett Sandstone Member, the Lak Member, and the Redwater Shale Member.

In the Fanny Peak quadrangle this formation is about 335 feet thick. The exposures are generally poor. The Hulett Sandstone Member is best exposed of all the units; it forms ledges or small cliffs in many places. The Canyon Springs Sandstone Member is absent. The regional and local characteristics are summarized on table 1; see also section 10.

MORRISON FORMATION

The Morrison Formation was identified in the Black Hills by Darton (1901b), who previously had called these rocks the Beulah Shale. Reeside and Yen (1952, p. 26) discussed in some detail the age and correlation of the Morrison in Wyoming and nearby areas. They concluded that the formation is of Late Jurassic age. Regional and local characteristics of the unit are summarized on table 1; see also section 11.

CRETACEOUS SYSTEM

LOWER CRETACEOUS SERIES

INYAN KARA GROUP

Rubey (1930, p. 5) applied the name Inyan Kara Group to a sequence of interbedded sandstone, siltstone, and mudstone of terrestrial to marginal marine origin that includes, in ascending order, the Lakota Sandstone and Fuson Shale of Darton (1901a) and the Fall River Sandstone of Russell (1927, 1928). Rubey was unable to separate the Fuson Shale from the Fall River Sandstone in the northern Black Hills; he proposed the term Inyan Kara Group for all these terrestrial to marginal marine rocks in the northern Black Hills because he could not divide them in the manner of Darton and Russell in the southern Black Hills.

Recent detailed studies by the U.S. Geological Survey of the entire west flank of the Black Hills indicate that the Inyan Kara Group is "* * * a controversial collection of enigmatic units with a shadowy past and an uncertain future" (Bergendahl, Davis, and Izett, 1961, p. 265). The Inyan Kara Group has been divided into two major units, the Lakota Formation and the Fall River Formation. The regional stratigraphy of these units and the evolution of their nomenclature are described in detail by Waagé (1959). The redefined Lakota Formation of Waagé includes the Lakota Sandstone, Minnewaste Limestone, and the Fuson Shale of Darton. The latter two units of Darton are now members of the Lakota Formation. The Lakota sandstone of Darton in the southern Black Hills has been redefined by Post and Bell (1961) as the Chilson Member of Waagé's Lakota Formation. The Fall River Formation is a redefinition of the Fall River Sandstone of Russell (1928).

In the Fanny Peak quadrangle, the Inyan Kara Group has an average thickness of 325 feet. Descriptions of the rocks in the group are summarized on table 1; see also sections 12 and 13.

Several characteristics make it possible to distinguish the rocks of the Lakota from those of the Fall River. The rocks of the Fall River commonly contain accessory muscovite in amounts visible to the unaided eye, but field and laboratory studies indicate that mica is very rare in the Lakota. The fine-grained rocks of the Fall River are generally thinner bedded and more laminated than those of the Lakota. Sandstones in the Fall River generally weather yellow or red brown, are quite well sorted, and rarely contain chert. Sandstones in the Lakota generally weather to gray, white, or brown, and generally are poorly sorted, especially in the coarser sizes. Chert conglomerate is common in the S_3 sandstone of the Lakota. The sandstones of the Lakota commonly contain what appear to be grains of aggregated yellow clay about the same size as the other grains in the rock. These grains give a characteristic spotted appearance to the rock. Thin-section studies reveal that some of these grains are weathered chert. Carbonaceous matter appears to be common in the rocks of the Chilson Member of the Lakota and in the Fall River Formation, but uncommon in the mudstone of the Fuson Member of the Lakota Formation.

LAKOTA FORMATION

The Lakota Formation in the Fanny Peak quadrangle has an average thickness of 200 feet and includes rocks of the Chilson and Fuson Members. The Minnewaste Limestone Member, which is between the Chilson and Fuson Members in some areas of the southern Black Hills, is absent in this quadrangle.

The contact of the Lakota Formation with the underlying Morrison Formation appears to be gradational around much of the western side of the Black Hills, but locally there appears to be an angular discordance. Waagé (1959, p. 50–52), in discussing this contact, pointed out that the Morrison is locally absent in the Storm Hill quadrangle in the northern Black Hills. Brobst (1961) has also reported a similar absence of the Morrison in the northeastern part of the Dewey quadrangle where the Lakota Formation directly overlies the Redwater Shale Member of the Sundance Formation.

Chilson Member—The Chilson Member of the Lakota Formation in the Fanny Peak quadrangle is composed of two units of rocks, a basal chocolate-brown carbonaceous siltstone and a white to brown sandstone (S_1). (The numbers here assigned to the sandstones of the Lakota and Fall River Formations are the same as the numbers assigned to equivalent sandstones mapped in other quadrangles in the southern Black Hills during the course of uranium studies in the area by the U.S. Geological Survey. Six major sandstone units have been mapped in the Inyan Kara Group. The subscript numbers 1 to 6 indicate an order of decreasing age. Only sandstones S_1, S_3, and S_5 were recognized in the Fanny Peak quadrangle. See Mapel and Gott (1959).)

The basal carbonaceous siltstone is generally poorly exposed on steep grassy slopes at the base of sandstone cliffs. The siltstone is chocolate brown when fresh and weathers to flakes of characteristic silvery gray. The unit ranges in thickness from 0 to 40 feet, but the average thickness is about 20 feet. The best exposures are along the base of the east face of the hogback formed by the rocks of the Inyan Kara Group in secs. 17, 20, and 29, T. 44 N., R. 60 W., Weston County, Wyo. The siltstone unit is locally absent, probably because of channeling prior to the deposition of the overlying sandstones. R. W. Schnabel (oral communication, 1959) found that similar siltstones intertongue with the S_1 sandstone in the Burdock quadrangle, 25 miles south of the Fanny Peak quadrangle. It is possible, therefore, that rocks of this unit in the Fanny Peak quadrangle are also a facies of the S_1 sandstone. The contact with the Morrison Formation appears to be gradational in this quadrangle.

The S_1 sandstone is a body of white to brown, crossbedded, quartzose sandstone, generally fine to medium grained, which also contains some carbonaceous material and silty and clayey lenses. The unit attains a maximum thickness of 100 feet on the cliffs in Whoopup Canyon, near the southwest corner of the quadrangle. About 2 miles east of the thick section at Whoopup Canyon, the sandstone is absent on the west wall of Ferguson Canyon; it presumably was removed by channeling prior to the deposition of the S_3 sandstone of the Fuson Member. Northward to U.S. Highway 16 along the east face of the hogback formed by the Inyan Kara rocks, the S_1 sandstone has an average thickness of 60 to 80 feet. On the cliffs east of LAK Reservoir it is at least 74 feet thick (section 12). The S_1 sandstone forms cliffs 40 feet high in sec. 25, T. 45 N., R. 61 W., Weston County, Wyo.

The abundant crossbedding, the heterogeneity of included material, the pinching and swelling of the unit, and the removal of the underlying beds of the basal siltstone suggest that the S_1 sandstone was deposited in a complex of fluvial channels. The orientation of the crossbeds suggests that the direction of flow was to the northwest.

Fuson Member.—The Fuson Member of the Lakota Formation in the Fanny Peak quadrangle is composed of two units of rocks, the S_3 sandstone, and a sequence of varicolored mudstone and interbedded siltstone and sandstone.

The S_3 sandstone of the Fuson Member is white to brown. The texture varies greatly, even on a single outcrop. In one vertical exposure of 50 feet the unit may contain irregular beds or lenses of chert pebble conglomerate, granule sandstone, and very coarse to very fine grained sandstone. The rock is locally cemented by calcite. The boundaries between the texturally different parts may be either sharp or gradational, and sorting within texturally different parts is generally good. Scour and fill structures are common; cross-bedding is abundant. Very locally, the sandstone is poorly bedded and even has a massive appearance.

The unit is predominantly a quartzose sandstone in which quartz constitutes more than 90 percent of the rock. The grains of quartz are frosted and rounded. Other constituents are traces of feldspar and yellow clayey-appearing grains that are altered chert or possibly feldspar. Among the heavy accessory minerals are magnetite, zircon, and rutile. Thin films of secondary iron oxide coat the grains in some places.

Locally the chert pebble conglomerate is abundant, especially just west of Ferguson Canyon in sec. 33, T. 44 N., R. 60 W., at the head of Whoopup Canyon in the NW¼ sec. 29, T. 44 N., R. 60 W., Weston County, Wyo., and near U.S. Highway 16 in SW¼NW¼ sec. 8, and the SW¼SW¼ sec. 5, T. 44 N., R. 60 W., Weston County. The well-rounded pebbles are white, gray, brown, and black and are as much as one-half inch long, although the average length is about one-fourth inch. The matrix is sand and clay.

The S_3 sandstone is well exposed on the dipslope of the mountain west of Ferguson Canyon (sec. 33, T. 44 N., R. 60 W.), as cliffs at the head of Whoopup Canyon (sec. 29, T. 44 N., R. 60 W.), in the vicinity of U.S. Highway 16 (secs. 5 and 8, T. 44 N., R. 60 W.), and as the cliffs on the west side of the LAK Reservoir (sec. 6, T. 44 N., R. 60 W.). All these exposures are in Weston County, Wyo. The unit has an average thickness of about 70 feet. It attains its maximum exposed thickness of about 100 feet at the head of Whoopup Canyon. The S_3 sandstone is locally absent as in Whoopup Canyon south of the SW¼ sec. 29, T. 44 N., R. 60 W., and along the east face of the Inyan Kara hogbackin secs. 17 and 20, T. 44 N., R. 60 W.,

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Weston County. The absence can be attributed to erosion or nondeposition. Between the exposures on the mountain west of Ferguson Canyon and those at the head of Whoopup Canyon the thick part of the unit trends northwest; this trend suggests that the thick part of the unit to the northwest may be buried by younger rocks on the hogback. S_3 sandstone reappears just south of U.S. Highway 16 (sec. 8, T. 44 N., R. 60 W., Weston County).

The top of the S_3 sandstone is generally marked by a distinct topographic break from steep cliffs to less steep, covered slopes formed by the less resistant overlying Fuson units, especially the unit of mudstone with which the S_3 sandstone appears to merge.

The contact of the S_3 sandstone with the underlying rocks appears to be irregular. The S_3 sandstone locally overlies the S_1 sandstone, or the basal carbonaceous siltstone, or even the Morrison Formation, as in Ferguson Canyon.

In the SW¼ sec. 31, T. 45 N., R. 60 W., Weston County, Wyo., the S_3 sandstone is separated from the S_1 sandstone by a 25-foot-thick interval of carbonaceous siltstone and mudstone. This carbonaceous sequence, possibly a fine-grained lateral facies of the S_3 sandstone, thins to the south and is exposed intermittently as thin discontinuous lenses of carbonaceous rocks on the cliffs to the west of the LAK Reservoir. To the north and west of the SW¼ of sec. 31, the carbonaceous unit thickens and becomes coal-bearing. It is 15 to 20 feet thick in cliffs along Salt Creek in NE¼ sec. 35, T. 45 N., R. 61 W., Weston County, Wyo., in the adjacent Newcastle, Wyo., quadrangle.

Geologic work in the Fanny Peak, Clifton, and Dewey quadrangles suggests that the S_3 sandstone is an elongate body of rock whose thickest and coarsest parts of the unit trend chiefly northwestward. The elongate shape of the thickest and coarsest parts of the unit, the great variation in grain size, the abundant crossbedding, and the unconformable contact with underlying rocks suggest that this body of rock is a complex of sandstone and conglomerate that was deposited in a system of river channels. The crossbedding suggests that the direction of flow was northwestward.

The mudstone unit of the Fuson Member averages about 60 feet thick and is a heterogeneous sequence of rocks composed principally of gray, yellow, red, or green mudstone. Some of this mudstone contains a few smoothly rounded pebbles or cobbles of chert or siliceous rock, as much as 1 or 2 inches in diameter. The rounded cobbles are reported at many places in the southern Black Hills and appear to be most common in the mudstone but rare in the sandstone of the Fuson. Thus, the cobbles are considered index criteria for mapping the Fuson Member.

Intercalated with the mudstone are some siltstone and thin beds of white, gray or yellow sandstone. Some of the sandstone stands out as thin discontinuous ledges 1 to 5 feet high. Most of the sandstone is loosely cemented by clay. In scattered places, cement of silica or calcite makes these rocks more resistant to weathering.

The upper part of the unit contains the zone of siderite pellets described by Waagé (1959, p. 55) as occurring in mudstone and sandstone between 1 and 12 feet of the top of the Lakota Formation. These pellets are spherulitic siderite and rarely exceed 3 mm in diameter. The pellets consist of radially oriented fibers surrounding opaque cores; they weather to earthy red and yellow specks. The spherules are believed to have formed by precipitation from a gel. This zone is exposed in SE¼ sec. 18, T. 44 N., R. 60 W., and in the road cut in the hogback on the south side of U.S. Highway 16, just east of the headquarters of the LAK Ranch.

The mudstone unit generally forms covered slopes that support grass and juniper on both dip and antidip slopes of the hogback of Inyan Kara. On the steeper parts of the dipslope of the hogback in sec. 18, T. 44 N., R. 60 W., Weston County, Wyo., this unit forms a small depression between the more resistant sandy units above and below.

The lower contact of this unit with the S_3 sandstone appears to be gradational; if so, then the poorly exposed contact with the S_1 sandstone is probably unconformable. An unconformable contact between the Fuson and Chilson Members has been found in the area between Edgemont and Hot Springs, S. Dak., where the rocks of the Fuson Member lap over those of both the Minnewaste and the Chilson Members (G. B. Gott and D. E. Wolcott, oral communication, 1960). The upper contact of this unit with the overlying Fall River Formation is an unconformity described in some detail by Waagé (1959, p. 52–55) as a regional transgressive disconformity.

The rocks of this unit are interpreted as chiefly lacustrine and swampy deposits laid down in the areas between the major systems of river channels.

FALL RIVER FORMATION

The Fall River Formation in the Fanny Peak quadrangle consists of about 125 feet of very fine to medium-grained sandstone, siltstone, and mudstone. All these rocks are interlayered and many are carbonaceous. The formation has been mapped as three units: lower, middle, and upper. Only the upper unit forms a continuously mappable unit along the entire length of the hogback formed by the Inyan Kara rocks in the Fanny Peak quadrangle. The middle and lower units had to be mapped as combined units at places because of changes in sedimentary facies. See section 13.

Lower and middle units—The lower unit of the Fall River Formation comprising interbedded, thinly laminated carbonaceous siltstone and thinly bedded sandstone is mappable as a separate unit only in the southern third of the quadrangle. The lower unit does not exceed a thickness of 20 feet in most places. North of the SW¼ sec. 20, T. 44 N., R. 60 W., Weston County, Wyo., this unit was mapped with the middle unit of the Fall River Formation.

The middle unit of the Fall River Formation is composed chiefly of yellow to red-brown S_5 sandstone and some interlayered siltstone and mudstone. Carbonaceous material is abundant in all these rocks. The S_5 sandstone is a coarse- to fine-grained rock in which facies of medium grain predominate. Most of the sandstone is probably more than 90 percent rounded quartz grains and accessory amounts (less than 5 percent) of plagioclase, microcline, muscovite, and chert. Most of the sandstone is friable, but locally it is cemented by calcite or silica. Scattered lenses or pods of red to gray clay 2 or 3 inches thick and several feet in diameter are common. Crossbedding is extremely common.

The S_5 sandstone has an average thickness of about 45 feet in the Whoopup Canyon area. Within 1.5 miles north of the head of Whoopup Canyon, the conspicuous individual beds of S_5 sandstone, as much as 30 feet thick, thin to beds only a few feet thick. Outcrops in this area are poor and these beds of sandstone become indistinguishable from those of the lower unit of the Fall River.

This middle unit is regarded as a complex of deposits in systems of river channels that have been traced along the southern and western flanks of the Black Hills from Hot Springs, S. Dak., to near the head of Whoopup Canyon in the Fanny Peak quadrangle, a distance of about 50 miles. Crossbeds indicate that the direction of flow was north to northwestward.

The "disappearance" of the S_5 sandstone can be explained in several ways. The thicker parts of this body of rock may lie farther west and down dip from the present crest and valley floors cut into the hogback of Inyan Kara. If they do, then the rocks exposed on the hogback are facies marginal to the main part of the channel. The S_5 sandstone from Whoopup Canyon southward toward Hot Springs has the characteristics of deposits of a continental river-channel system. It seems possible that the river which deposited the S_5 sandstone might have emptied into an estuary or marginal marine swamp in the vicinity of the head of Whoopup Canyon; if it did, the deposition of thick channel sandstone might have ceased and deposition of more thinly bedded deposits might have begun.

It also must be noted that the nature of the rocks of the Fall River Formation is somewhat different in the northern and southern Black

Hills. In the southern Black Hills the middle unit of the Fall River, the S_5 sandstone, is a conspicuous part of the formation. In the northern Black Hills this middle unit is missing and thick channel-fill deposits of sandstone are less conspicuous. The individual beds of sandstone may be only a few feet thick and are included in a sequence of thinly and relatively evenly bedded siltstones and mudstones. The sections of the Fall River described in this paper are much more typical of the Fall River Formation in the northern than southern Black Hills. These sections may be compared to those measured in the Dewey quadrangle, Wyoming-South Dakota (Brobst, 1961), which are considered typical of the Fall River Formation in the southern Black Hills. The differences between the rocks of the Fall River Formation in the northern and southern Black Hills also are discussed by Waagé (1959, p. 59–62).

The combined lower and middle units have an average thickness of about 85 feet and consist of interbedded sandstone, siltstone, and mudstone. Outcrops of this unit are so scattered that it is impossible to trace very far given beds or specific sequences. The sandstones of the lower and middle units combined are chiefly tan to brown and composed of fine- to medium-grained quartz. Crossbedding is common. The individual beds rarely exceed a few feet in thickness and scour and fill structures a few inches to a few feet thick are common. Interlayered with the sandstone are beds of tan and gray to black siltstone and mudstone. Carbonaceous matter is abundant, and in some beds it is disseminated throughout the rocks as bits and fragments of charcoaly material, or in siltstone and mudstone it may form black laminae alternating with laminae of other colors. In places it is so abundant as to form lignitic layers.

The contact with the underlying Lakota Formation is an unconformity, as previously stated, that has been termed a regional transgressive disconformity by Waagé (1959, p. 52–55).

Curious burrows were found in sandstone near the base of the Fall River Formation in the little remnant of these rocks in sec. 36, T. 45 N., R. 61 W., Weston County, Wyo. The burrows are U-shaped and randomly oriented in the rock. Each limb is about 2 inches long and the distance across the open end also is about 2 inches from outside edge to outside edge of the limbs. P. E. Cloud, Jr., examined the burrows and stated in a written communication (Feb. 28, 1958) that "* * * the present burrows were probably made by an unknown crustacean in a sediment that was rich in organic matter at the time of its deposition. If the field evidence is not opposed, I'd suggest an intertidal environment, but of course it *might* be a lake (shore zone) or stream."

Upper unit.—The upper unit of the Fall River Formation is a complex sequence of interlayered siltstone, mudstone, and sandstone containing abundant carbonaceous matter. Individual beds are a few inches or a few feet thick, at most. This unit has an average thickness of about 40 feet. It is particularly well exposed in the road cut in the hogback of Inyan Kara on the south side of the old U.S. Highway 16 in the NW¼ sec. 8, T. 44 N., R. 60 W., and in road cuts on the east side of the road in SE¼ sec. 6, T. 44 N., R. 60 W., Weston County, Wyo.

The contact of the upper and middle units is a rather abrupt change in a few feet and can be placed only approximately where the discontinuous thick-bedded sandstone in the middle unit gives way to predominant siltstone and mudstone and thinner, more evenly bedded sandstone of the upper unit.

The contact with the overlying black Skull Creek Shale is gradational in a zone probably not exceeding 5 to 10 feet through which the amount of black shale increases upward and sandstone decreases. In this zone of transition is a dark-brown calcareous impure sandstone 1 to 4 feet thick, which has been traced northward continuously from the Dewey fault (Brobst, 1961) into the Newcastle quadrangle, to the west of the Fanny Peak quadrangle. The top of this calcareous sandstone has been mapped as the top of the Fall River Formation.

The thin and even bedding of the rocks in the upper unit of the Fall River, and the position of the unit between the rocks of continental origin in the middle and lower units of the Fall River and the rocks of marine origin in the Skull Creek suggest a continental to marginal marine origin.

SKULL CREEK SHALE

The black Skull Creek Shale is about 200 feet thick in the Fanny Peak quadrangle where it generally is poorly exposed in a small valley between the ridges formed by the overlying Newcastle Sandstone and the underlying Inyan Kara Group. The stratigraphy of this formation is summarized on table 1.

NEWCASTLE SANDSTONE

On the western side of the Black Hills the Newcastle Sandstone of Early Cretaceous age consists of lenticular bodies of sandstone and interbedded shale and siltstone and a few beds of impure coal and bentonite. The formation pinches and swells laterally and ranges in thickness from 0 to about 100 feet. The regional and local features are summarized on table 1.

In the Fanny Peak quadrangle the Newcastle Sandstone consists of a sequence of lenticular masses of crossbedded carbonaceous gray to brown sandstone interbedded with shale, siltstone, and thin layers of bentonite exposed irregularly on a low hogback from the NE¼ sec. 7, T. 44 N., R. 60 W., southward to sec. 31, T. 44 N., R. 60 W., Weston County, Wyo. The unit is 20 to 62 feet thick and its thickness and composition change in short lateral distances. At the south end of the hogback, in the southwest corner of the quadrangle, sandstone is exposed on cliffs 60 feet high. Near the north end of the hogback in the NE¼SE¼ sec. 7, T. 44 N., R. 60 W., considerably less sandstone is found (section 14).

The variations in composition and thickness in short distances, the carbonaceous matter, and the crossbedding suggest that the rocks of the Newcastle Sandstone were formed in a shallow to marginal marine environment.

MOWRY SHALE

The Mowry Shale in the Fanny Peak quadrangle consists of about 150 feet of dark-gray siliceous shale containing intercalated thin beds of sandstone and bentonite. The formation weathers characteristically to silver-gray flakes—a marked contrast to the black clays derived from the weathering of the enclosing Belle Fourche and Skull Creek Shales. Fish scales are abundant. The Mowry Shale is best exposed in sec. 18, T. 44 N., R. 60 W., Weston County, Wyo. The regional and local stratigraphy of this formation is summarized on table 1.

UPPER CRETACEOUS SERIES

BELLE FOURCHE SHALE

The Belle Fourche Shale consists of gray to jet-black shale containing zones of oligonite (iron-manganese carbonate) concretions and many beds of bentonite. The shale is about 400 feet thick in the Fanny Peak quadrangle where it is best exposed in sec. 18, T. 44 N., R. 60 W., Weston County, Wyo. The regional and local stratigraphy of this formation is summarized on table 1.

GREENHORN FORMATION

In the Fanny Peak quadrangle the Greenhorn Formation consists of about 270 feet of yellow-brown and gray limestone, calcareous shale, and marl. It is poorly exposed in the low hills just east of Stockade Beaver Creek and south of U.S. Highway 16. The regional and local stratigraphy of the formation is summarized on table 1.

CARLILE SHALE

The Carlile Shale consists of three members, base to top: lower unnamed member, Turner Sandy Member, and Sage Breaks Member. The rocks are chiefly gray shale, containing zones of calcareous and ferruginous concretions, and sandstone. In the Fanny Peak quadrangle the three members have a total thickness of about 535 feet as determined from exposures in sec. 7, T. 44 N., R. 60 W., Weston County, Wyoming. The stratigraphy of this formation is summarized on table 1.

NIOBRARA FORMATION

In the Fanny Peak quadrangle, the Niobrara Formation consists of about 170 feet of yellow to gray chalk marl, calcareous shale, and numerous thin beds of bentonite. The formation is poorly exposed in the low hills east of Stockade Beaver Creek and south of U.S. Highway 16. The stratigraphy of this unit is summarized on table 1.

PIERRE SHALE

The Pierre Shale in the Black Hills region consists chiefly of gray to black shale, sandy shale, and sandstone having many intercalated beds of bentonite. The regional and local aspects of the unit are summarized on table 1.

Only the lowermost 400 feet of the Pierre Shale are exposed in low hills east of Stockade Beaver Creek and south of U.S. Highway 16 in the Fanny Peak quadrangle. The lower 50 feet is considered part of the Gammon Ferruginous Member, and the remainder is considered part of the Mitten Black Shale Member, or possibly equivalents of the Sharon Springs Member (J. R. Gill and W. J. Mapel, oral communications, 1960). The alluvial deposits of Stockade Beaver Creek undoubtedly cover more Pierre shale.

QUATERNARY DEPOSITS

TERRACE GRAVEL

Deposits of terrace gravel are abundant along the east margins of Stockade Beaver Creek, and small thin remnants of more extensive deposits are scattered across the strip surface of the Minnekahta Limestone. Most of the deposits now are probably less than 25 feet thick. They are composed of rounded to angular rock fragments of mixed sizes in a silty to sandy matrix. The fragments were derived principally from the Lakota, Fall River, Minnekahta, Minnelusa, and Pahasapa. Most of the deposits are at altitudes ranging from 4,200 to 4,800 feet, but no criteria were established for differentiating between deposits at various altitudes.

LANDSLIDE DEBRIS

The rocks of the Inyan Kara Group overlie incompetent shaly formations, and thus are susceptible to landsliding on the steep antidip slopes of the hogback of Inyan Kara. A large area of landslide debris was mapped on the west side of Stockade Beaver Creek in the northwest corner of the quadrangle. A smaller landslide was mapped at the mouth of Ferguson Canyon.

ALLUVIUM

Alluvium occurs in the valleys of the major streams and extends into their tributaries. It is composed of calcareous silty material and interbedded lenses of conglomerate. The conglomerate beds contain subrounded to angular fragments of rocks chiefly from the Minnekahta, Pahasapa, Opeche, and Minnelusa. The fragments range in size from a fraction of an inch to 2 feet in their longest dimension. Some of the larger angular boulders possibly have not been moved more than a few hundred feet. Channeling and crossbedding are common. The thickness of the alluvium could not be determined but is probably more than 25 feet in many places. A rancher reported 103 feet and 40 feet of alluvium in two water wells in NE¼NW¼ sec. 27 and the NE¼NE¼ sec. 28, T. 44 N., R. 60 W., respectively.

SPRING DEPOSITS

Five small deposits of tufa, porous deposits of calcium carbonate formed by springs, are found along the steep monoclinal terrace along the east side of Stockade Beaver Creek north of LAK Reservoir. The tufa is white to tan, and leaf and twig impressions are abundant. The deposits probably are only a few feet thick. Terrace gravels below the spring in the SW¼ sec. 20, T. 45 N., R. 60 W., Weston County, Wyo., are cemented by tufa.

The waters issue from either the Opeche Formation or the Minnekahta Limestone. The source of the water is believed to be chiefly the Minnelusa Formation. Analyses of the spring water are given and discussed in the section to the Minnelusa Formation.

STRUCTURAL GEOLOGY

The Fanny Peak quadrangle lies on the west flank of the Black Hills, an asymmetrical dome in western South Dakota and northeastern Wyoming. The general configuration of the dome is shown in figure 66 by the top of the Minnekahta Limestone. Precambrian rocks are exposed only in the central part of the uplift. Sedimentary rocks of Paleozoic, Mesozoic, and Cenozoic age are exposed around the Precambrian core, the oldest rocks being closest to the core (Darton, 1904). Structure in the sedimentary rocks is similar to that shown in figure 66.

The Fanny Peak quadrangle encompasses the area of the west flank of the Black Hills in which the northwesterly structural trends of the northern Black Hills turn to the northerly trends of the southern Black Hills (fig. 66). Some of the details of this change in structural trends as well as the major structures of the Fanny Peak quadrangle are indicated by the structure contours on plate 25.

The two major structural features in the Fanny Peak quadrangle are the Black Hills and the Fanny Peak monoclines (pls. 25, 26). These two monoclines appear to intersect in secs. 5 and 8, T. 44 N., R. 60 W., Weston County, Wyo. Thus, in parts of the quadrangle each monocline forms the boundary structure between the Black Hills on the east and the Powder River Basin on the west.

The Black Hills monocline trends north-northwest from near Edgemont, S. Dak., for about 40 miles to the Fanny Peak quadrangle, where it turns and trends northwest for an additional 40 miles. The change in trend occurs at the intersection with Fanny Peak monocline. South of U.S. Highway 16, the Black Hills monocline lies east of the Fanny Peak monocline. The structural terrace between the two monoclines between U.S. Highway 16 and the Dewey fault has been termed the Dewey terrace (pl. 26; Brobst, 1961).

The Fanny Peak monocline trends about N. 15° E. on the western side of the quadrangle; south of sec. 5, T. 44 N., R. 60 W., Weston County, Wyo., it forms the structural boundary between the Black Hills and the Powder River Basin.

North of sec. 5 the Fanny Peak monocline is sharply defined. The rocks stand nearly verticle and the structural relief is about 1,200 feet in a distance of one-quarter mile. Within 5 miles north of the Fanny Peak quadrangle, the monocline passes into a steeply dipping fault having about 800 feet of throw. This displacement can be seen at the mouth of Thompson Canyon (sec. 27, T. 46 N., R. 60 W.) where the Minnekahta Limestone on the downthrown western side abuts the upper part of the Pahasapa Limestone on the eastern side of the fault.

Other, smaller monoclines occur west of Boles Canyon and along the east side of the valley of Stockade Beaver Creek. The monocline along Stockade Beaver Creek has 600 feet of structural relief and trends northward across the quadrangle boundary for another 5 miles.

Some faulting at the surface is associated with the Black Hills and Fanny Peak monoclines, particularly at their apparent intersection in secs. 5 and 8, T. 44 N., R. 60 W., Weston County, Wyo. A fault in sec. 5 displaces the Gypsum Spring Formation 300 feet to the west on the south (upthrown) side of the fault. This fault disappears to the southwest in the upper part of the Fall River Formation and to the northwest in the Spearfish Formation. Also in sec. 5 a group of faults cut the Minnekahta and Opeche and are lost in the breccia of units 1 and 2 of the Minnelusa Formation. A steeply dipping fault having a northwest trend in sec. 8 resulted in an offset of the hogback of the Inyan Kara. Many subsidiary fault planes of small displacement can be seen in the exposures of the Inyan Kara rocks along U.S. Highway 16. Most of these small faults strike S. 85° W. to N. 60° W.

and all dip steeply. Other faults are shown on plate 25; their possibly different origin is discussed in the following section on the interpretation of the structural features.

Jointing is common in the competent rocks. Conspicuous sets of steeply inclined to vertical joints trend about N. 45° E., and N. 20° to 45° W.

INTERPRETATION

The monoclines in the Fanny Peak quadrangle are among the dominant structural features of the west side of the Black Hills. The fact that these monoclines are characterized by changes in the attitude of beds from nearly horizontal to nearly vertical and to nearly horizontal again in short distances suggests that the major forces were vertical. The Fanny Peak monocline merges on strike into a steeply inclined fault of about 800 feet of displacement north of the Fanny Peak quadrangle. It seems reasonable to assume that this fault continues southward at depth into the Fanny Peak quadrangle where the steeply dipping rocks of the monocline are draped over the fault. This fault probably continues southward along the west side of the Dewey terrace (pl. 26) as the border structure between the Black Hills and the Powder River Basin.

The Black Hills and Fanny Peak monoclines probably were formed at about the same time—in latest Cretaceous or in Tertiary time, because rocks of Late Cretaceous age are involved in the folding. The structure contours on plate 25 show that the trend of the Fanny Peak monocline appears to be superimposed upon and to somewhat offset the northwest trend of the Black Hills monocline in the vicinity of their intersection in secs. 5 and 8, T. 44 N., R. 60 W., Weston County, Wyo. Reasoning on this evidence leads the authors to suggest that tectonic activity along the Fanny Peak monocline in this area continued longer than that along the Black Hills monocline. The concentration of faults in secs. 5 and 8, T. 44 N., R. 60 W., is probably the result of adjustments to forces applied to rocks already folded prior to the time of major tectonic activity along the Fanny Peak monocline.

The authors can find no convincing evidence to cause doubt about either the continuity of the Fanny Peak structure north and south of LAK Draw, or its being the youngest major structure in the quadrangle. They do recognize, however, that the continuity of the Black Hills monocline north and south of LAK Draw is questionable. Other possible interpretations are: (1) The Black Hills monocline extending into this quadrangle from the northwest may end at the Fanny Peak monocline in secs. 5 and 8, T. 44 N., R. 60 W., or (2) prior to the formation of the Fanny Peak monocline it may have been connected with the structural feature that forms the hogback of Minnekahta in secs. 8, 9, and 16, T. 44 N., R. 60 W.; this feature dies out at the mouth of Redbird Canyon in secs. 21 and 22. (3) The feature we term the "Black Hills monocline" south of LAK Draw may be a separate one which ends on the east side of the Fanny Peak monocline or might have been continuous with the monocline just east of Stockade Beaver Creek; (4) another possibility is that the monocline east of Stockade Beaver Creek once was part of the structure which forms the hogback of the Minnekahta north and east of LAK Draw.

The major fault associated with the Fanny Peak monocline certainly must involve the Precambrian basement complex. At the mouth of Thompson Canyon, the Precambrian rocks are probably within 500 feet of the surface on the upthrown eastern side of the fault. Whether the movement on this fault first occurred in latest Cretaceous or Tertiary time, or is a rejuvenation of older Paleozoic or even Precambrian fault zones has not been established. J. J. Norton (oral

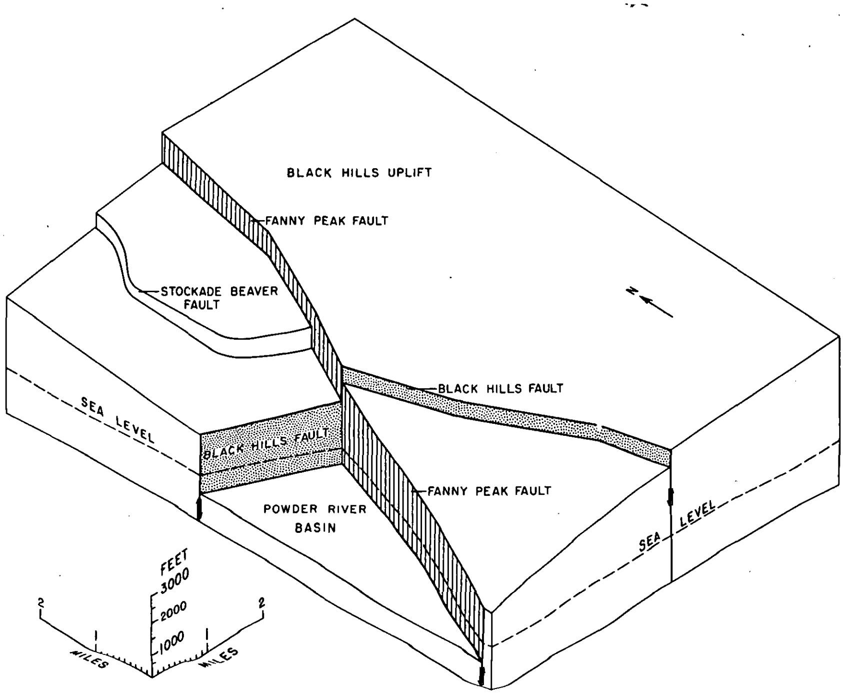

FIGURE 74.—Isometric diagram depicting probable major fault blocks at depth in the Fanny Peak quadrangle, Wyoming-South Dakota. Upper surface of blocks is top of Precambrian rocks.

communication, 1960) stated that north- and northwest-trending structures of Precambrian age have been found in the Custer area in the Precambrian core of the Black Hills.

The authors conclude that high-angle faulting involving Precambrian rocks is the cause of the monoclinal structures in the Fanny Peak quadrangle. Our interpretation of this faulting is shown in figure 74.

The faults in NE¼ sec. 28, SE¼ sec. 16, NW¼ sec. 20, and SW¼ sec. 9, T. 44 N., R. 60 W., are possibly the result of collapse in the breccia units of the underlying Minnelusa Formation. The fault in the NW¼ sec. 20 might also be affected by some slippage of the rocks on the monocline. The faults in the SW¼ sec. 6 and the NW¼ sec. 19, T. 44 N., R. 60 W., are probably the result of slippage of the rocks on the monoclines.

The anticline trending north from Fanny Peak and the adjacent syncline in the Boles Canyon area are probably the result of faulting in the subsurface. No further data are available on these features.

ECONOMIC GEOLOGY

The Spearfish Formation contains much gypsum, but it is largely covered and has such a steep dip that little is readily available near the surface. Beds of bentonite in the sedimentary rocks above the Inyan Kara Group are numerous but too thin and dip too steeply to be of economic value now. No obvious uranium ore deposits were found in the rocks of the Inyan Kara Group in this quadrangle.

The gravel deposits in the quadrangle afford construction materials as needed. Several inactive gravel pits are located in the terrace gravels, notably in Gillette Canyon and on the low hills east of Stockade Beaver Creek south of U.S. Highway 16.

The Minnekahta Limestone is a high-calcium limestone in this region according to analyses by P. H. Bates and A. J. Phillips (Darton and Paige, 1925, p. 9). Samples from the east side of Stockade Beaver Creek indicate that the limestone contains about 95 percent calcium carbonate. One-half mile east of LAK Reservoir, the Minnekahta Limestone has been quarried for construction material.

The water of Stockade Beaver Creek and the springs along its valley are used for irrigation purposes. The surface and ground waters of the area have been discussed by Darton (1904; 1909).

MEASURED SECTIONS

1. *Section of the lower limestone of units 4, 5, 6 of the Minnelusa Formation in NW¼NE¼ sec. 21, T. 45 N., R. 60 W., Weston County, Wyo.*

	Feet
Minnelusa Formation (part):	
Lower limestone (part):	
15. Shale, gray, calcareous; upper part covered	5
14. Shale, red, calcareous, containing green shale blotches; gray limestone bed 20 ft from base of unit; a few thin gray limestone beds 20 to 25 ft from base. Fossiliferous; contains *Schizophoria* aff. *S. texana* Girty (Fossil identification by J. T. Dutro, Jr.)	33
13. Limestone, dark-gray; mottled pink and green in places; weathers dove gray; cherty	25
12. Sandstone, white, calcareous, cherty, fine-grained	20
11. Sandstone and limestone; poorly exposed	16
10. Limestone, red and brown; weathers white; cherty	6
9. Mudstone, yellow to purple, noncalcareous	5
8. Covered	45
7. Dolomite, yellow-brown	3
6. Covered	16
5. Limestone, brown-gray; weathers gray; contains chert nodules	6
4. Sandstone, light-brown, calcareous; contains chert nodules	5
3. Limestone, light-brown, sandy, dolomitic	2
2. Covered	10
Incomplete thickness of limestone	197
Pahasapa Limestone:	
1. Limestone, gray on fresh and weathered surfaces; contains fossil brachiopod and coral; forms steep cliffs in canyons (not measured).	

2. *Sections of part of the Minnelusa Formation in Redbird Canyon, NW¼ sec. 9, T. 3 S., R. 1 E., Custer County, S. Dak.*

	Feet
Minnelusa Formation (part):	
Breccia:	
22. Breccia; rocks are slightly brecciated at bottom and highly brecciated at top; boundary with underlying unit uncertain; forms steep cliff	300. 0
Total thickness of breccia	300. 0
Sandstone:	
21. Sandstone, yellow, calcareous, fine-grained; contains silty limestone and calcareous siltstone; boundary with overlying unit uncertain; forms cliff	40. 0

	Feet
Minnelusa Formation (part)—Continued	
Sandstone—Continued	
20. Sandstone, yellow, calcareous, cherty, fine-grained, unevenly bedded; 1.5-ft-thick limestone bed 15 ft above base	32. 0
19. Limestone and silty limestone, buff and gray; forms partly covered slope	3. 0
18. Sandstone, yellow, calcareous, cherty, fine-grained; 1-in. chert bed at top; forms partly covered slope	13. 0
17. Limestone, gray, buff, and purple	1. 5
16. Covered	4. 0
15. Limestone, gray; partially covered	2. 5
14. Covered	7. 0
13. Limestone, gray, massive	1. 8
12. Sandstone, red, orange, and white; weathers orange; calcareous, friable, fine grained, laminated; calcareous gray-green siltstone at top; forms steep slope	12. 0
Total thickness of sandstone	116. 8
Upper limestone:	
11. Limestone, gray, cherty; part of cliff	3. 0
10. Limestone, buff to gray, silty, cherty, brecciated; part of cliff	4. 2
9. Limestone, silty limestone, and calcareous siltstone, gray, buff, gray-green, and purple, cherty, unevenly bedded; part of cliff	23. 0
8. Limestone, silty limestone, and calcareous siltstone, gray, buff, to green, cherty; partly covered areas probably contain shale or siltstone	13. 0
7. Covered; gray shale at top	14. 0
6. Sandstone and silty limestone, gray to purple, calcareous, cherty, fine-grained	1. 5
5. Siltstone, light-gray, calcareous	3. 0
4. Siltstone, calcareous siltstone, and silty limestone, light-green	9. 5
3. Shale, light-green, noncalcareous; grades into overlying unit	. 5
Total thickness of upper limestone	71. 7
Lower limestone (part)	
2. Shale, purple and gray contains green blotches; calcareous to noncalcareous	13. 0
1. Shale, red with green calcareous blotches; bottom not exposed	34. 0
Incomplete thickness of lower limestone	47. 0
Incomplete thickness of Minnelusa formation	535. 5

3. *Section of part of the Minnelusa Formation in Redbird Canyon S½ sec. 9, T. 3 S., R. 1 E., Custer County, S. Dak.*

	Feet
Minnelusa Formation (part):	
Breccia (part):	
13. Sandstone, red, fine-grained, brecciated, and siltstone beds; individual fragments as much as tens of feet long, some crossbedded; forms steep slope; overlying brecciated beds form steep cliff	43. 0
Incomplete thickness of breccia	43. 0
Sandstone (part):	
12. Limestone, gray with a pinkish tinge; weathers gray; sandy; forms small cliff	23. 3
11. Sandstone, tan to white; weathers red to gray; calcareous, friable, fine grained; forms small cliff	16. 0
10. Sandstone, white, tan to red; weathers brown; fine grained, calcareous; partly covered	29. 7
9. Chert, black; contains small calcite veins; part of cliff	. 3
8. Limestone, sandy, and calcareous sandstone, tan; weathers red and brown; beds are from about 4 in. to 2.5 ft thick; part of cliff	12. 1
7. Sandstone, fine-grained, very friable; lower 44 in. is a white calcareous sandstone that has yellow streaks and weathers brown red; next 40 in. is a yellow and tan noncalcareous sandstone which is calcareous at the top and contains red weathered patches; windblown cavities as much as 20 ft long are common; many calcareous sandstone veins; forms reentrant	7. 0
6. Sandstone, yellow, calcareous, fine-grained, friable, cross-bedded; calcareous sandstone ribs form a boxwork pattern	32. 0
5. Sandstone, tan to maroon, calcareous, fine-grained; weathers maroon to brown; forms slope	5. 3
4. Sandstone, yellow, calcareous, fine-grained; weathers yellow and dark yellow, and patches of red; thin calcareous sandstone veins traverse unit; forms small cliff	5. 3
3. Sandstone, yellow, calcareous, fine-grained, friable, cross-bedded; foreset beds about 1 to 2 ft thick; many calcareous sandstone ribs; windblown cavities as much as 5 ft long are common	26. 7
2. Sandstone, white, tan to yellow; weathers white to yellow; calcareous, friable; thin bedded; thin beds of chert (less than 1 in. thick) near top; many calcareous sandstone veins	14. 0
1. Covered slope (not measured).	
Incomplete thickness of sandstone	171. 7
Incomplete thickness of Minnelusa Formation	214. 7

4. *Composite section of part of the Minnelusa Formation in Frannie Peak Canyon. Units 1 to 12 in SE¼ sec. 32, T. 45 N., R. 60 W.; units 13 to 48 in NE¼ sec. 5, T. 44 N., R. 60 W., Weston County, Wyo.*

Minnelusa Formation (part):	
Breccia (part):	*Feet*
48. Sandstone, white, red, and yellow, fine-grained, calcareous; some red and gray limestone and dolomite beds and fragments; breccia fragments range from less than ¼ in. to more than 10 ft long; the friable fragments are generally rounded and the brittle and more resistant are angular. Unit is indistinctly weathered red and white; in some places the color contacts are sharp, in others they are transitional or indistinct. Matrix is fine-grained calcareous sandstone	250. 0+
47. Limestone, gray and buff, sandy; grades into overlying unit	1. 0
Incomplete thickness of breccia	251. 0+
Sandstone:	
46. Sandstone, buff to white, calcareous, fine-grained, unevenly bedded; contains limonite specks	8. 0
45. Sandstone, buff and white, calcareous; forms a ledge	7. 0
44. Limestone, buff, silty	. 2
43. Sandstone, white, buff, and tan, calcareous, poorly bedded	11. 0
Total thickness of sandstone	26. 2
Upper limestone:	
42. Covered	4. 0
41. Limestone, gray, silty; bottom 1 in. is purple	2. 0
40. Shale, black and brown	1. 5
39. Limestone, gray, maroon, and pink, silty; 1-in chert bed in the middle	3. 3
38. Limestone, gray, silty; grades up into fine-grained white sandstone having thin chert beds about 1 in. thick; hematite specks common; upper 2 ft is a desiccation breccia containing fragments of the underlying limestone incorporated in the sandstone	3. 5
37. Limestone, dark-gray to maroon	2. 0
36. Limestone, gray and maroon, silty, cherty, laminated	8. 0
35. Sandstone, maroon and white, calcareous, fine-grained	2. 0
34. Sandstone, gray and brown, friable, fine-grained; forms reentrant	. 5
33. Sandstone, maroon and yellow, calcareous, fine-grained	3. 7
32. Limestone and silty limestone, gray and maroon; brecciated	5. 0
31. Calcareous siltstone (2 in. thick) at base grading up into silty limestone (2 ft thick) that grades up into fine-grained calcareous sandstone; unit is white to brown	3. 8
30. Sandstone, mottled pink and white, calcareous, fine-grained	1. 7

Minnelusa Formation (part)—Continued Upper limestone—Continued	*Feet*
29. Limestone, purple-gray, cherty, and interlayers of gray calcareous siltstone	1. 2
28. Limestone and silty limestone, gray to maroon	1. 7
27. Siltstone, gray, calcareous; gouged	. 2
26. Limestone, gray; calcareous siltstone present; many small brachiopod fragments; fractured and healed with calcite veins ¼ to 1 in. thick	5. 5
25. Limestone, red, maroon, orange, gray, and white, cherty; brecciated, breccia fragments from ¼ in. to more than 1 ft long	9. 0
24. Limestone, gray to pink, silty	. 5
23. Siltstone, gray, maroon, and olive-green, calcareous; contains maroon paper shale which may be gouge	1. 4
22. Siltstone, gray, calcareous; hematite specks; upper 2 ft contains vugs filled with calcite	4. 0
21. Sandstone, maroon, yellow, green, calcareous, laminated	1.3
20. Sandstone, gray, maroon, pink, and white, calcareous; laminated at the top	2.6
19. Sandstone, buff, calcareous, friable; weathers back under overlying ledge	.6
18. Limestone, light-gray; weathers same; limonite specks throughout; well jointed; uppermost 2 ft is silty; lowest 14 in. is gray brown to olive green and coarser grained than overlying rock	10.0
17. Sandstone, yellow, tan, pink, orange, and white, calcareous, fine-grained, unevenly bedded	9.0
16. Limestone, brecciated, and red, white, and dark gray chert and red to yellow sandstone; fragments as much as 1 ft in diameter	2.0
15. Limestone; upper 0.5 ft is red, sandy, slabby, and brecciated; middle 1 ft is dense and gray; lower 2.5 ft is gray to red gray and sandy	10.0
14. Shale, black, calcareous; forms reentrant	.9
13. Limestone; upper 3 in. is dark gray; next 6 ft is gray, green gray, and red and thin bedded and has calcareous concretions	6.3
12. Sandstone, brown, fine-grained, friable	.3
11. Limestone, gray and maroon, silty, cherty	4.0
10. Sandstone, white, pink, and red, calcareous, fine-grained; limonite specks	5.3
9. Siltstone, gray to tan, calcareous	4.3
8. Limestone, gray, silty, brecciated; contains maroon chert	8.5
7. Siltstone, gray and green, calcareous	.2
6. Limestone, gray	7.0
5. Shale, dark-gray with green blotches, calcareous	.5
4. Limestone, gray, silty; calcite-filled vugs	2.0
3. Covered	25.0
Total thickness of upper limestone unit	164.3

	Feet
Minnelusa Formation (part)—Continued	
Lower limestone (part):	
2. Shale, purple, calcareous; green blotches; upper boundary covered	5.0
1. Shale, red with green blotches, calcareous; lower boundary not exposed	25.0
Incomplete thickness of lower limestone	30.0
Incomplete thickness of Minnelusa Formation	471.5

5. *Log of Minnekahta Limestone, Opeche Formation, and upper part of Minnelusa Formation from drill core of hole 2, Pass Creek, (SW¼ NE¼ NW¼ sec. 1, T. 6 S., R. 1 E.) Custer County, S. Dak.*

[Logged by C. G. Bowles, U.S. Geological Survey. Well collar elevation 3,890 ft. Depth of hole is 682 ft.]

	Ft	In
96. Gravel, gypsiferous	15	0
Minnekahta Limestone:		
95. Limestone	30	0
Opeche Formation:		
94. Shale to siltstone, red to purple	45	0
93. Siltstone, red, and some gypsum	20	0
92. Gypsum and anhydrite, milky to brownish-orange, and inclusions of brown clay	5	0
91. Limestone, mottled gray, green, and brown, dolomitic. About 40 percent inclusions of brown and gray-green mudstone		2
90. Mudstone, dark, silty, bands and veinlets	6	10
89. Siltstone, dark red-brown; argillaceous in upper 3 ft and and lower 4 ft. Some stringers of gypsum	15	0
88. Mudstone grading downward to siltstone, dark red-brown; some veinlets of fibrous gypsum	12	7
87. Anhydrite, dark amber-gray; silty in upper 2 ft; 1 in. silty shale at base	7	8
86. Siltstone grading downward to silty mudstone; dark red-brown	3	11
85. Core missing		10
Total thickness of Opeche Formation	117	
Minnelusa Formation:		
Unit 1:		
84. Sandstone, light-brown to yellow-brown, very fine grained; calcareous cement; crossbedded in upper 15 ft	54	6
83. Anhydrite, light- and medium-gray; some seams of brown clay in 2-ft zone 4 ft above base; lower 2 ft 4 in. contains 5 to 40 percent laminations, streaks, and some groundmass of red dolomitic limestone	17	7

Minnelusa Formation—Continued

Unit 1—Continued	*Ft*	*In*
82. Limestone, dolomitic; dark-red siltstone one-fourth in. thick at top	8	7
81. Anhydrite, light-gray; dense in upper 2.5 ft, rest is blue gray and dark amber gray; crystalline. Thin clay bed at top; dark brown gray in lower 2 ft	17	1
80. Sandstone, fine to very fine grained; red-brown calcareous cement; 1½-in. band of gypsum 8 ft 6 in. above base	27	8
79. Sandstone, dark red-brown, very fine grained, and interbedded siltstone; gypsum stringers in lower 2 ft	5	7
78. Siltstone grading downward into interbedded mudstone, dark red brown; gypsum stringers in lower 2 ft	3	0
77. Anhydrite, brown-gray, dense; transluscent in upper 3 ft, dark-gray and dolomitic in middle. Petroliferous odor in lower part	12	10
76. Limestone, greenish black, dolomitic; silty in lower 3 ft 10 in.; some gypsum veinlets; upper 7 ft 2 in. fossiliferous; few vertical fractures filled with calcite; slight petroliferous odor in lower part	17	0
75. Anhydrite, amber, gray, and medium dark-gray; silty in upper 3 ft 5 in	18	8
74. Dolomite, medium-gray, grading downward into anhydrite in lower 2 ft; 30 percent very fine sand in upper 1 ft 6 in.; some gypsum stringers in 6-in. zone 1 ft below top	3	6
73. Anhydrite	3	0
72. Sandstone, very fine grained; dolomitic and calcareous cement	6	2
71. Anhydrite, medium dark-gray	2	8
70. Limestone, dolomitic, medium dark-gray argillaceous	7	8
69. Mudstone, gray-black, silty; upper 6 in. calcareous	1	6
68. Anhydrite, medium-gray	2	0
67. Siltstone, medium-gray to gray-red; some gypsum stringers	1	0
66. Anhydrite, medium-gray; flow bands and some brecciation in 1 ft zone 1 ft above base	3	3
65. Limestone, light olive-gray; 1-in. band of silty mudstone at top, clay disseminations decreasing downward	5	9
64. Anhydrite, light blue-gray; irregular 1-in. band of dolomite 2 ft above base	7	0
63. Sandstone, grayish-red and medium-gray, very fine-grained; anhydrite partially hydrated to gypsum in 2-ft zone 2 ft below top	13	0
62. Anhydrite, brown-gray; some gypsum replacement at upper contact; some dolomite	8	11
61. Dolomite, pale-red; thin laminae of red shale in upper 5 in	2	4
60. Anhydrite, pale-red; some dolomite stringers	5	7
59. Sandstone, very fine grained, and gray-green siltstone; some detrital anhydrite partly altered to gypsum	3	4

Minnelusa Formation—Continued

Unit 1—Continued	*Ft*	*In*
58. Anhydrite, medium light-gray and gray-orange-pink; altered to gypsum in lower 1 ft 8 in	26	6
57. Sandstone, medium light-gray, very fine grained; dolomitic cement; some specks of manganese oxide	10	4
56. Anhydrite, medium- to dark-gray, partially altered to gypsum in upper 1 ft 4 in.; 5 percent streaks of siltstone in 9-in. zone 10 ft below top; 20 percent laminae of olive-gray dolomite in lower 2 ft 7 in	26	7
55. Dolomite, gray-red, silty; laminated, a few gypsum stringers	1	0
54. Anhydrite, dark-gray; silty in lower 5 in		11
53. Siltstone, gray-red; a few thin gypsum stringers	1	9
52. Dolomite, moderate-red		7
51. Siltstone, gray-red-purple	3	2
50. Mudstone, gray-red-purple, silty	3	0
49. Siltstone, dusky-red and light gray-green; some detrital anhydrite grains in lower 2 ft 6 in	9	8
48. Anhydrite, brown-gray; some inclusions of dusky red siltstone	4	4
47. Siltstone, dark red-brown and brown-gray, dolomitic; grades into silty dolomite in lower 2 ft 6 in	6	0
46. Dolomite, moderate-red and greenish-gray		10
45. Anhydrite, pink-gray; grades to dolomite in 1-ft zone in middle of unit; some streaks and grains of dolomite	6	3
44. Dolomite, gray-red, argillaceous; anhydrite growths increase downward from 2 to 35 percent of total constituents	1	9
43. Mudstone, dark red-brown, dolomitic; some growths of anhydrite	2	2
42. Anhydrite, dusky-blue; a few streaks of red dolomite	17	6
41. Dolomite, pale red-purple and olive-gray	2	3
40. Anhydrite, dusky-blue; 25-percent growths of dolomite in upper 4 in	8	4
39. Dolomite, pale red-purple; thin gypsum and shale bed 2 in above base	1	6
38. Anhydrite, medium light-gray; some streaks of dolomite and brown mudstone		11
37. Mudstone and siltstone, dark red-brown to gray-purple; 1 ft very fine grained sandstone 2 ft 6 in. below top	6	0
36. Anhydrite, gray; trace of streaks of dolomite	12	6
35. Dolomite, gray-red-purple; some anhydrite growths	2	6
34. Sandstone, dusky-purple grading downward to pale red-brown and green-gray; fine-grained; a few anhydrite growths; some specks of manganese oxide (?) 3 ft above base. Considered the sandstone overlying the "red shale marker" beds	16	9
33. Shale, soft, green-gray to red-brown. Top of "red shale marker"	5	0
32. Siltstone, banded green-gray to red-brown; some gypsum stringers in upper 1 ft and lower 2 ft	3	10
31. Anhydrite, brown-gray		8

	Ft	In
Minnelusa Formation—Continued		
Unit 1—Continued		
30. Siltstone, gray-red, grading to dolomite at base; a few anhydrite growths	1	8
29. Shale, gray-red; considered base of "red shale marker" beds		6
Unit 2:		
28. Dolomite, green-gray and pale-red	1	3
27. Anhydrite, gray; 15 percent streaks of dolomite		10
26. Core missing	1	0
25. Shale, pale red-brown	1	0
24. Anhydrite, mottled gray, pale red, and olive-gray	4	6
23. Dolomite, gray-red-purple and olive-gray	1	2
22. Anhydrite, mottled gray and gray-red-purple; 15 percent streaks and stringers of dolomite	5	8
21. Sandstone, greenish-gray and gray-red-purple, very fine grained	5	1
20. Anhydrite, medium-gray	1	7
19. Shale, gray-black, fossiliferous	1	2
18. Sandstone, olive-gray, very fine grained	5	2
17. Anhydrite, mottled greenish-gray and gray-red-purple; some stringers of dolomite	3	3
16. Dolomite, gray-green and gray-red-purple		9
15. Anhydrite, gray-black; black carbonaceous shale streaks in lower 1 ft	2	0
14. Dolomite, olive-gray, argillaceous; 2-in. bands of black carbonaceous shale at top; 2 ft below top some black hydrocarbon along fractures and in vugs	5	4
13. Sandstone, light olive-gray, very fine grained	1	9
12. Anhydrite, medium olive-gray; some stringers of sandstone and dolomite	4	6
11. Shale, gray-black; petroliferous odor	1	11
10. Anhydrite, dark-gray	3	1
9. Dolomite, gray-red to olive-gray; some anhydrite grains; 5-in. zone dark-gray siltstone 1 ft below top and 11-in. zone of siltstone 2 ft 8 in. below top	4	8
8. Anhydrite, medium dark-gray		9
7. Siltstone and sandstone, gray-red, dolomitic	2	5
6. Anhydrite, gray		8
5. Sandstone, gray-red and light-olive-gray, very fine grained; some anhydrite growths	7	3
4. Dolomite, olive-gray; 15 percent gray anhydrite	1	2
3. Anhydrite, medium-gray; 15 percent grains of olive-gray dolomite	4	11
2. Sandstone, light olive-gray; dolomitic cement having petroliferous odor; 1-in. bed of dark green-gray carbonaceous siltstone at top	1	10
1. Dolomite light-olive-brown; oil stains	1	5
Total thickness of Minnelusa Formation (upper part)	520	

6. *Section of part of the Minnelusa Formation and the Opeche Formation in Gillette Canyon NW¼ sec. 27, T. 44 N., R. 60 W., Weston County, Wyo.*

	Feet
Minnekahta Limestone:	
11. Limestone, gray to purple (not measured).	
Opeche Formation:	
10. Siltstone, light-purple; light-green silty streaks and specks; sharp contact with overlying limestone	13. 0
9. Siltstone, sandstone, and shale, red; small green siltstone specks; thin limestone beds near top; green sandy limestone 68 ft from base of unit; fine-grained sandstone predominant 44 ft from base of unit	89. 0
8. Sandstone, red, calcareous, fine-grained, massive	1. 0
7. Siltstone and very fine-grained sandstone, red, very friable	2. 3
6. Covered	5. 5
Total thickness of Opeche Formation	110. 8
Minnelusa Formation (part):	
Breccia (part):	
5. Sandstone, red, buff, and maroon, fine-grained, massive, well-fractured; bottom 2 ft is mottled red and white; next 11 ft is covered; next 37 ft is white and noncalcareous; top 1 ft is white and calcareous	50. 0
4. Sandstone, red to buff; weathers maroon; small calcite-filled vugs; upper 4 in. is purple limestone	2. 5
3. Sandstone, tan, buff to red-brown; weathers buff, orange to maroon; fine-grained, friable, brecciated; a few thin calcite veins; unit is brecciated; forms reentrant	3. 1
2. Limestone, brown, maroon, gray-red, and white; weathers gray to buff; thin-bedded; beds range from 1 to 6 in. in thickness; small calcite-filled vugs; thin calcareous sandstone beds scattered throughout	6. 7
1. Sandstone, white and red; weathers white, buff, and red; calcareous, fine-grained, massive; laminated in places; considerably fractured; crossbedded, foreset beds about 2 in. thick; penecontemporaneous faults having displacements of as much as 3 in	10. 5
Incomplete thickness of breccia of Minnelusa Formation	72. 8

7. *Section of the Opeche Formation in SW¼ sec. 27, T. 44 N., R. 60 W., Weston County, Wyo.*

	Feet
Minnekahta Limestone:	
7. Limestone, gray to purple (not measured).	
Opeche Formation:	
6. Shale, siltstone, and fine-grained sandstone, red; sharp contact with overlying limestone	42.0
5. Gypsum, white, granular, bedded; interbedded with red siltstone and shale	10.0
4. Siltstone, red, calcareous, and red shale and fine-grained sandstone	38.5
3. Gypsum, white, interbedded with red siltstone and shale near the top	8.0
2. Siltstone, red, calcareous, and red shale flecked with green	11.5
Total thickness of Opeche Formation	110.0
Minnelusa Formation (part):	
Breccia (part):	
1. Sandstone, white to red, calcareous, fine-grained, well-jointed; mostly covered; bottom is not exposed	82.0
Incomplete thickness of breccia of Minnelusa Formation	82.0

8. *Section of the Opeche Formation in SE¼ sec. 17, T. 3 S., R. 1 E., Custer County, S. Dak.*

	Feet
Minnekahta Limestone:	
5. Limestone, gray to purple, silty (not measured).	
Opeche Formation:	
4. Siltstone, shale, and fine-grained sandstone, red	52.5
3. Gypsum, white interbedded with red siltstone and fine-grained sandstone	26.5
2. Siltstone, shale, and fine-grained sandstone, red	25.5
Total thickness of Opeche Formation	104.5
Minnelusa Formation:	
1. Sandstone, white to red (not measured).	

9. *Section of the Minnekahta Limestone in NE¼ sec. 5, T. 44 N., R. 60 W., Weston County, Wyo.*

	Feet
Minnekahta Limestone:	
5. Limestone and silty limestone, gray and purple; weathers same; massive to thin bedded; beds range from about ¼ in. to 3 ft in thickness	20.0
4. Limestone, silty, and calcareous siltstone, buff, gray, and purple, massive to slabby	3.0
3. Siltstone, buff to gray, slabby	.5
2. Siltstone, calcareous, and silty limestone, buff, gray, and maroon, thin-bedded, faintly laminated; black mineral grains in a dendritic pattern	1.0
1. Siltstone, buff to gray, slabby	.6
Total thickness of Minnekahta Limestone	25.1
Opeche Formation (not measured).	

10. *Section of the Gypsum Spring and Sundance Formations in SE¼ sec. 18, T. 45 N., R. 60 W., Weston County, Wyo.*

	Feet
Sundance Formation (part):	
Redwater Shale Member (part)	
8. Shale, dark-green and green-gray, weathers light gray to green; noncalcareous; contains many *Belemnites densus* fragments; top not exposed; overlain by black and dark-brown shale and buff fine- to medium-grained sandstone slump material of the Morrison Formation	90. 0
Incomplete thickness of Redwater Shale Member	90. 0
Lak Member:	
7. Siltstone, sienna-brown; weathers pink red; calcareous, poorly bedded, friable; some green siltstone beds near top; forms steep slope; sharp contact with overlying green shale	70. 3
Total thickness of Lak Member	70. 3
Hulett Sandstone Member:	
6. Shale and siltstone, dark-green; weathers bright light green; calcareous; shale is fissile; grades upward into red siltstone	6. 5
5. Sandstone, tan; weathers buff to red brown; calcareous, fine grained, massive; with many light olive-green siltstone partings as much as 4 in. thick; current- and oscillation-type ripple marks on bedding planes; many windblown holes; forms steep cliff	26. 7
4. Sandstone, tan, calcareous, fine-grained, friable; beds more than 1 ft thick; forms steep slope under overlying unit	17. 4
Total thickness of Hulett Sandstone Member	50. 6
Stockade Beaver Shale Member:	
3. Shale, dark gray-green; weathers olive green, fissile. Top 15 ft contains sandstone interbeds that are light olive green, weather gray to buff, are calcareous and fine grained, and range in thickness from a few inches to slightly more than 1 ft thick. Unit grades into overlying unit	63. 2
Total thickness of Stockade Beaver Shale Member	63. 2
Incomplete thickness of Sundance Formation	274. 1

	Feet
Gypsum Spring Formation:	
2. Gypsum, white, in beds about ½ in. thick; granular; forms small escarpment; sharp contact with overlying green shales	11. 3
Total thickness of Gypsum Spring Formation	11. 3
Spearfish Formation (part):	
1. Siltstone and fine-grained sandstone, red; with thin gypsum stringers at top; forms steep slope under overlying gypsum and a wide valley elsewhere	10. 0+
Incomplete thickness of Spearfish Formation	10. 0+

11. *Section of the Morrison Formation NW¼NE¼ sec. 29, T. 44 N., R. 60 W., Weston County, Wyo.*

	Feet
Lakota Formation, not measured.	
Morrison Formation (complete):	
11. Claystone, gray-green, well-exposed	29
10. Claystone, gray-green, poorly exposed	21
9. Claystone, varicolored gray to purple-red	3
8. Claystone, gray-green	8
7. Limestone, gray	1. 5
6. Claystone, gray-green	2
5. Limestone, gray	1
4. Claystone, gray-green	5. 5
3. Claystone, green to gray; ostracodes abundant	5. 5
2. Claystone, green to gray; upper 5 ft is red to purple	15. 5
1. Limestone, gray, sublithographic	. 5
Thickness of the Morrison Formation	92. 5
Sundance Formation (not measured).	

12. *Section of the Lakota Formation and part of the Fall River Formation on the cliffs west of the dam at LAK Reservoir, NW¼ sec. 6, T. 44 N., R. 60 W., Weston County, Wyo.*

	Feet
Fall River (part):	
1. Sandstone, orange to pale-brown, slumped, slabby, fine-grained, thin-bedded	5
Lakota Formation:	
Fuson Member:	
10. Covered slope. Slump and talus. Contact of Fall River and Lakota is somewhere below the top of this unit	48
9. Clayey sandstone, gray-green; forms minor blocky ledge. Bedding surfaces and joints stained brown to orange	3
8. Mostly covered. Dug holes indicated yellow and gray to green-gray sandstone becoming clayey upward	25

Lakota Formation—Continued	
Fuson Member—Continued	*Feet*
7. Mostly covered. Dug holes indicated light-gray claystone having scattered sand grains at base, and becoming sandier upward, going from light gray to red and purple. Becomes clayey sandstone about 4 ft up in section	5
6. S_3 sandstone, chert conglomerate; white to gray, crossbedded	10
5. S_3 sandstone, light-gray to brown; thin bedding accentuated by weathering; forms cliff	40
Measured thickness of Fuson Member	131
Chilson Member (part):	
4. Sandstone, fine-grained, carbonaceous, thin-bedded; and highly carbonaceous, coaly beds	3
3. S_1 sandstone, brown, fine-grained; rather massive; three distinct beds	25
2. S_1 sandstone, light- to dark-gray, fine- to very fine-grained, lenticular, very carbonaceous; weathers to exfoliating massive knobs. Forms reentrant in cliff face. Thins to south	3
1. S_1 sandstone, light-gray; weathers light gray to orange; irregular stained bands of red to yellow; fine grained, fairly well sorted, crossbedded; vertical joints; weathers as a cavernous cliff. Upper one-third more massive and only poorly crossbedded	46
Thickness of Chilson Member (part)	77
Slope covered to creek.	

13. *Section of the Inyan Kara Group along old U.S. Highway 16, east of LAK Ranch office, SW¼NW¼ sec. 8, T. 44 N., R. 60 W., Weston County, Wyo.*

Fall River Formation:	
Upper unit:	*Feet*
24. Covered area to exposures of Skull Creek Shale	10. 0
23. Sandstone, fine-grained, carbonaceous; brown iron stains; beds 1 to 6 in. thick	4. 0
22. Shale and mudstone, carbonaceous	3. 2
21. Silty sand, gray to buff, thinly laminated	1. 0
20. Mudstone, gray, carbonaceous, laminated. Lower 2 ft is greatly iron stained	2. 5
19. Sandstone, brown, thin-bedded, 1 to 8 in. thick, fine-grained, weathers gray. Gray and brown muddy interlayers 1 in. or less thick	4. 0
18. Sandy silt, brown, gray, and red, thin-bedded	3. 6
17. Mudstone, dark-gray, laminated; brown stains on weathered surface	1. 5
16. Sandstone, gray, fine- to medium-grained; mainly massive. Limonite stains. Upper 1 ft has black carbonaceous laminae	6. 9
15. Silty sand, crossbedded. Individual beds 2 in. thick. Ferruginous concretions ½ in. in diameter in lower 6 in. Disseminated carbonaceous specks	2. 0

Fall River Formation—Continued	
Upper unit—Continued	*Feet*
14. Like unit 9	2. 0
13. Siltstone, sandstone, and mudstone interbedded. Sandstone beds about 1 in. or less thick. Unit is brown, gray, yellow; some iron staining	8. 0
12. Sandstone, fine-grained, carbonaceous	0. 4
11. Siltstone, gray, carbonaceous	0. 4
Middle and lower units:	
10. Sandstone, brown on fresh surface, gray on weathered surface; fine to medium grained; iron stains on joints and fractures	12. 8
9. Sandstone, fine-grained. Iron stains	1. 5
8. Sandstone, brown on fresh surfaces, gray on weathered surfaces; fine to medium grained; carbonaceous matter; poorly crossbedded; iron stains especially in the upper 6 ft	22. 0
7. Sandstone similar to unit 8, but thinner bedded. Individual beds are ½ in. thick near base and about 1 in. thick near the top. Carbonaceous laminae that become more abundant at the base	6. 0
6. Sandstone, brown on fresh surfaces, gray on weathered surfaces; fine to medium grained. Carbonaceous matter is most abundant near the base	5. 5
5. Sandy siltstone, laminated; lower 1 ft dark-gray and has little sand	4. 5
4. Silty sandstone, fine-grained; iron stains along the fractures	4. 7
3. Siltstone, gray, extremely carbonaceous	0. 5
Thickness of Fall River Formation	107. 0

Lakota Formation:	
Fuson Member:	
2. Claystone, brown-stained	7. 5
1. Sandstone, fine-grained; contains siderite pellets (base of exposure)	9. 0
Thickness of Fuson Member	16. 5

14. *Section of the Newcastle Sandstone NE¼SE¼ sec. 7, T. 44 N., R. 60 W., Weston County, Wyo.*

Mowry Shale.	
Newcastle Sandstone:	*Feet*
6. Siltsone, gray; poorly exposed. Bentonitic shale about 15 ft above base. Grades into gray shale of Mowry	15
5. Sandstone, fine-grained	1
4. Siltstone, gray	5
3. Sandstone, brown, fine-grained, carbonaceous; some scattered brown concretionary pellets ¹⁄₁₆ to ⅛ in. diameter. Some interbedded gray siltstone	7
2. Siltstone, light- to dark-gray, and some lenses of silty brown sandstone about 1 ft thick and 10 ft long	30
1. Sandstone, brown, fine-grained, carbonaceous	4
Thickness of Newcastle Sandstone	62
Skull Creek Shale.	

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