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Geology of the Flint Hill Quadrangle, Fall River County, South Dakota

GEOLOGICAL SURVEY BULLETIN 1063-M

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

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By HENRY BELL III *and* EDWIN V. POST

GEOLOGY AND URANIUM DEPOSITS OF THE SOUTHERN BLACK HILLS

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A description of the stratigraphy and structure in the quadrangle, with emphasis on the rocks of the Inyan Kara Group of Early Cretaceous age

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CONTENTS

ILLUSTRATIONS

TABLES

GEOLOGY AND URANIUM DEPOSITS OF THE SOUTHERN BLACK HILLS

GEOLOGY OF THE FLINT HILL QUADRANGLE, FALL RIVER COUNTY, SOUTH DAKOTA

By HENRY BELL III and EDWIN V. POST

ABSTRACT

The Flint Hill quadrangle, at the south end of the Black Hills in Fall River County, S. Dak., contains sedimentary rocks of Jurassic, Cretaceous, Tertiary (?), and Quaternary age.

The Jurassic rocks are the marine sandstones, siltstones, and shales of the Lak and Redwater Shale Members of the Sundance Formation, and the nonmarine Unkpapa Sandstone and Morrison Formation.

The Cretaceous rocks consist of the Inyan Kara Group of Early Cretaceous age, which underlies most of the quadrangle, and the overlying Skull Creek Shale, Newcastle Sandstone, Mowry Shale, Belle Fourche Shale, and Greenhorn Limestone. The Inyan Kara Group consists of the Lakota and Fall River Formations, both of which contain complex interfingering and gradational sandstones of fluvial origin and mudstones deposited in lake and swamp environments. The lithologic sequence and the thickness of units in these rocks change abruptly within short distances.

Tertiary (?) and Quaternary deposits consist predominantly of unconsolidated sand and gravel.

The principal structural feature in the quadrangle is the south-plunging Chilson anticline, which is superimposed on the regional southward dip at this end of the Black Hills. Some structural deformation apparently took place during Lakota time and influenced the course of the streams that deposited the fluvial sandstones of the Lakota Formation.

Uranium, the major mineral resource in the quadrangle, has been produced from the Inyan Kara Group. Most commonly, thick sandstone units are the host rocks and less commonly interbedded sandstone and mudstone units. Carnotite, tyuyamunite, corvusite, and rauvite, the principal ore minerals, commonly impregnate sandstone and are associated with carbonaceous material, iron oxide stain, and carbonate cement. Many deposits occur in structural irregularities of both sedimentary and tectonic origin.

The ore-forming elements probably were transported in carbonate-rich groundwater solutions through thick porous and permeable sandstones and were precipitated from the carbonate solutions by reducing conditions associated with rocks containing much organic debris.

Sand and gravel deposits exist within the quadrangle. Coal has been produced in the past for local use, but the deposits are small and of no economic significance at the present time. Oil and gas exploration has been unsuccessful.

INTRODUCTION

The Flint Hill quadrangle, which is bounded by parallels 43°15′ and 43°22′30″ and by meridians 103°37′30″ and 103°45′, is at the extreme south end of the Black Hills in southwestern South Dakota (fig. 92). The quadrangle is in the lower, more arid part of the Black Hills characterized by intermittent streams occupying narrow canyons separated by flat-topped divides. Sparse growths of pine trees

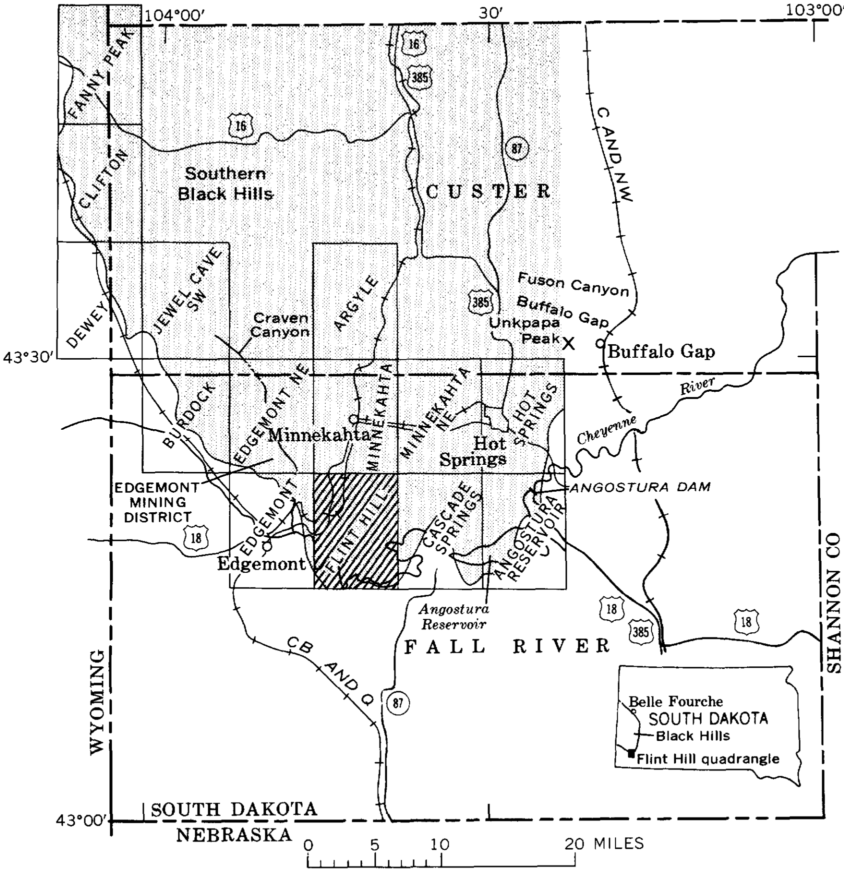

FIGURE 92.—Location of the Flint Hill and other 7½-minute quadrangles mapped in the southern Black Hills.

are concentrated in locally favorable environments such as rocky slopes and north-facing canyon walls. Elevations in the quadrangle range from 3,300 feet along the Cheyenne River to 4,600 feet along the north boundary. Local relief is as much as 600 feet in some canyons.

The principal occupation in the quadrangle is ranching. Ranches are small, ranging from 1 to 10 square miles in size, and are devoted to raising cattle and grain.

Edgemont and Hot Springs, S. Dak., with populations in 1960 of approximately 1,500 and 5,000 respectively, are the nearest communities to the Flint Hill quadrangle. The west edge of the quadrangle is 5.4 miles from Edgemont and the north edge is 17 miles from Hot Springs via U.S. Highway 18, which passes through the western part of the quadrangle. A spur of the Chicago, Burlington, and Quincy Railroad passes through the quadrangle and ends at Hot Springs. With the exception of Highway 18, which is paved, the roads in the quadrangle are graded dirt or unimproved country roads.

The climate in the Flint Hill quadrangle is semiarid. Total annual precipitation is about 17 inches, and the maximum monthly precipitation occurs during May and June. Temperatures range from a minimum of about −30°F in midwinter to a maximum of about 105°F in July or August.

The first comprehensive geologic work in the southern Black Hills was done by N. H. Darton and others of the U.S. Geological Survey between 1898 and 1925 (Darton, 1899, 1901, 1902; Darton and Smith, 1904; Darton and Paige, 1925). Many other geologic studies subsequently have been made for special purposes, especially by the South Dakota State Geological Survey and the South Dakota School of Mines.

Carnotite, a uranium ore mineral, was discovered in Craven Canyon 8 miles north of Edgemont in June 1951 (Page and Redden, 1952; Baker and others, 1952). Additional uranium ore discoveries in the area during 1951 and 1952 led prospectors to stake many hundreds of claims throughout the Black Hills. By December 1952, uranium ore production had increased to such an extent that an ore-buying station was established at Edgemont by the U.S. Atomic Energy Commission. Continued production led to the construction of a mill, which began processing ore in 1956. The area in the southern Black Hills in which the uranium ore deposits are clustered is now called the Edgemont mining district.

We began a study of the geology and mineral resources of the Flint Hill quadrangle in 1953 as part of a comprehensive geological investigation of the southern Black Hills undertaken by the U.S. Geological Survey on behalf of the Division of Raw Materials of the U.S. Atomic

423-557 O - 71 - 2

Energy Commission. Since 1953, 14 other 7½-minute quadrangles, extending from Hot Springs to Edgemont, S. Dak., and northward along the South Dakota–Wyoming boundary (fig. 92), have been mapped by the U.S. Geological Survey.

The uranium deposits occur in the fluviatile and lacustrine rocks of the Inyan Kara Group of Early Cretaceous age. These complex rocks were mapped at a scale of 1:7200 to relate local features such as detailed lithology, type of cement, and sedimentary structure to the distribution of the uranium deposits (Bell and Post, 1957a, b, c, d, e, f). This geologic mapping, revised somewhat and reduced to a scale of 1:24,000, is reproduced as plate 32.

Members of the U.S. Atomic Energy Commission suboffice in Hot Springs, S. Dak., were most helpful. We are grateful for their assistance and for access to data collected in their studies. The fossil identifications and chemical and spectrographic analyses were made by members of the U.S. Geological Survey. We were assisted in the field at various times by James Knox, D. C. Lamb, W. C. Lary, W. B. Bryan, and D. W. Lane. Without the cooperation and help of the landowners, prospectors, and miners in the area, the project could not have been undertaken or completed.

REGIONAL STRATIGRAPHIC SETTING

The Black Hills is an elliptical mountainous area developed on a huge northwest-trending anticline. Precambrian igneous and metamorphic rocks are exposed in the center of the Black Hills. These are surrounded by the eroded uplifted edges of Paleozoic and Mesozoic sedimentary rocks. The rocks that crop out in the Flint Hill quadrangle are part of the sedimentary cover surrounding the central core of the Black Hills.

The general character and thickness of the unexposed Paleozoic and Mesozoic rocks in the quadrangle are described in table 1. The exposed formations in the Flint Hill quadrangle are the upper part of the Sundance Formation, the Unkpapa Sandstone, and the Morrison Formation, all of Jurassic age, the Lakota and Fall River Formations, which constitute the Inyan Kara Group of Early Cretaceous age, and which are the most widely exposed rocks in the quadrangle; and the Skull Creek Shale, Newcastle Sandstone, and Mowry Shale of Early Cretaceous age and the Belle Fourche Shale and Greenhorn Limestone of Late Cretaceous age, which are exposed in a small area in the southwestern part of the quadrangle. Some small thin Tertiary(?) gravel deposits occur in the quadrangle. Quaternary alluvial deposits are thickest along the Cheyenne River, but are also present in some of the larger canyons, where landslide debris is also common. Windblown sandy material is present south of the Cheyenne River and on some of the flat intercanyon divides.

TABLE 1.—*General section of unexposed rocks of Cambrian to Triassic age in the southern Black Hills, S. Dak.*

[Modified from Darton and Paige (1925)]

Age	Formation	Character	Thickness (feet)
Triassic and Permian	Spearfish Formation	Siltstone, sandy shale, and maroon sandstone; 2 gypsum beds 30 and 50 ft thick, represented by anhydrite in subsurface.	500–600
Permian	Minnekahta Limestone	Limestone, reddish-gray, finely crystalline to lithographic, platy, massive; bedding commonly contorted.	50±
	Opeche Formation	Sandstone, shaly, red, interbedded with purplish shale and thin beds of anhydrite or gypsum.	75–115
Permian and Pennsylvanian	Minnelusa Formation	Sandstone, reddish-gray, with some limestone, red and gray shale, anhydrite or gypsum, and carbonaceous seams.	1,050±
Mississippian	Pahasapa Limestone	Limestone, light-colored, massive; locally contains vast caverns.	300–630
Mississippian and Devonian	Englewood Formation	Limestone, pale-pink to buff, slabby; shale locally at base.	30–60
Ordovician and Cambrian	Deadwood Formation	Sandstone, light-colored, quartzitic; some conglomerate and shale.	4–100

JURASSIC ROCKS

SUNDANCE FORMATION

The oldest rocks exposed in the Flint Hill quadrangle are the Lak and Redwater Shale Members of the Sundance Formation of Late Jurassic age. The Sundance Formation, originally described by Darton (1901, p. 520–524), ranges in thickness from 295 to 430 feet and consists of five members that were named by Imlay (1947).[1] The lower three members of the formation—the Canyon Springs Sandstone, Stockade Beaver Shale, and the Hulett Sandstone—are not exposed in the Flint Hill quadrangle.

[1] Since this work was done, the Redwater Shale Member has been revised. Approximately the lower 25 feet of the Redwater, as mapped in this report, is equivalent to the Pine Butte Member, and the thin slabby sandstone at the top is equivalent to the Windy Hill Sandstone Member (Pipiringos, 1968, p. D12, fig. 8, and p. D13 and D23).

LAK MEMBER

The Lak Member of the Sundance Formation is exposed only in the bottom of Hell Canyon and Falls Canyon in the northeastern part of the Flint Hill quadrangle. Most of the member is covered by landslide debris and talus. The Lak is best exposed in sec. 10, T. 8 S., R. 4 E., in Falls Canyon, where it consists of 60–100 feet of reddish-brown silty sandstone that forms low rounded slopes and banks along the streambed.

REDWATER SHALE MEMBER

The Redwater Shale Member conformably overlies the Lak Member of the Sundance Formation. The Redwater consists predominantly of greenish-gray glauconitic silty shale and mudstone with thin beds of glauconitic sandstone and fossilferous limestone. It is about 170 feet thick and contains abundant marine fossils. The contact between the Redwater Shale Member and the Lak Member is exposed near the junction of Hell Canyon and a tributary canyon in sec. 17, T. 8 S. R. 4 E. The best exposure of the Redwater Shale Member, however, is in a tributary of Falls Canyon in sec. 9, T. 8 S., R. 4 E., where the contact with the underlying Lak Member is covered. The Redwater is partly exposed in several places in Hell Canyon, but it is largely covered by talus and landslide debris. Only the upper few feet of the member is exposed in Chilson Canyon and along the Cheyenne River in sec. 11, T. 9 S., R. 3 E. Casts of cubic crystals, probably pseudomorphous after halite, have been found on the bedding planes of a thin slabby sandstone at the top of the Redwater in outcrops along the Cheyenne River and in the tributary to Falls Canyon in sec. 9, T. 8 S., R. 4 E.

UNKPAPA SANDSTONE

The Unkpapa Sandstone is exposed in the northeastern part of the quadrangle, where it conformably overlies the Redwater Shale Member of the Sundance Formation. The Unkpapa is more than 120 feet thick in Hell and Falls Canyons, but it is absent in Chilson Canyon in sec. 36, T. 8 S., R. 3 E., and along the Cheyenne River in sec. 11, T. 9 S., R. 3 E. The Unkpapa probably is not present in sec. 18, T. 8 S., R. 4 E., where only the Morrison Formation is exposed. Outcrops in Hell Canyon and Devil Canyon, therefore, are near the west limit of the formation.

The Unkpapa is a cliff-forming sandstone, but locally the upper part is a slope-forming variegated siltstone. This upper part contains thin limestone beds which suggest that there may be interfingering between the Unkpapa and the Morrison Formations.

The Unkpapa is typically a pale-red to white very fine grained cross-bedded sandstone with some minor beds of green, gray, or red mudstone. The sandstone weathers to rounded cliffs and steep gullied slopes. It is generally massive, but locally it shows faint long, sweeping cross-strata suggestive of eolian deposition. These crossbeds are characteristic of the Unkpapa Sandstone where it is conspicuously exposed in the Cascade Springs, Angostura Reservoir, and Hot Springs quadrangles. The cliff-forming Unkpapa Sandstone is best exposed in the Flint Hill quadrangle in Hell Canyon and in the NE¼ sec. 9, T. 8 S., R. 4 E. A stratigraphic section of the Unkpapa Sandstone and the upper part of the Redwater Shale Member of the Sundance Formation measured at the latter locality is given below.

The Unkpapa Sandstone and part of the Sundance Formation measured at tributary to Falls Canyon in the NE¼ sec. 9, T. 8 S., R. 4 E.

[Measured by Henry Bell and E. V. Post]

	Thickness (feet)
Morrison Formation, not measured.	
Unkpapa Sandstone:	
Sandstone, orange, reddish-orange, white, or red; very fine grained; reddish colors in upper 1.5 ft; hard and well cemented with calcium carbonate; abundant calcareous concretions; very coarse grained in upper 10 ft	44
Mudstone; green-gray in upper half, mottled green-gray and red in lower half; upper part is silty and grades into very fine grained poorly sorted sandstone	5½
Sandstone, white, pale-pinkish-brown, red, or reddish-orange; mottled; very fine grained, very friable; crossbedded in lower part, but tabular bedded in upper part; poorly developed calcareous concretions and zones of tight cement produce a nodular surface: forms a rounded cliff and steep gullied topography	34
Mudstone; red with some thin beds that are green gray, silty, and calcareous; some massive hackly-weathering mudstone	7
Total thickness of Unkpapa Sandstone	90½
Sundance Formation:	
Redwater Shale Member (in part):	
Sandstone, reddish-gray, very fine grained, calcareous, thin-bedded, ripple-marked; has cubic pseudomorphs on undersurfaces of beds (Windy Hill Sandstone Member, as used by Pipiringos, 1968)	1
Siltstone and claystone interbedded, pale-yellowish-brown and greenish-yellow-brown, very finely laminated; more silty parts are calcareous	2½
Claystone, greenish-gray, very unctuous; physical characteristics suggest that the material is bentonitic	½

	Thickness (feet)
Sundance Formation—Continued	
Redwater Shale Member (in part)—Continued	
Siltstone, light-gray, finely laminated, with films of dark-gray claystone on laminae	2
Sandstone, pale-light-gray to greenish-gray, calcareous, friable, very thinly bedded; contact with underlying unit sharp; contact with overlying unit gradational; forms poorly defined ledge	1½
Siltstone, pale-greenish-gray, calcareous, thinly laminated and minutely wavy; films of gray claystone on laminae; similar to siltstone above, but contains fewer laminae with claystone	11
Mudstone, gradational upward to siltstone, dark-greenish-gray changing to light-greenish-brown; mudstone at base somewhat fissile, some mudstone occurs as irregular flakes and blebs within the siltstone; micaceous; contains scattered flattened ellipsoidal calcareous concretions parallel to bedding; float of thin fragments of highly fossiliferous limestone apparently comes from this interval; forms steep slope; lower 15 ft poorly exposed	31
Thickness of Redwater Shale Member measured	49½

Locally the upper part of the Unkpapa Sandstone consists of gray, olive-green, or variegated maroon and green-gray siltstone containing some argillaceous gray nodular limestone and some calcareous sandstone. The uppermost part of the formation seems to have been weathered and slightly reworked prior to deposition of the overlying Morrison Formation or Lakota Formation. The upper argillaceous part of the Unkpapa is best exposed in Hell Canyon, where it is 15–32 feet thick. The following section includes this upper part of the Unkpapa Sandstone.

Upper part of the Unkpapa Sandstone measured at Hell Canyon, NW¼ sec. 28, T. 8 S., R. 4 E.

[Measured by C. G. Bowles]

	Thickness (feet)
Lakota Formation, not measured.	
Unkpapa Sandstone (in part):	
Siltstone, dark-olive-green, calcareous; partly covered	12
Mudstone, dark-gray-green, hackly fracture; much detrital limestone in upper inch	13
Siltstone, maroon and some green	20
Sandstone and siltstone, partly covered slope, not measured.	
Thickness of the Unkpapa Sandstone measured	45

The upper part of the Unkpapa in Hell Canyon contains rocks considered by Darton and Smith (1904) to be part of the Morrison Formation. The argillaceous nodular limestones are similar to limestones characteristic of the Morrison Formation. We believe, however, that the variegated siltstones are a facies of the Unkpapa Sandstone that contains interbedded tongues of limestone and marl characteristic of the Morrison Formation to the west.

MORRISON FORMATION

The Morrison Formation crops out most conspicuously in the Cheyenne River canyon and in Chilson Canyon in the center of the quadrangle. It overlies the Sundance Formation in both areas. A few feet of Morrison overlies the Unkpapa Sandstone in the upper part of Hell Canyon.

The Morrison Formation is predominantly a pale-greenish-gray calcareous mudstone that breaks into hackly or prismatic fragments and further disintegrates to a characteristic spheroidal surface. The formation includes numerous beds, most less than 5 feet thick, of argillaceous and silty light-gray or yellowish limestone. In the lower part of the formation are a few thin beds of sandstone. Carbonaceous material is scarce or lacking in the mudstones of the Morrison Formation, in contrast to similar but carbonaceous mudstones in the Lakota Formation.

The maximum thickness of the Morrison Formation in the southern part of the quadrangle is about 90 feet. In Chilson Canyon in secs. 25 and 36, T. 8 S., R. 3 E., the formation is 60–70 feet thick and lies on the Redwater Shale Member. A section measured in Chilson Canyon in the SW¼SW¼ sec. 25, T. 8 S., R. 3 E. that is characteristic of the formation in the Flint Hill quadrangle follows.

Morrison Formation in Chilson Canyon in SW¼SW¼ sec. 25, T. 8 S., R. 3 E.

[Measured by Henry Bell]

	Thickness (feet)
Lakota Formation, not measured.	
Morrison Formation:	
Mudstone, light-gray, predominantly clay, calcareous; some pyrite and gypsum	15½
Limestone, light-gray	2
Mudstone, gray, predominantly clay; includes 8-in.-thick bed of very fine grained hard calcareous sandstone	11
Limestone, light-gray, argillaceous	2½
Mudstone, green to dark-gray, sandy, includes a 1-ft-thick bed of sandy limestone	10
Limestone, light-gray, sandy, argillaceous, hard	2
Mudstone, olive-brown to gray, sandy	9½
Limestone, gray, argillaceous, hard	1
Mudstone and siltstone, greenish-brown and gray, sandy; siltstone in two beds 4–6 in. thick; calcareous and hard	10½
Total thickness Morrison Formation	64
Sundance Formation, not measured.	

A section measured by C. G. Bowles (written commun., 1959) in Hell Canyon in sec. 21, T. 8 S., R. 4 E., where the Morrison Formation is thin, follows.

Morrison Formation in sec. 21 T. 8 S., R. 4 E.

	Thickness (feet)
Lakota Formation (in part):	
Sandstone; 6-in.-thick shale seam at base; some oolitic chert at base; not measured.	
Conglomerate of argillaceous yellow limestone	2
Morrison Formation:	
Shale, yellow, calcareous; some thin marl beds	5
Mudstone, dark-green; few bands of calcareous silt	3
Limestone, yellow, argillaceous; similar to that in the Lakota conglomerate above: some limy silt	3
Limestone, silty, yellow and maroon	2
Total thickness Morrison Formation	13
Unkpapa Sandstone (in part):	
Siltstone, maroon and green; 2-ft-thick silty limestone bed in center; limestone has conchoidal fracture giving nodular appearance	15
Total thickness Unkpapa Sandstone measured	15

The contact of the Morrison Formation with the underlying Redwater Shale Member of the Sundance Formation appears to be conformable. A thin slabby calcareous sandstone containing cubic pseudomorphs, probably of halite, on the bedding planes forms the uppermost unit of the Redwater both where it is overlain by the Morrison near the Cheyenne River in sec. 11, T. 9 S., R. 3 E., and where it is overlain by the Unkpapa in a tributary to Falls Canyon in sec. 9, T. 8 S., R. 4 E. The extension of the top of the Redwater Shale Member without interruption beyond the limits of the Morrison Formation and beneath the Unkpapa Sandstone indicates that there was no post-Redwater or pre-Morrison erosion.[2] It also suggests that the Morrison Formation and the Unkpapa Sandstone were deposited contemporaneously. These formations appear to interfinger within a narrow zone that trends northward through the center of the Flint Hill quadrangle. A thin extension of the Morrison Formation in Hell Canyon, however, indicates that deposition of Morrison-type sediment may have persisted longer than the deposition of Unkpapa sediment.

The contact of the Morrison Formation with the overlying Lakota Formation is disconformable where the lowermost unit of the Lakota is sandstone. The contact seems to be conformable where the lowermost unit of the Lakota is mudstone. The surface of the Jurassic rocks was apparently scoured by Lakota streams, which subsequently deposited sand filling the scours. A thin layer of scattered pebbles of oolitic chert

[2] Farther to the south, however, the Windy Hill Sandstone Member (here included at the top of the Redwater) truncates the underlying units of the Redwater (Pipiringos, 1968, p. D4, fig. 3, and p. D24).

and limestone at the base of the Lakota, notably in Hell Canyon, represents Morrison-type sediment that was reworked and deposited with the sand of the Lakota Formation. The scoured surface of the Jurassic rocks is indicated on a structure-contour map drawn on the top of the Morrison Formation and Unkpapa Sandstone (fig. 93). The structure

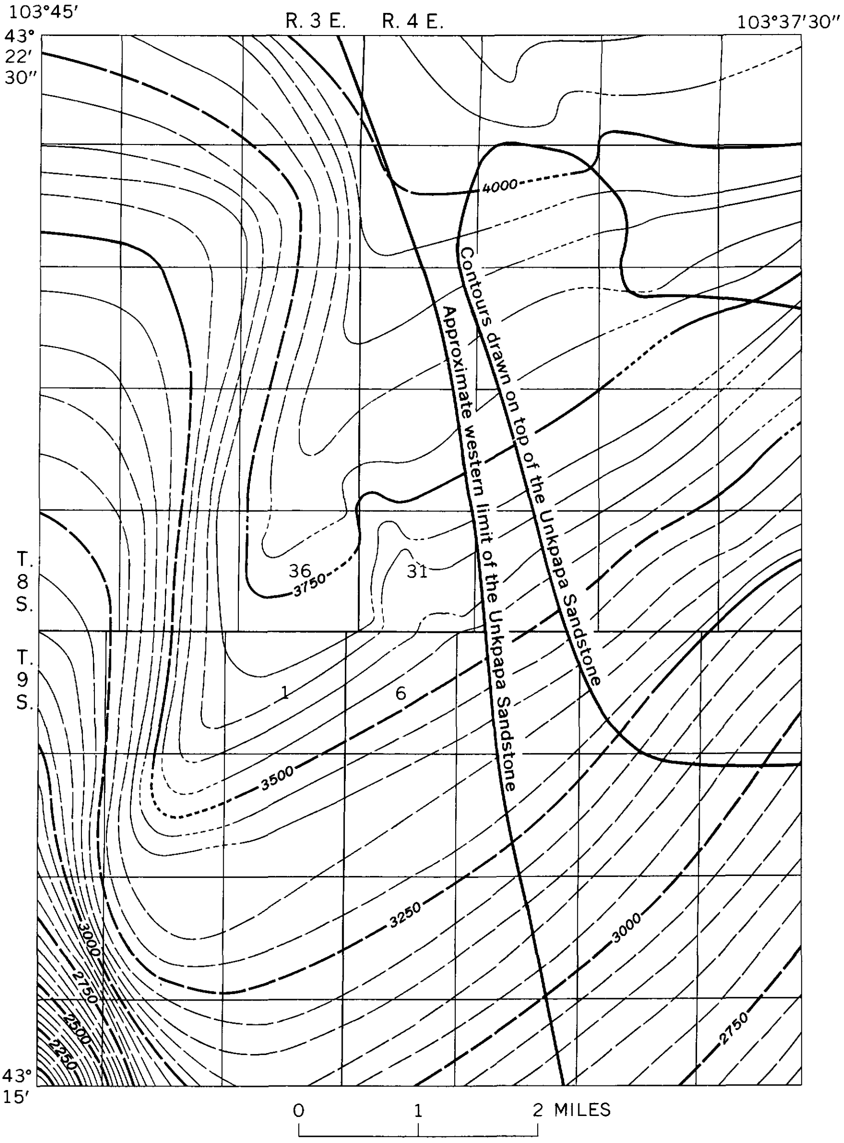

FIGURE 93.—Structure contours drawn on the top of the Morrison Formation and Unkpapa Sandstone, and the approximate west limit of the Unkpapa Sandstone in the Flint Hill quadrangle. Long dashes where inferred below the topographic surface; short dashes where restored. Contour interval 50 feet. Datum is mean sea level.

423-557 O - 71 - 3

contours outlining the scour near the center of the quadrangle were drawn in part from outcrop data and in part from information obtained from diamond drilling done by the U.S. Atomic Energy Commission (Bartley, 1955). The contours indicating the scour in the northeast corner of the quadrangle were drawn from outcrop data only. These northwest-trending channels are parallel to the general trend of the Lakota streams, as determined from crossbed orientations and the general distributive pattern of the channel-filling sandstones. Scouring of the Morrison Formation along this trend has been noted also by Gott and Schnabel (1963, p. 153, 154, and pl. 12) in the Edgemont NE. quadrangle.

The only fossils found in the Morrison Formation in the Flint Hill quadrangle are charophytes and ostracodes. Sohn (1957) has found that the ostracode faunule of the Morrison Formation, although similar to that of the Lakota Formation, characteristically lacks species of the subfamily Cyprideinae that have an easily recognized ventroanterior notch. The presence of species of *Theriosynoecum*, a genus known only from the Morrison Formation, and the lack of notched forms among Morrison ostracodes suggest to Sohn that these fossils may be used to separate the mudstones of the Morrison Formation from similar-appearing mudstones in the Lakota Formation.

The charophytes of the Morrison Formation in the Black Hills have been described by Peck (1957).

CRETACEOUS ROCKS

Rocks of Cretaceous age underlie the major part of the Flint Hill quadrangle. These rocks range from the Early Cretaceous Lakota and Fall River Formations—the most extensively exposed of all formations in the quadrangle—through the Skull Creek Shale, Newcastle Sandstone, and Mowry Shale of Early Cretaceous age and the Belle Fourche Shale and Greenhorn Limestone of Late Cretaceous age. Cretaceous rocks younger than the Fall River Formation occur only in the southern and southwestern parts of the quadrangle.

LOWER CRETACEOUS ROCKS

INYAN KARA GROUP

HISTORY OF STRATIGRAPHIC NOMENCLATURE

The history of the nomenclature of the Inyan Kara Group in the Black Hills has been described many times, most recently and thoroughly by Waagé (1959). Hayden (1862; Meek and Hayden, 1858,

1861) included rocks of the Inyan Kara Group in his Formation No. 1 or Dakota Sandstone because of their similarity to rocks exposed along the Missouri River near the boundary between South Dakota and Nebraska. Darton (1901) considered the sandstones forming the outermost hogback and called "Dakota sandstone" to be of Late Cretaceous age. He considered the cliff-forming sandstones of the inner hogback, a thin limestone, and the more easily eroded sandstones and shales that in many places separate the two hogbacks to be of Early Cretaceous age. Darton (1901) named the easily eroded sandstones and shales the Fuson Formation; the limestone, the Minnewaste Limestone; and the lower cliff-forming rocks, the Lakota Sandstone. Russell (1927, p. 402) used the name Fall River Sandstone in the Black Hills rather than Dakota Sandstone because the sandstone was found to contain a fossil flora older than the fossil flora in the type Dakota Sandstone cropping out along the Missouri River. The Fall River, as well as the overlying Skull Creek Shale, Newcastle Sandstone, and Mowry Shale, are now known to be of Early Cretaceous age. Rubey (1931) introduced the term Inyan Kara Group to include the Lakota Sandstone, Fuson Shale, and the Fall River Sandstone in the northern and western Black Hills, where he considered Darton's subdivisions difficult to map.

Waagé (1959) redefined the Lakota and Fall River Formations. The Lakota Formation, as redefined, consists of (1) a lower member, locally equivalent to the Lakota Formation as used by Darton, which we named the Chilson Member (Post and Bell, 1961); (2) the Minnewaste Limestone Member; and (3) the Fuson Member.

The Fall River Formation, as redefined by Waagé (1959), corresponds closely to the Fall River as originally described by Russell (1927, 1928).

The Lakota and Fall River Formations are separated, according to Waagé, by a regional transgressive disconformity that marks a change from a terrestrial environment, which includes river-channel and floodplain, swamp, and lacustrine deposits, to a marginal marine environment in which estuarine, coastal-swamp, tidal-flat, and deltaic deposits were formed. Waagé included the marginal marine rocks in the Fall River Formation, and only terrestrial rocks in the Lakota Formation.

Within the Inyan Kara Group in the southern Black Hills there are persistent and distinctive channel sandstones (Gott, 1956). These sandstones originally were informally numbered S_1 through S_6 from oldest to youngest (Mapel and Gott, 1959). Subsequently, various mudstone beds or intervals of interbedded sandstone and mudstone were identified as being lateral equivalents of certain channel sandstones (Post and Bell, 1961, p. D174), and the informal number designation was applied to these sandstone-mudstone complexes as units within the formations of the Inyan Kara Group. Thus, in the Lakota Formation of the Flint Hill quadrangle, the Chilson Member includes informal units numbered 1 and 2, and the Fuson Member includes unit 4. Informal unit 3 of the Fuson Member is absent in the Flint Hill quadrangle. The Fall River Formation, in this quadrangle, includes in its middle unit channel sandstone S_5 and in its upper unit channel sandstone S_6.

LAKOTA FORMATION

The Lakota Formation, the lowermost formation of Early Cretaceous age in the Black Hills, is composed principally of sandstone of fluvial origin and mudstone of paludal and lacustrine origin. The formation is commonly about 400 feet thick in the Flint Hill quadrangle, but it ranges from 310 to 485 feet in thickness.

Three members of the Lakota Formation have been mapped in the Flint Hill quadrangle. These are, in ascending order: (1) the Chilson Member, (2) the Minnewaste Limestone Member, and (3) the Fuson Member. With the exception of the Minnewaste Limestone Member, which is there absent, the general characteristics of the Lakota Formation are given by a composite section measured in Chilson Canyon near the center of the quadrangle (fig. 94). Plate 33 illustrates the thickness and correlation of these units from place to place within the Flint Hill quadrangle.

CHILSON MEMBER

The Chilson Member of the Lakota Formation in the Flint Hill quadrangle comprises two informal units, each of which is a complex of fluviatile channel sandstone and interbedded or laterally adjacent mudstone. Unit 1 is the older; it occupies approximately the west half of the quadrangle, and is overlapped from the southeast by unit 2.

UNIT 1

Unit 1 of the Chilson Member includes the prominent S_1 channel sandstone as well as carbonaceous siltstone that is interbedded with and adjacent to S_1 sandstone (pl. 32).

The S_1 sandstone has a wide distribution in the southwestern two-thirds of the Flint Hill quadrangle. Its lithology, sedimentary structures, and pattern of distribution in the southwestern Black Hills (fig. 95) indicate that it was deposited in a river-channel system trending generally northwest.

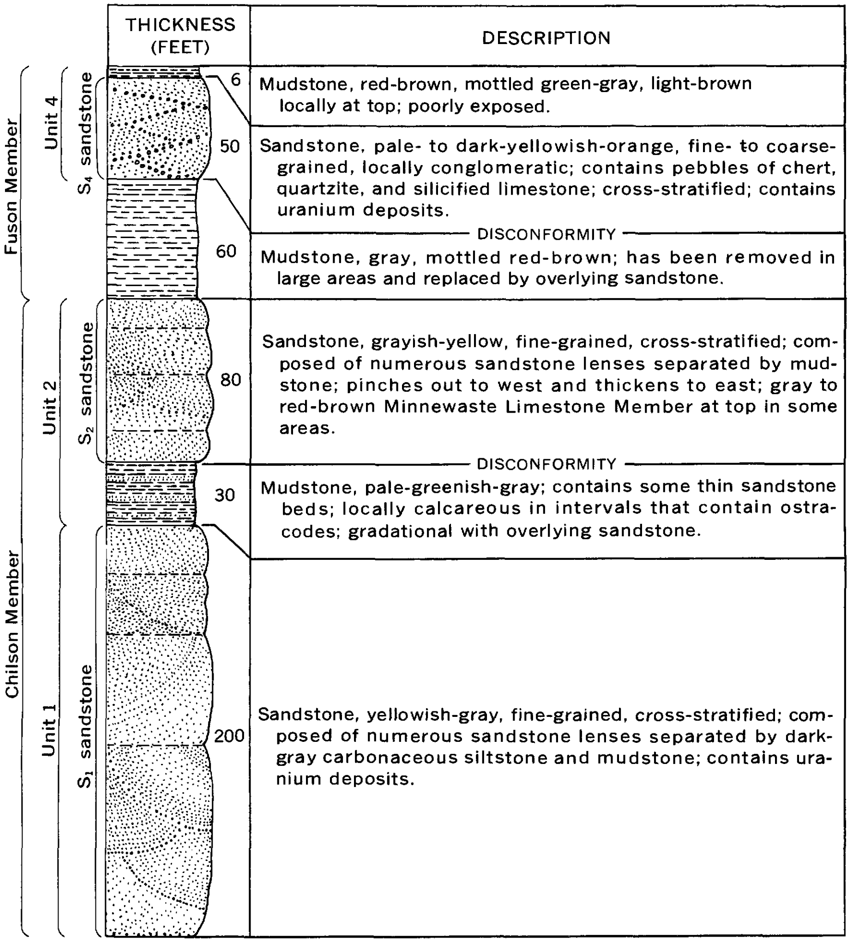

FIGURE 94.—Composite section of the Lakota Formation in Chilson Canyon, sec. 32, T. 8 S., R. 4 E., Fall River County, S. Dak.

The S_1 sandstone commonly forms prominent cliffs, which are especially conspicuous in Chilson Canyon in the center of the quadrangle and along the Cheyenne River in the southwestern part of the area. The maximum thickness of the S_1 sandstone, 300 feet, is exposed along the Cheyenne River.

The S_1 sandstone is composed of many cross-stratified lenses of sandstone 50 feet or more thick and several hundred feet wide. The thickness and uniformity of the cross-strata vary directly with the thickness of the lenses. Mudstone beds ranging in thickness from less than 1 foot to 4 feet commonly separate the sandstone lenses. These mudstones vary in character from laminated carbonaceous siltstones

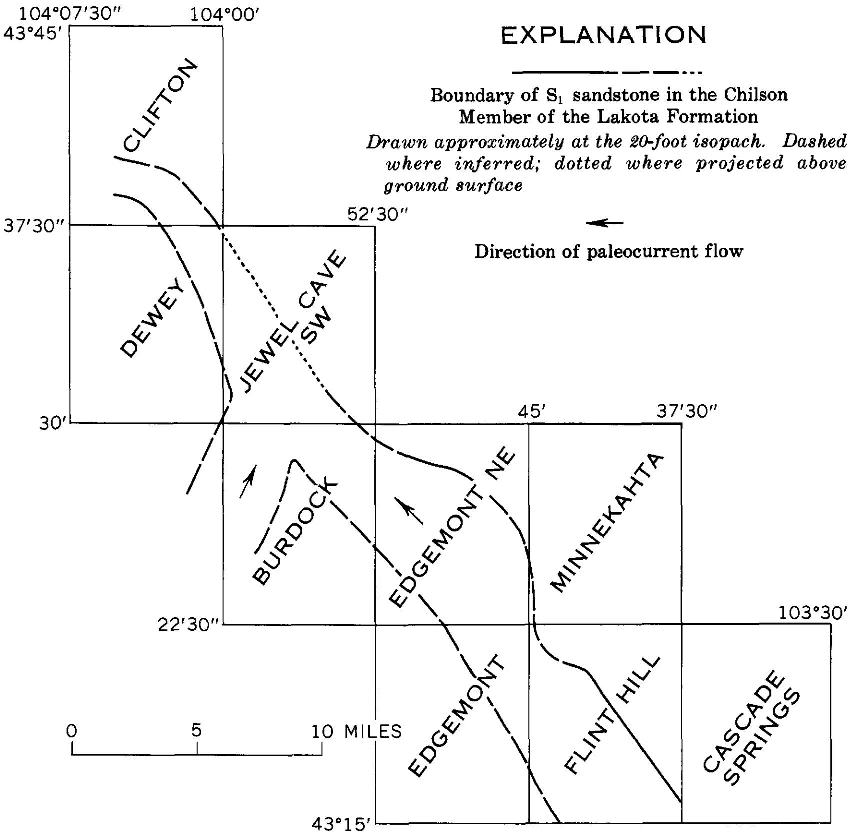

FIGURE 95.—Distribution of the S_1 sandstone in the Chilson Member of the Lakota Formation, southwestern Black Hills.

to calcareous ostracode-bearing argillaceous rocks. A 1½-foot-thick ostracode-bearing mudstone was used by U.S. Atomic Energy Commission geologists to correlate between 23 diamond-drill holes over a distance of more than a mile in an area east of Chilson Canyon in the center of the Flint Hill quadrangle (Bartley, 1955). Locally a thin coal bed separates sandstone lenses. Figure 96 shows a cliff of typical lenticular S_1 sandstone along the Cheyenne River in the southwestern part of the quadrangle.

The S_1 sandstone is generally yellowish gray and fine to very fine grained, grading in places to siltstone; it is well-sorted, and tends to be finer grained than other sandstones of the Lakota Formation (fig. 97).

The S_1 sandstone is composed almost entirely of subrounded quartz grains; it contains less than 5 percent chert and only minor amounts

FIGURE 96.—Lenticular S_1 sandstone of the Chilson Member of the Lakota Formation along the Cheyenne River in sec. 24, T. 9 S., R. 3 E. Coal bed separating sandstone lenses indicated by dashed line.

of feldspar. Many of the grains show partial secondary quartz overgrowths in optical continuity with the original grain. At many places, the lower part of sandstone lenses contains abundant fragments of mudstone derived from underlying mudstone beds.

The only fossils found in the S_1 sandstone are a few unidentified silicified logs and some bone fragments.

Sandstone at the top of unit 1 in Chilson Canyon from the SW¼ sec. 32, T. 8 S., R. 4 E., to the southern part of sec. 5, T. 9 S., R. 4 E., shows unusually steep dips that apparently reflect rapid thinning of the sandstone to the east. The nature of the outcrops suggests that the upper surface of unit 1 is convex. A similar suggestion is presented by a lens of S_1 sandstone in Hell Canyon. This lens is normally less than 15 feet thick, but it thickens abruptly to more than 130 feet in the SE¼ sec. 17 and the adjacent part of sec. 16, T. 8 S., R. 4 E.

A unit of laminated carbonaceous siltstone mapped in the north-central part of the quadrangle is considered to be a lateral facies of the S_1 sandstone. It was probably deposited on a flood plain adjacent to the river channel in which S_1 sandstone was deposited. As the course of the river shifted position laterally, some carbonaceous siltstone was scoured away or buried by the S_1 sandstone at the same time that carbonaceous siltstone was being deposited on S_1 sandstone in the

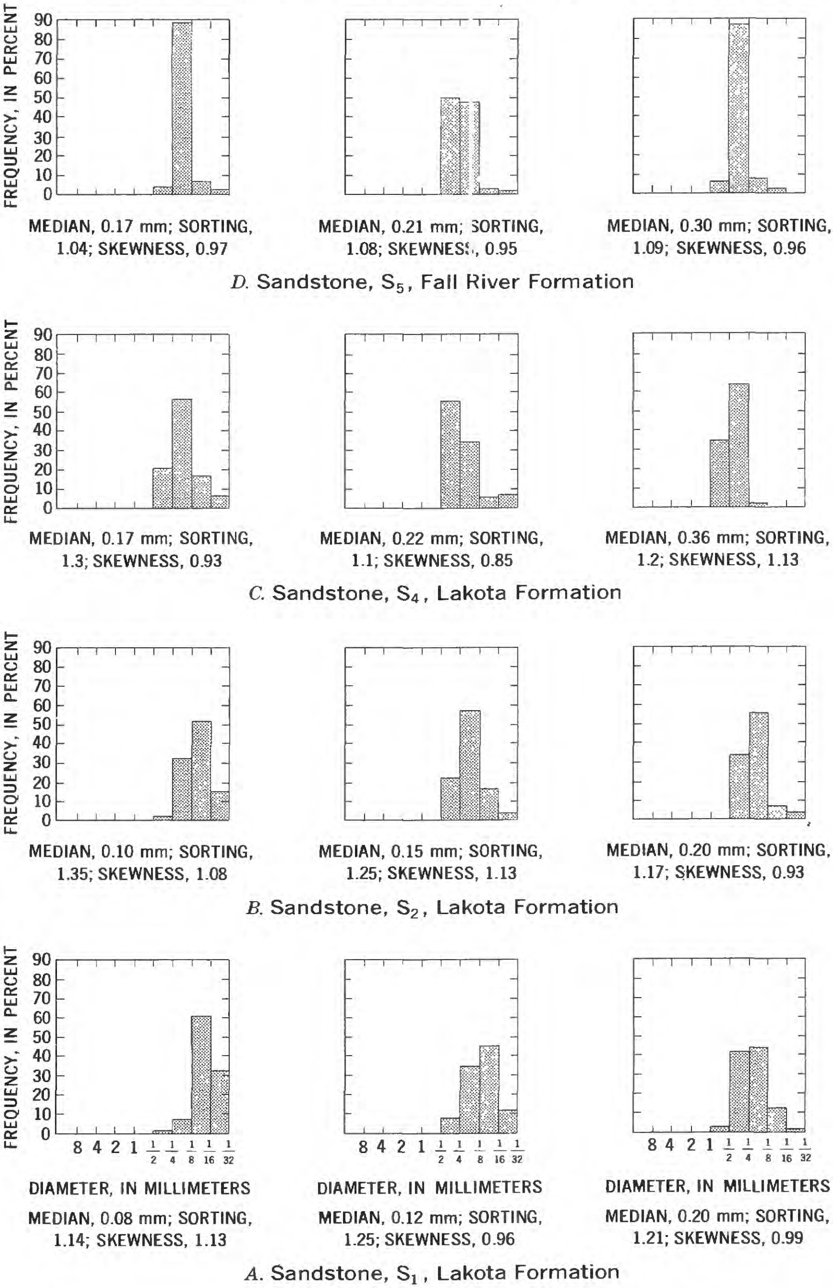

FIGURE 97.—Histograms of three selected samples from each of the S_1, S_2, S_4, and S_5 sandstones in the Lakota and Fall River Formations.

original channel. Thus, the siltstone unit as a whole interfingers with and is contemporaneous wtih the S_1 sandstone.

The siltstone is medium to dark gray, laminated to thin bedded, and in places includes some thin fine-grained sandstone and a few thin beds of claystone. The carbonaceous material is generally very finely divided, but some small fragments of charred wood that show cellular structure are present. Pyrite is common, as are selenite and jarosite, both of which are found on weathered surfaces, along bedding planes, and in fractures.

The maximum thickness of the carbonaceous siltstone in the Flint Hill quadrangle is about 110 feet, in secs. 18 and 19, T. 8 S., R. 4 E.

Rocks similar to this siltstone seem to be more widespread in the Edgemont NE quadrangle, where a thickness of more than 75 feet occurs to the northeast and southwest of the S_1 sandstone (Gott and Schnabel, 1963, p. 152).

Beds a few feet thick of paper-thin dark-brown highly organic petroliferous siltstone have been found associated with calcareous concretions, fetid limestone, and cone-in-cone limestone in the north-central part of the Flint Hill quadrangle. The dark petroliferous siltstone commonly contains abundant ostracode remains as well as the crustacean *Isaura*. Clusters of *Isaura* have been found in the center of calcareous concretions.

Fossil spores and pollen in thin sections of brownish-gray very thinly laminated siltstone collected in the north-central part of the quadrangle have been recognized by Estella Leopold and Helen Penn of the U.S. Geological Survey. They have recognized spores of the fern genera *Aneimia* and *Triletes* and the coniferous family Taxodiaceae and genus *Piceites*. The fern genus *Aneimia*, they reported (written commun., 1955), is associated with tropical forms in both Cretaceous and modern floras.

Semiquantitative spectrographic analyses and results of destructive distillation and solvent extraction of petroleum from two samples of carbonaceous siltstone are given in tables 2 and 3 (samples 4 and 5). Table 3 shows that these two samples contain as much as 10 times more petroliferous material than other mudstones in the Lakota Formation. Table 2 suggests that lanthanum and possibly scandium are preferentially concentrated in the more petroliferous rocks.

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TABLE 2.—*Semiquantitative spectrographic analyses of some mudstone, siltstone, and claystone samples from the Chilson Member of the Lakota Formation, Flint Hill quadrangle*

[Samples 1, 4, 5, 8, and 11 analyzed by R. G. Havens; others by J. C. Hamilton. Tr. near threshold. Elements looked for but not detected: Ag, As, Au, Be, Bi, Cd, Ce, Dy, Er, Gd, Ge, Hf, Hg, In, Ir, Li, Nd, Os, P, Pd, Pt, Pb, Re, Rh, Ru, Sb, Sm, Sn, Ta, Te, Th, Tl, U, W, Zn]

Sample No.	Laboratory No.	Field No.	Locality and description of samples	Si	Al	Fe	Ti	Mn	Ca	Mg	Na	K	B	Ba
			Devil Canyon, NE¼sec. 4, T. 9 S., R. 4 E.											
1	243800	HB-7-53	Mudstone of unit 1, green-gray; contains carbonaceous material and ostracodes.	xx.	x.+	x.—	0.x	0.0x—	0.x+	0.x+	0.x	x.	0.00x+	0.0x
2	227765	HB-9-53	Mudstone of unit 2, sandy, green-gray; contains ostracodes.	x.+	x.	.x+	.0x+	.x	xx.	.x+	.x	x.—	Tr.	.0x+
			Marty ranch; SE ¼sec. 12, T. 8 S., R. 3 E.											
3	227764	HB-31-54	Mudstone of unit 2, dark-olive-gray; contains ostracodes.	x.+	x.+	x.—	.0x+	.x	xx.	.x+	.x	x.—	Tr.	.0x
4	243803	HB-33-54	Siltstone, dark-gray-brown, laminated, carbonaceous; contains ostracodes.	x.	x.	.x+	.0x+	.x	xx.	.x+	.x	.x+	0	.0x+
5	243804	HB-35-54	Siltstone, dark-gray, laminated, carbonaceous; contains ostracodes.	xx.	x.	x.—	.x—	.0x	.x+	.x	.x—	x.—	.00x	.00x+
6	228957	HB-36-54	Siltstone, brown-gray, laminated	xx.	x.	.x+	.x	.00x	.0x+	.x	.x	x.	.00x	.0x
			Buck Canyon; SE¼sec. 15, T. 8 S., R. 4 E. (measured section p. 530)											
7	228953	HB-14-54	Bed 2. Mudstone, dark-brownish-gray, sandy carbonaceous; contains ostracodes.	xx.	x.+	x.—	.0x+	.00x	.x—	.x+	.0x+	x.—	.00x	.00x+
8	243801	HB-20-54	Bed 7. Siltstone, dark-brown; contains ostracodes	xx.	x.—	.x+	.x—	.0x+	x.+	.x+	.x	x.—	.00x—	.0x
9	228954	HB-21-54	Do	xx.	x.+	x.—	.x—	.00x+	.x—	.x+	.0x+	x.—	.00x	.0x—
10	228955	HB-22-54	Bed 9. Mudstone, olive-gray; contains charophytes and ostracodes.	x.+	x.	.x+	.0x+	.0x+	xx.	.x+	.x—	x.	Tr.	.00x+
11	243802	HB-24-54	Bed 11. Claystone, brownish-gray; contains ostracodes	xx.	x.+	x.—	.x—	.0x	x.	x.—	.x	x.	.00x	.00x+
12	228959	HBP-51-54	Bed 13. Mudstone, olive-gray; contains charophytes and ostracodes.	xx.	xx.	x.—	.x	.0x	x.	.x+	.x—	x.	.00x	.0x—
13	228960	HBP-60-54	Bed 17. Mudstone, light-gray, silty	xx.	x.+	x.—	.x	.00x	.x—	.x	.x—	x.	.00x	.0x
Approximate limits of detection of elements reported, in percent.				0.001	0.001	0.001	0.0005	0.0005	0.001	0.001	0.05	0.5	0.005	0.0001

TABLE 2.—*Semiquantitative spectrographic analyses of some mudstone, siltstone, and claystone samples from the Chilson Member of the Lakota Formation, Flint Hill quadrangle*—Continued

Sample No.	Laboratory No.	Field No.	Co	Cr	Cu	Ga	La	Mo	Nb	Ni	Pb	Sc	Sr	V	Y	Yb	Zr
1	243800	HB-7-53	0.000x+	0.00x+	0.00x	0.000x+	0.00x	0.000x+	0.00x+	0.00x	0.00x	0.00x−	0.0x−	0.00x	0.00x	0.000x+	0.0x−
2	227765	HB-9-53	0	.00x	.00x−	.00x−	0	0	0	0	0	0	.0x+	.00x+	.00x−	.000x−	.0x−
3	227764	HB-31-54	0	.00x	.00x−	Tr.	0	0	0	.000x	Tr.	0	.0x	.00x+	.00x−	.000x	.00x
4	243803	HB-33-54	.000x	.00x	.00x−	Tr.	.00x	0	0	.000x+	0	.000x+	.0x	.00x+	.00x	.000x	.00x+
5	243804	HB-35-54	.000x+	.00x+	.00x+	Tr.	.00x	0	Tr.	.00x+	Tr.	.000x+	.00x	.00x	.00x−	.000x−	.00x+
6	228957	HB-36-54	0	.00x	.00x−	Tr.	0	0	0	.000x	0	0	.00x+	.00x−	.00x−	.000x−	.0x−
7	228953	HB-14-54	0	.00x	.00x−	Tr.	0	0	0	.000x	0	0	.00x+	.00x−	.00x−	.000x−	.0x−
8	243801	HB-20-54	.000x	.00x+	.00x−	Tr.	0	0	0	.000x+	.00x−	0	.0x−	.00x+	.00x−	.000x−	.0x−
9	228954	HB-21-54	0	.00x	.000x+	Tr.	0	0	0	.000x+	.000x+	0	.00x	.00x−	.00x−	.000x−	.00x+
10	228955	HB-22-45	0	.00x	.000x+	Tr.	0	0	0	.000x	0	0	.0x	.00x	0	0	.00x
11	243802	HB-24-54	.000x	.00x+	.00x	.000x+	0	0	Tr.	.00x−	.00x−	.00x−	.0x−	.00x+	.00x−	.000x	.0x−
12	228959	HBP-51-54	0	.00x	.00x	.000x+	0	0	0	.000x+	.00x−	.000x+	.0x−	.00x+	.00x	.000x	.00x+
13	228960	HBP-60-54	0	.00x	.00x−	Tr.	0	0	0	.000x+	0	0	.0x−	.00x	.00x−	.000x	.0x−
Approximate limits of detection of elements reported, in percent.			0.0005	0.0001	0.00005	0.001	0.05	0.001	0.001	0.0005	0.001	0.001	0.0001	0.001	0.001	0.0001	0.001

NOTE.—The concentrations of the elements determined by semiquantitative spectrographic analysis are bracketed into groups each of approximately one-third of an order of magnitude, x+ indicating the higher portion (10-5 percent); x, the middle portion (5-2 percent); and x−, the lower portion (2-1 percent). Comparisons of this type of semiquantitative results with those obtained by quantitative methods, either chemical or spectrographic, show that the assigned group includes the quantitative value in about 60 percent of the analyses.

TABLE 3.—*Results of destructive distillation and solvent extraction of petroliferous material from some mudstone, siltstone, and claystone samples in the Chilson Member of the Lakota Formation*

Sample No. (Compare with table 2)	Laboratory No.	Field No.	Locality and description of samples	U [1] (percent)	eU [2] (percent)	Oil extracted by destructive distillation				Oil extracted by solvent		
						Percent by weight of sample [3]	Specific gravity [3]	Percent ash [4]	Percent U in ash [4]	Percent [4]	Percent ash [4]	Percent U in ash [4]
1	241886	HB-7-53	NE¼ sec. 4, T. 9 S., R. 4 E.; mudstone of unit 1, green-gray; contains carbonaceous material and ostracodes.	0.003	0.004	0.70	.400	0.017	.0037	0.73	1.60	0.0017
4	241888	HB-33-54	SE¼ sec. 12, T, 8 S., R. 3 E,; siltstone of unit 1, dark-gray-brown, laminated; contains carbonaceous material and ostracodes.	.005	.001	7.4	.804	.010	.0052	1.02	3.36	.0054
5	241889	HB-35-54	SE¼ sec. 12, T. 8 S., R. 3 E.; siltstone of unit 1, dark-gray, laminated; contains carbonaceous material and ostracodes.	<.001	.001	7.2	.665	.019	.0037	1.27	.93	.0079
8		HB-20-54	SE¼ sec. 15, T. 8 S., R. 4 E.; siltstone of unit 2, dark-brown; contains ostracodes; item 7, measured section, page 531.	.003	<.001	.69	.420					
9		HB-21-54	do	.0002	<.001	.41	.400					
11	241887	HB-24-54	SE¼ sec. 15, T. 8 S., R. 4 E.; claystone of unit 2, brownish-gray; contains ostracodes; item 11, measured section, page 531.	.001	<.001	.13	.146	.545	.0002	.37	12.56	.0003

[1] Fluorimetric method; analysts H. H. Lipp and J. P. Schuch.
[2] Analyst C. G. Angelo.
[3] Analyst R. F. Gantnier.
[4] Analyst F. L. Ferguson.

UNIT 2

The prominent sandstone cliffs in the lower part of the Lakota Formation in the eastern third of the Flint Hill quadrangle are formed by the S_2 sandstone (pl. 32). In much of the Cascade Springs quadrangle to the east, unit 2 comprises the whole of the Chilson Member of the Lakota Formation. Westward in the Flint Hill quadrangle, the lower part of unit 2 fingers into mudstone, and the sandstone occupies only the upper part of the Chilson Member. In the central part of the Flint Hill quadrangle, unit 2 overlaps unit 1, and in much of the northern and western parts of the quadrangle, sandstone of unit 2 fingers laterally into an upper unit of interbedded sandstone and mudstone and a lower unit of mudstone.

The S_2 sandstone reaches a maximum thickness of about 200 feet in this quadrangle. It resembles the S_1 sandstone very closely, being light gray to yellowish gray, but it commonly grades to shades of moderate orange pink or moderate reddish orange. The sandstone is fine to very fine grained, rarely grades to siltstone, is well sorted, and, like S_1, is composed dominantly of subrounded quartz grains with less than 5 percent chert grains and only minor amounts of feldspar (fig. 97). Like the S_1 sandstone, this unit consists of many overlapping lenses of cross-stratified sandstone separated by thin mudstone beds. Unlike the S_1 sandstone, however, sandstone of unit 2 contains little carbonaceous material. It commonly contains silicified logs, which have been found protruding from cliffs.

A prominent red sandstone bed marks the top of unit 2. It is 5–10 feet thick is generally fine grained and moderately calcareous, shows little bedding, and weathers somewhat cavernously. Although this red sandstone is not differentiated on plate 32, it has been traced discontinuously from the Cascade Springs quadrangle, where it is widely exposed, as far west as Chilson Canyon in the Flint Hill quadrangle, where it occurs in the SW¼SW¼ sec. 13, T. 8 S., R. 3 E. It is found in Wolf Canyon in the SE¼ sec. 30, T. 8 S., R. 4 E., where it is brecciated, on the northeast side of Hell Canyon in sec. 22, T. 8 S., R. 4 E., in Dick Canyon, Devil Canyon, southeast of the Cheyenne River in the SE¼ sec. 3, T. 9 S., R. 4 E., and north of the county road in the NE¼ sec. 19, T. 8 S., R. 4 E. It has also been recognized in the canyon of the Cheyenne River in the southwestern part of the Flint Hill quadrangle.

The red sandstone is overlain by the Minnewaste Limestone Member of the Lakota Formation or by variegated claystone of the Fuson Member where the Minnewaste is absent. Structure contours drawn on the top of the Chilson Member of the Lakota Formation and therefore on the top of the red sandstone where it is present are shown in figure 98.

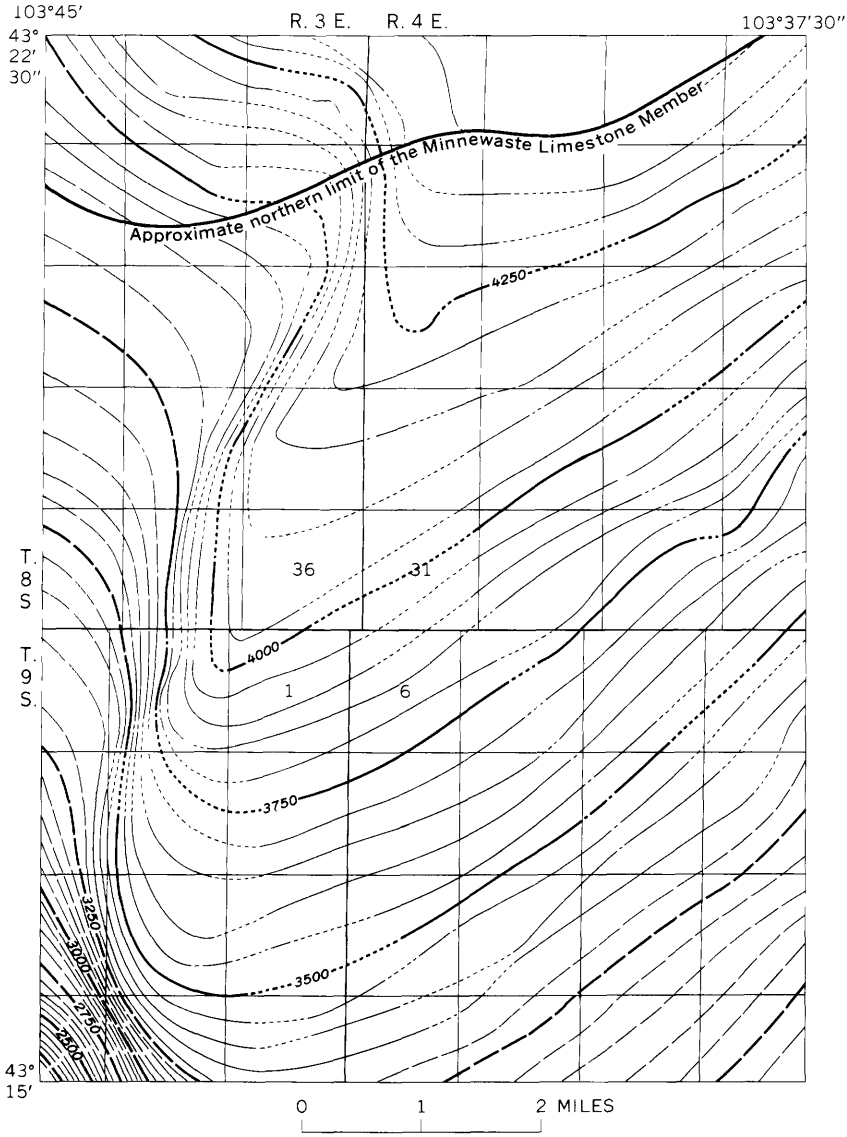

FIGURE 98.—Structure contours drawn at the top of the Chilson Member of the Lakota Formation, Flint Hill quadrangle. Long dashes where inferred below the topographic surface; short dashes where restored. Contour interval 50 feet. Datum is mean sea level.

Poorly preserved high-spired many-whorled gastropods suggestive of the genus *Hydrobia*, plates of an unidentified turtle, and bone fragments and teeth of a fish were found in the red sandstone in the south-central part of sec. 22, T. 8 S., R. 4 E., along the rim of Hell Canyon.

Interbedded sandstone and mudstone form much of unit 2 in the north-central and northwestern parts of the Flint Hill quadrangle.

This rock is a lateral equivalent of the S_2 sandstone and represents an intermediate stage in the lateral gradation from sandstone to mudstone. The change from the thick S_2 sandstone to interbedded sandstone and mudstone results from the thickening of the mudstone beds between sandstone lenses accompanied by a corresponding thinning and decrease in both grain size and degree of sorting of the sandstone lenses.

The mudstones of unit 2 vary widely in composition and character. They range in color from yellowish gray through greenish gray to grayish red, and contain varied proportions of clay, silt, sand, carbonate, and organic carbon. Some mudstones are laminated, some are massive, few are fissile. The laminated rocks generally contain higher proportions of silt and sand than the massive ones. X-ray diffraction studies of the clays in 17 samples of Lakota mudstones indicate that kaolinite and illite are the most common clay minerals, with lesser amounts of montmorillonite and chlorite present. Clays of mixed lattice structure are common in many of the samples.

Interbedded sandstone and mudstone of unit 2 locally contain abundant fossils. Ostracodes, gastropods, pelecypods, charophyte oogonia, and fish remains are found. Ostracodes are locally so abundant that they form thin beds of coquinoid calcareous mudstone. Several new genera and species of ostracodes have been identified by I. G. Sohn of the U.S. Geological Survey in collections from this quadrangle. In lieu of having been formally named, they are represented in this report as new genera A through F, and new species A of the genus *Pseudocypridina*. The fish *Lepidotus lakotanum* was identified by D. H. Dunkle of the U.S. Geological Survey in a thin sandstone from this unit in the SW¼ sec. 12, T. 8 S., R. 3 E. The ostracodes *Pseudocypridina inornata*, *Metacypris* sp., and a new as yet undescribed genus were found in the sandstone with the fish remains.

Fossil logs have been found lying on the ground where interbedded sandstone and mudstone of unit 2 crop out. One of these logs was 29 feet long, and another, partly hollow, was 5 feet long and 2 feet in diameter and included two stumps of branches. R. A. Scott of the U.S. Geological Survey found the logs to be too poorly preserved for identification. In the Minnekahta quadrangle to the north, rocks of this unit in the Cycad National Monument contained well-preserved fossil cycads.

A stratigraphic section of the interbedded sandstone and mudstone of unit 2 that was measured at a good exposure on the north side of Buck Canyon in the SE¼ sec. 15, T. 8 S., R. 4 E., is described below. Table 2 gives the results of semiquantitative spectrographic analyses of seven samples (Nos. 7–13) from this section. Table 3 shows that the amount of petroliferous material obtained by destructive distillation and by solvent extraction from some of these rocks is small in contrast to siltstones of unit 1.

Part of the Chilson Member of the Lakota Formation and Unkpapa Sandstone in Buck Canyon in the SE¼ sec. 15, T. 8 S., R. 4 E.

[Measured by Henry Bell and E. V. Post]

	Thickness (feet)
Lakota Formation:	
Chilson Member (in part), unit 2:	
24. Sandstone, light-yellowish-gray, very fine grained, tabular bedded; forms massive cliff	Not measured
23. Claystone, medium-gray; fissile at base, more massive with hackly fracture at top	7
22. Sandstone, greenish-gray, mottled with red, very fine grained, silty; irregular bedding	5
21. Claystone and siltstone. Claystone is medium gray to brownish gray, unctuous; siltstone is mottled purplish gray, massive	7
20. Sandstone, orange-gray to yellowish-gray, very fine grained, massive	15
19. Siltstone, gray to purplish-gray, thin-bedded, carbonaceous; contains microscopic plant spores	7
18. Mudstone, greenish-gray; some beds very silty and carbonaceous	18
17. Siltstone and sandstone. Siltstone is brown and carbonaceous; sandstone is light yellowish gray, very fine grained, and iron stained. One thin mudstone bed	9
16. Mudstone, olive-gray and brownish-gray. Brownish-gray mudstone in lower 17 ft contains large carbon fragments; some thin calcareous sandstone, gypsum, and pyrite; upper 7 ft contains *Clavator nodosus* Peck n. sp., *Praechara voluta* (Peck), *Praechara symmetrica* Peck n. sp., *Pseudocypridina inornata* (Peck), *Bairdiocypris* sp	37
15. Sandstone, yellowish-gray, fine-grained, calcareous, iron-stained; contains abundant interstitial clay, carbonaceous material, and gypsum; contains *Protelliptio*? cf. *P. douglassi* Stanton, *Unio farri* Stanton, *Lioplacodes*? sp., *Cypridea* cf. *C. wyomingensis* Jones, *Metacypris* sp., *Darwinulla* sp	15
14. Mudstone, olive- to brownish-gray; contains finely disseminated carbonaceous material; upper 2 ft contains *Metacypris angularis* Peck, *Pseudocypridina inornata* (Peck), *Cypridea* cf. *C. wyomingensis* Jones, *Macrodentina*? sp., *Darwinulla* sp	19
13. Mudstone, olive-gray; contains *Clavator nodosus* Peck n. sp., *Praechara voluta* (Peck), *Praechara symmetrica* Peck n. sp., *Tectochara grambastorus* Peck n. sp., *Pseudocypridina inornata* (Peck), *Cypridea longispina* Peck, *Metacypris persulcata* Peck	7
12. Sandstone, yellowish-gray, fine to very fine grained, calcareous; abundant green-gray interstitial clay, abundant carbonaceous material	4

Part of the Chilson Member of the Lakota Formation and Unkpapa Sandstone in Buck Canyon in the SE¼ sec. 15, T. 8 S., R. 4 E.—Continued

	Thickness (feet)
Lakota Formation:—Continued	
Chilson Member (in part), unit 2:—Continued	
11. Claystone, brownish-gray, silty, hackly fractured; contains *Metacypris angularis* Peck, *Pseudocypridina inornata* (Peck), "*Candona*"? sp., "*Bairdiocypris*" sp	1
10. Mudstone, brownish-gray, silty; bedding irregular; contains *Metacypris persulcata* Peck, *Metacypris angularis* Peck, "*Candona*"? sp., "*Bairdiocypris*" sp., new genus E; rock is more resistant to weathering than unit above	3
9. Mudstone, olive-gray, calcareous, hackly fractured; contains *Clavator nodosus* Peck n. sp., *Pseudocypridina inornata* (Peck), *Cypridea longispina* Peck, *Metacypris persulcata* Peck, "*Bairdiocypris*" sp	8
8. Siltstone, white, in beds about 1 ft thick; upper 1½ ft is very fine grained calcareous sandstone that forms a prominent ledge	9
7. Siltstone, dark-brown and dark-gray; some gypsum and jarosite; contains *Metacypris* sp	5
6. Mudstone, olive-gray, hackly fractured; contains *Metacypris angularis* Peck, *Pseudocypridina inornata* (Peck), *Pseudocypridina* n. sp., new genus C, new genus D, distorted internal mold suggestive of *Amplovalvata* Yen	2
5. Sandstone, yellowish-gray, very fine grained; abundant interstitial material	1
4. Mudstone, olive-gray, silty; contains *Metacypris angularis* Peck, *Pseudocypridina inornata* (Peck), *Macrodentina*? sp., *Darwinulla* sp., new genus B	3
3. Sandstone and mudstone interbedded. Sandstone is yellowish-gray, very fine grained, forms thin ledges; mudstone is olive gray, silty	4
2. Mudstone, dark-brownish-gray, sandy; abundant carbonaceous material; contains *Metacypris angularis* Peck, *Pseudocypridina inornata* (Peck), *Pseudocypridina* n. sp., *Macrodentina*? sp., new genus A. new genus E	1
1. Mudstone, olive-gray, hackly fractured, unctuous; minor amounts of silt	16
Total measured thickness of unit 2, Chilson Member of the Lakota Formation	203
Unkpapa Sandstone:	
Mudstone and marl; mudstone is greenish gray and contains very fine sand grains; marl is very light gray and occurs as discontinuous beds as much as 3 ft thick	16
Sandstone, white to very light gray, very fine grained to silty, crossbedded, friable	27
Total measured thickness, Unkpapa Sandstone	43

Pale-greenish-gray or yellowish-gray mudstone, some of which is calcareous, forms part of unit 2 in the northern and eastern parts of the quadrangle. This rock is gradational with the interbedded sandstone and mudstone and is a lateral equivalent of the S_2 sandstone. The mudstone commonly contains beds of poorly sorted calcareous sandstone generally less than 10 feet thick. Sections of mudstones as much as 250 feet thick are found in upper Hell Canyon and upper Chilson Canyon. In Chilson Canyon in sec. 32, T. 8 S., R. 4 E., this mudstone overlies sandstone of unit 1 and grades laterally with the interbedded sandstone and mudstone in unit 2.

Some of the calcareous mudstone is fissile, but much is massive and weathers with a hackly fracture into roughly rectangular fragments. Ostracodes and fish bone fragments have been found in the mudstone. Carbonaceous material is locally abundant, and some of the material is petroliferous (samples 1, 8, 9, and 11, table 3). The results of semiquantitative spectrographic analyses of nine samples of this mudstone, siltstone, and claystone are given in table 2 (samples 1–2 and 7–13).

Interpretation of Environments

The general characteristics of the rocks in the Chilson Member of the Lakota Formation suggest that these rocks were deposited in an area of low relief by rivers flowing in broad channel systems. Extensive flood-plain lakes, swamps, and marshes bordered the river channels. The water flowing in the rivers was fresh and probably contained more than 30 ppm (parts per million) CaO. Vegetation was abundant in the swamps and lakes and along the rivers. The accumulation of abundant organic debris in swamps and lakes caused the water to be locally acidic. The climate was probably humid temperate to tropical.

The elongate belts of thick sandstone, the lenticular shape of individual beds, the numerous local unconformities, crossbeds, and intraformational conglomerates all suggest the fluviatile origin of the sandstones in units 1 and 2. It seems likely that sandstone bodies S_1 and S_2 were deposited by aggrading rivers. The interfingering of the sandstone with siltstone and mudstone indicates that these different rock types were deposited contemporaneously by the river in different locations. Braiding or meandering of the river caused scours that were usually filled with sand to form sandstone lenses. One of several such scours shown in figure 96 is of particular interest because it was not immediately filled with sand but persisted as a depression long enough for the parent material of a coal bed 55 inches thick to accumulate.

The red sandstone at the top of the Chilson Member probably represents a period of extensive subaerial oxidation and dehydration after the bulk of the Chilson rocks had been deposited. The increase of red and orange color and decrease in carbonaceous material in rocks of unit 2 give the impression that the oxidizing environment developed throughout unit 2 time and culminated during the time of deposition of the red sandstone.

The fauna and flora of the various mudstones of units 1 and 2 give an indication of the environmental conditions that existed during the deposition of the rocks of the Chilson Member. The laminated carbonaceous siltstone of unit 1 seems to have been deposited in an acid-reducing environment rich in carbon dioxide, hydrogen sulfide, and methane that allowed the preservation of much carbonaceous material and the formation and preservation of pyrite. I. G. Sohn of the U.S. Geological Survey has pointed out (written commun., 1958) that the many contorted ostracode carapaces in these rocks suggest the decalcification of the shell by sulfurous acid at the time of burial, leaving only a flexible chitinous carapace that is readily bent under the compressive stresses resulting from burial.

Isaura found in the carbonaceous siltstones of unit 1 and in some of the mudstones in unit 2 presumably lived in a continental environment similar to that in which they live today. Present-day forms of *Isaura* are found between the 20°C and 30°C isotherms in the circum-Mediterranean area, in inland basins such as those of the middle Danube River, the Nile Valley, and the great rift valley of East Africa (Kobayashi, 1954). Many *Isaura* are found in temporarily flooded shallow rice fields where the soil has a pH of from 4.5 to 7.5 (Mattox, 1954; Martin, 1957) and a redox potential commonly less than 0.2 volts (Sturgis, 1957).

Abundant immature ostracodes in various growth stages are found associated with mature shells, many of which are articulated, in unit 2 mudstones. This suggests that these fossils were deposited in quiet lakes in which there were no currents to winnow out the small from the large shells.

Charophytes are commonly associated with the ostracodes in calcareous mudstone. Charophytes, classified by some authorities as green algae, are represented today by types introduced during late Mesozoic time (Peck, 1957, p. 2). Modern types of charophytes live submerged in shallow, quiet or slowly moving bodies of fresh or brackish water. Chara have never lived in a typical marine environment.

Charophytes have been found by Olsen (1944) to live in brackish water in the Baltic Sea out to about the isohaline equal to 18 parts chloride per 1,000. This is about half the chlorinity of normal sea water. Olsen also stated that charophytes are most commonly found in alkaline waters; only five of 19 species he studied lived in water with a pH as low as 5, whereas none of the other 14 species lived in water of pH less than 6.1. The lower limit of CaO content of the water in which many of these charophytes lived is about 30 ppm. The charophytes probably were major contributors of calcium carbonate to the calcareous mudstones of the Chilson Member of the Lakota Formation. Twenhofel (1939, p. 332) cited evidence that the charophytes in Green Lake, Wis., deposit annually about 130 tons of calcium carbonate per square mile of the lake.

The gastropods and pelecypods are fresh-water forms. The fish found in the mudstone facies of the Chilson Member do not preclude a fresh-water environment. According to D. H. Dunkle of the U.S. Geological Survey (written commun., 1955), the fish genus *Lepidotus* probably contains more than 100 species identified from remains "found in all manner of aquatic environments (fresh to marine water) * * *."

MINNEWASTE LIMESTONE MEMBER

The Minnewaste Limestone Member of the Lakota Formation is typically a clean dense light-gray limestone containing local lenses of sandy gray calcareous mudstone. Where the limestone is thin, it is very sandy and brecciated, possibly as a result of nearshore wave action. The matrix of the breccia is lithologically identical to the breccia fragments. Minnewaste breccia at the mouth of Devil Canyon is partly cemented by chalcedony.

The thickness of the Minnewaste Limestone Member in this quadrangle is nowhere more than 5 feet, and locally it is no more than 1 foot. Where thickest, in the southwestern part of the quadrangle and in lower Chilson Canyon, the unit consists of either a single bed of sandy limestone 2–3 feet thick or two beds separated by a thin bed of sandy gray calcareous mudstone. The most extensive exposures of the Minnewaste are along the Cheyenne River in the southwestern and south-central parts of the quadrangle. The limestone is also exposed along the west side of the Cheyenne River just south of the mouth of Devil Canyon in the center of sec. 4, T. 9 S., R. 4 E., and near the mouth of Chilson Canyon in sec. 9, T. 9 S., R. 4 E. At the corner common to secs. 13, 14, 22, and 23, T. 8 S., R. 3 E., 1 foot of limestone assigned to the Minnewaste was observed in drill core. The Minnewaste along the Cheyenne River in sec. 12, T. 9 S., R. 3 E., has been locally removed by erosion preceding the deposition of overlying sandstone. Typical Minnewaste has not been recognized in sec. 7, T. 8 S., R. 4 E., but a thin hard calcareous mudstone may represent the member.

FUSON MEMBER

The Fuson Member of the Lakota Formation is widely distributed throughout the Flint Hill quadrangle, where it ranges in thickness from about 15 to nearly 125 feet but is commonly 70 feet thick. The Fuson consists predominantly of variegated mudstone, but in much of the quadrangle the mudstone has been partly or completely removed by erosion and replaced by channel sandstone S_4.

The basal contact of the Fuson Member with the underlying Minnewaste Limestone Member is readily discernible. The contact is difficult to locate, however, where the limestone is absent and the upper part of the Chilson Member consists of mudstone or interbedded sandstone and mudstone.

The top of the Fuson Member is defined as the disconformity that separates the Fall River and Lakota Formations. Laminated carbonaceous siltstone and very fine grained sandstone commonly compose the lowermost rock unit in the Fall River Formation. The Fuson Member has been locally scoured, however, and, in part of the quadrangle, channel sandstone S_5 in the middle unit of the Fall River Formation lies disconformably on the Fuson Member. The Fall River–Lakota contact is difficult to establish where Fall River sandstone S_5 rests on Fuson sandstone S_4, as in sec. 8, T. 8 S., R. 4 E.

At some places, such as near the mouth of Brady Canyon, where Fuson mudstone forms the uppermost unit of the Lakota Formation, the top 1–2 feet of the mudstone consists of very light gray to cream-colored claystone peppered with tiny manganosiderite pellets and light-brown rectangular grains suggestive of weathered pyrite. Waagé (1955, 1959) suggested that this interval represents a zone of weathering similar to a zone that he has recognized in equivalent rocks in Colorado and Wyoming. These manganosiderite pellets, locally characteristic of the upper part of the Lakota Formation in the Flint Hill quadrangle, have been noted in the subsurface east of the Black Hills where they have been used in correlating beds of Lower Cretaceous rocks (Baker, 1947; Gries, 1954).

The major part of the Fuson Member consists of mudstone characteristically different from the mudstone of the Chilson Member of the Lakota Formation. Fuson mudstone is commonly gray mottled with red, green, or brown; it contains much less silt than mudstone in the lower part of the Lakota, and is massive, plastic, and noncarbonaceous. Scattered polished well-rounded poorly spherical pebbles of pink quartzite and gray chert locally weather out of the mudstone and are characteristic of the Fuson Member.

Several types of sandstone occur interbedded with Fuson mudstone. The most common type, found in the upper part of the mudstone, is generally white, highly argillaceous, and massive, and it commonly contains small red spots of hematitic cement. The best exposures of sandstone of this type are in Deadhorse Canyon in sec. 15, T. 8 S., R. 3 E., and in sec. 13, T. 9 S., R. 3 E., near the Cheyenne River. Similar sandstones are present at the mouth of Chilson Canyon in the north-central part of sec. 16, T. 9 S., R. 4 E. They are too thin to be shown on plate 32, but they are illustrated in figure 99.

FIGURE 99.—Fuson and Fall River rocks at mouth of Chilson Canyon, sec. 16, T. 9 S., R. 4 E.; $Kfms_5$, channel sandstone S_5, Fall River Formation; Kflst, basal carbonaceous siltstone and sandstone of the Fall River Formation; D, disconformity; $Klfs_4$, channel sandstone S_4, of Fuson Member of Lakota Formation; Klfs, white, speckled with red, massive argillaceous sandstone of Fuson Member.

Thin calcareous ripple-bedded fine-grained yellowish-gray sandstone with streaks and lenses of clay parallel to the bedding is characteristic of the lower 15 feet of the Fuson. This sandstone, poorly exposed in most places, generally has a pock-marked surface resulting from differential weathering of the more argillaceous or less well-cemented parts.

Gray limestone concretions and some gray calcareous sandstone occur in the lower part of the Fuson Member in the extreme SW¼ sec. 20 and the NW¼ sec. 29, T. 8 S., R. 4 E., and on the north wall of Dick Canyon in sec. 28, T. 8 S., R. 4 E. A medium-gray conglomerate as much as 1 foot thick that consists of dense yellowish-gray limestone pebbles in a very calcareous sandstone matrix has been found locally near the base of the Fuson Member.

Ostracodes have been found in the calcareous rocks in the lower part of the Fuson Member. I. G. Sohn commented (written commun., 1955) that the ostracodes in these rocks differ from those in other collections from the Lakota Formation by containing a large smooth genus not typical of Lower Cretaceous rocks.

Unit 4

Unit 4 of the Fuson Member of the Lakota Formation comprises channel sandstone S_4 and local deposits of mudstone or interbedded sandstone and mudstone that overlie the S_4 sandstone. The S_4 sandstone has been traced in outcrop and in diamond-drill holes from the central part of the Cascade Springs quadrangle northwest to the south-central part of the Jewel Cave SW quadrangle (fig. 100). The S_4

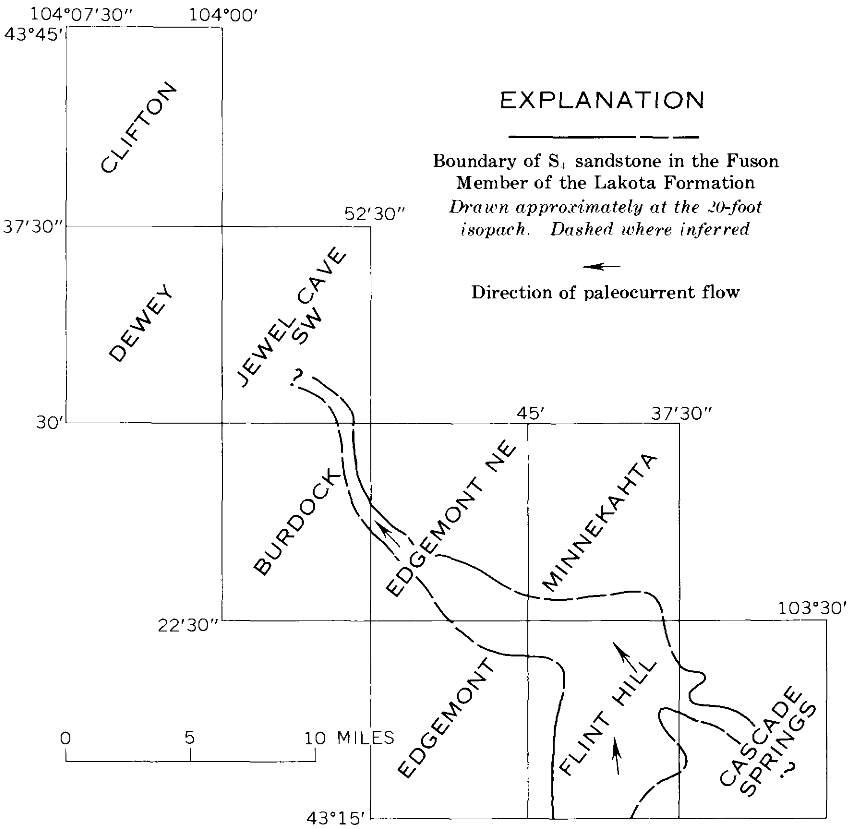

FIGURE 100.—Distribution of the S_4 sandstone of the Fuson Member of the Lakota Formation in the southwestern Black Hills.

sandstone ranges in thickness from 0 to 165 feet. The sandstone is thickest and most widespread in the Flint Hill quadrangle, where it fills a northwest-trending channel cut into and locally through the underlying mudstones of the Fuson Member (fig. 101). The marked disconformity at the base of the S_4 sandstone can be noted at several place (pl. 32). One of the best exposures of the disconformity is at the mouth of Devil Canyon in sec. 4, T. 9 S., R. 4 E. The S_4 standstone rests on the S_2 sandstone of the Chilson Member in the cliff on the north side of the canyon, where the following section was measured, but 1,100 feet to the southwest across the canyon, it rests on mudstone of the Fuson Member (fig. 102).

Fall River Formation (part) and Lakota Formation, north wall at mouth of Devil Canyon, sec. 4, T. 9 S., R. 4 E.

[Measured by Henry Bell and E. V. Post]

	Thickness (feet)
Fall River Formation (in part):	
S_5 sandstone; weathers orange brown; coarse grained at base grading upward to fine grained; contains white to pale-yellowish-white clay fragments and zones of abundant clay pebbles along basal contact. Overlying covered slopes and poorly exposed thin sandstone units not measured	36
Siltstone, light-gray to purplish-gray; mottled at base with light-brown iron stain; laminated; covered with efflorescent salts; some botryoidal nodules of iron oxides	14
Thickness Fall River Formation measured	50
Lakota Formation:	
Fuson Member, unit 4:	
Sandstone, brown to light-brown, medium- to fine-grained; weathers brown to orange brown; sparse iron concretions, planar crossbedding	34
Interbedded sandstone and siltstone. Sandstone is pale light-brown and brown, individual laminae, very fine to coarse grained, each lamina well sorted; siltstone pale gray, fissile to massive, most beds less than 0.5 ft thick. Unit iron stained at top and truncated by overlying sandstone	9.8
Sandstone, light-brown, medium- to coarse-grained; conglomerate at base contains quartz and clay pebbles; planar crossbedding. Much iron stain in basal part, especially where conglomeratic	121.2
Chilson Member, unit 2:	
Sandstone, pale-brown to white; weathers pale light gray with some light-brown mottling; very fine to fine-grained; in general well sorted, but contains zones of siltstone flakes and blebs; fairly well cemented; spherical iron concretions and light-brown iron stain irregularly parallel to bedding; contains some greenish-gray fissile mudstone a short distance east; crossbedded	40.6

Fall River Formation (part) and Lakota Formation, north wall at mouth of Devil Canyon, sec. 4, T. 9 S., R. 4 E.—Continued

	Thickness (feet)
Lakota Formation—Continued	
Chilson Member, unit 2—Continued	
Sandstone, pale-brown; weathers pale light gray; fine grained, a few thin units of fine-to medium-grained very friable sandstone containing siltstone pebbles and cobbles; sandstone contains a few white weathered feldspar grains; crossbeds indistinct	70.3
Talus covered; scattered poor exposures suggest greenish-gray sandy siltstone and dark-greenish-gray to greenish-brown fissile mudstone	11.8
Sandstone, pale-light-brown; weathers pale gray and light-brown; very fine to fine grained; numerous thin beds of siltstone and mudstone, particularly near top and bottom; siltstone pebble conglomerate along diastems and bedding planes; sandstone friable, cementation uneven; iron concretions, especially near top of unit; brown iron stain along bedding planes. Bed of siltstone 2 ft thick at base separates this unit from sandstone below; planar and high-angle crossbeds	40.5
Sandstone, pale-light-brown; weathers light-brown; very fine grained; contains small brown limonitic spots; stratified with irregular laminated pink to gray siltstone along bedding planes	33.2
Talus covered; probably mudstone similar to unit below	9.7
Mudstone, greenish-gray, some brownish-gray; fissile; some thin beds of very sandy mudstone; some carbonaceous material with light-brown iron stain, and thin films of gypsum near bottom	38.5
Sandstone and mudstone, alternating and gradational; sandstone very fine grained, mudstone pale brown to pale greenish gray. Sandstone contains *Bairdiocypris* aff. *B. morrisonensis*, *Pseudocypridina inornata* (Peck), *Metacypris* sp., *Metacypris persulcata* Peck, *Pseudocypridina* sp., fishbone fragments	13.6
Mudstone, brownish-green to greenish-gray; weathers greenish gray; sandy; sharp contact with unit below, gradational with sandstone above; sparse carbonaceous material; contains *Metacypris persulcata* Peck *Pseudocypridina inornata* (Peck); yields petroliferous distillate	10.7
Chilson Member, unit 1:	
Mudstone, brown to pale-greenish-gray; very fine grained sandstone at top contains considerable interstitial mudstone. Unit is well cemented and hard; near base it contains abundant ostracodes	4.9
Sandstone and mudstone interbedded. Sandstone is pale brown to white, weathers pale brown, very fine grained to silty. Mudstone is greenish gray to brownish green	7.4
Total thickness Lakota Formation	446.2
Unkpapa Sandstone (in part):	
Sandstone, white, grades to pale brown near top; weathers light gray to light brown; very fine grained to silty; well sorted; calcareous, but very friable; forms massive rounded ledge	15

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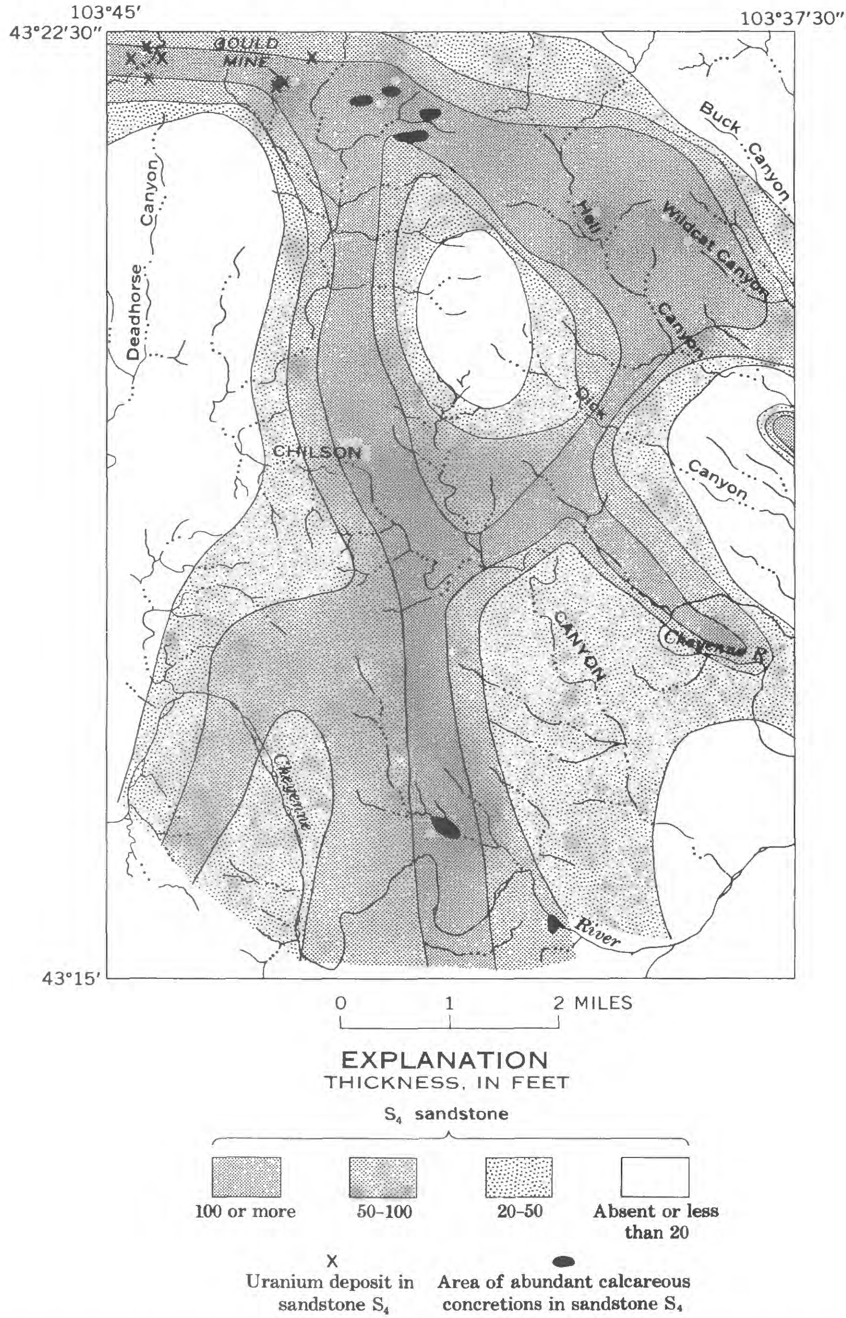


FIGURE 101.—Approximate thickness of the S_4 sandstone of the Fuson Member of the Lakota Formation and areas in which it contains abundant calcareous concretions in the Flint Hill quadrangle.

The S_4 sandstone commonly ranges from pale to dark yellowish orange, locally becoming various shades of brown near the base as a result of the concentration of iron oxides. The rock is fine to coarse grained. In many places there are beds or lenses of pebble conglomerate in which the pebbles are as much as 1 inch in diameter and consist predominantly of chert with some quartz and silicified fossiliferous limestone. The pebbles occur in a medium- to coarse-grained sandstone matrix and are not in contact with one another. Fossils identified in the pebbles of this conglomerate by Helen Duncan and L. G. Henbest of the U.S. Geological Survey include fenestellid and fistuliporoid bryozoans, and possible sponge spicules, as well as the fusulinids *Millerella*(?) sp., and "*Nankinella*" *plummeri* Thompson which are probably of Pennsylvanian age.

These pebbles suggest that exposed Pennsylvanian rocks in the source areas contributed detritus to the Lakota sediments. Pennsylvanian rocks containing similar fossils to those in the pebbles are present in the Bighorn Mountains and the Laramie and Hartville uplifts of Wyoming and in the Black Hills at Loring Siding, about 15 miles north of the Flint Hill quadrangle. These areas are unlikely sources for the sediments of the Lakota Formation, for sedimentary structures indicate that Lakota rocks were derived from the southeast. Pennsylvanian rocks of equivalent age are also present in the subsurface in Nebraska and Kansas, a more probable source for the sediment forming rocks of the Inyan Kara Group.

Where the prominent conglomeratic beds are absent, S_4 is commonly characterized by streaks of very coarse grained sandstone along cross-laminae and especially along the base of sandstone lenses and at the base of the unit.

Although pebble conglomerate is conspicuous and characteristic of the unit, much of the S_4 sandstone is better sorted and contains less interstitial material than sandstones in the lower part of the Lakota Formation. Three histograms representative of the grain-size distribution of S_4 are shown in figure 97. These suggest that the sorting characteristics of S_4 resemble more closely those sandstones of the Fall River Formation than the sandstones in the Chilson Member of the Lakota Formation.

Thin sections of the S_4 sandstone show that the rock consists primarily of subangular to subrounded quartz grains, with less than 5 percent chert grains. Many of the quartz grains show undulatory extinction; some granules are composites of two or three quartz crystals separated by thin zones of crushed quartz (mortar structure); many of the grains have partial oriented secondary overgrowths that appear to have been partly worn away by abrasion subsequent to their forma-

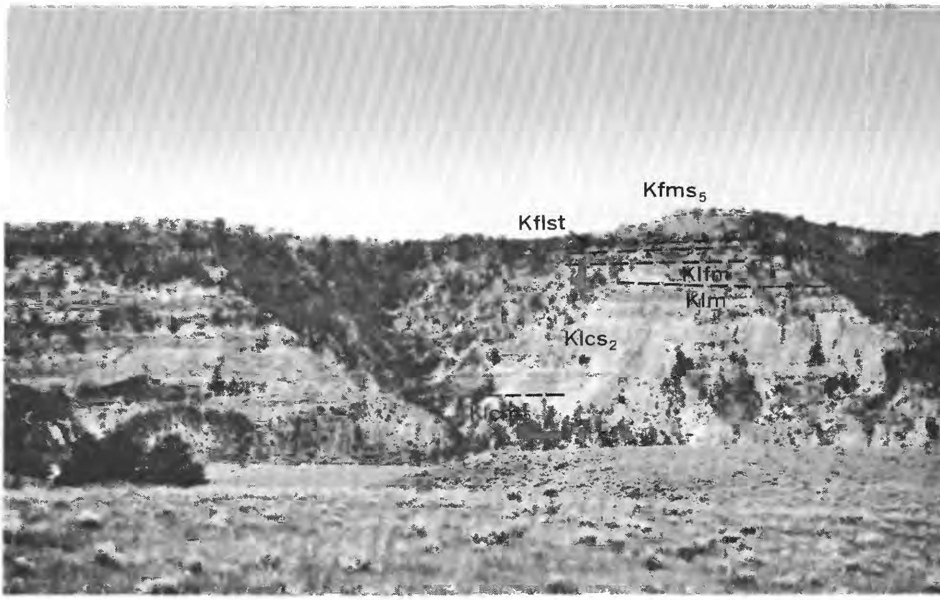


FIGURE 102.—Section of Inyan Kara Group exposed at mouth of Devil Canyon showing scour filled by S_4 sandstone cut through Fuson and Minnewaste Limestone Members and into Chilson Member of Lakota Formation. Klcm$_2$, mudstone of unit 12, Chilson Member; Klcs$_2$, S_2 sandstone of unit 2, Chilson Member, with thin Minnewaste Limestone Member (Klm)

tion. A few quartz grains contain inclusions of zircon. These features suggest that S_4 is a multicycle sandstone originally derived from a metamorphic terrane and brought to the Black Hills from Pennsylvanian rocks of an earlier sedimentary cycle.

Heavy minerals separated from the S_4 sandstone at the Gould mine (east-central part of sec. 11, T. 8 S., R. 3 E.) by N. P. Cuppels consist predominantly of zircon with lesser amounts of olive-brown tourmaline. Mapel, Chisholm, and Bergenback (1964) have found these heavy minerals in Lakota sandstones throughout the western Black Hills.

Locally, sandstone S_4 includes beds of sedimentary breccia consisting of angular fragments of claystone or siltstone in a matrix of medium- to coarse-grained sandstone. Particularly good exposures of a breccia of this type are found in the Gould mine.

Cuppels (1962, pp. 67–69) reported that the sedimentary breccia at the Gould mine is part of the fill in an irregular scour cut into fine-grained sandstone comprising the major part of the S_4 sandstone. The lowermost part of the fill is a chert pebble conglomerate consisting of pebbles as much as one-half inch in diameter in a matrix of poorly sorted coarse-grained sandstone. This conglomerate grades upward into and forms the matrix of the sedimentary breccia. The breccia fragments are light-gray to white claystone and clayey siltstone rang-

at top to left of Devil Canyon; Klfm, mudstone of Fuson Member; Klfs$_4$, S_4 sandstone of unit 4, Fuson Member; Kflst, carbonaceous siltstone of lower unit of Fall River Formation; Kfms$_5$, S_5 sandstone of middle unit of Fall River Formation.

ing from one-fourth inch to 10 feet in greatest dimension. The breccia unit pinches and swells, rarely exceeding 12 feet in thickness. It was probably formed as a result of the slumping, brecciation, and reworking of a nearby mudstone bed that formed part of the S_4 channel complex.

Calcite cement is locally abundant in S_4 sandstone, commonly forming spherical concretions less than 6 inches in diameter that tend to coalesce and form areas of tightly cemented sandstone (pl. 32, fig. 101). In some of these areas, calcite cements joints, and the material filling the joints appears to be identical with material forming the concretion.

Iron oxide stain and cement is common, particularly at the base of the S_4 sandstone and along joints. Areas of intense iron stain have been noted in the Gould mine adjacent to prominent joints. Large fragments in the iron-stained sedimentary breccia commonly have unstained centers.

The S_4 sandstone consists of many separate lenses of sandstone that overlap and truncate adjacent lenses, and is, in this way, similar to most of the thick sandstone units in the Inyan Kara Group. The sandstone is commonly cross-stratified within these lenses as shown in figure 103. Sets of cross-strata 6 inches to 4 feet thick consist of alternating coarse- and fine-grained laminae that dip steeply, predominantly in

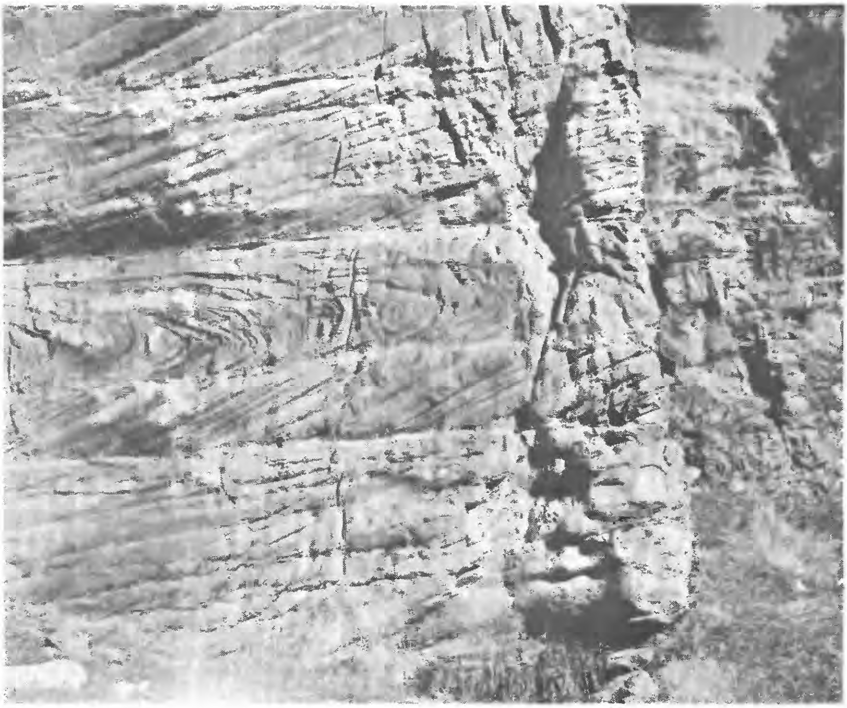


FIGURE 103.—Cross-stratification characteristic of the S_4 sandstone, Lakota Formation, Fall River County, S. Dak.

a northwesterly direction. These sets are separated by planar laminae. This particular type of cross-stratification is characteristic of the S_4 sandstone, although it is locally found in the other sandstone units of the Inyan Kara Group.

Cross-lamination of this sort was produced by McKee (1957) during experiments with a delta tank by repeatedly raising the water level of a nonturbulent stream that carried a constant load and flowed at a slow but constant velocity.

Some of the cross-strata shown in figure 103 are overturned, probably as a result of drag by masses of saturated sand moved by flood waters (McKee and others, 1962).

Mudstone with local interbedded sandstone has been mapped at the top of the S_4 channel sandstone in a few places such as at the mouth of Brady Canyon and in the northwest corner of the quadrangle. These rocks are believed to represent the final deposits in a filled river channel.

FALL RIVER FORMATION

Several distinct lithologic characteristics of the Fall River Formation serve to differentiate it from the Lakota Formation, although, in general, both formations consist of thick cliff-forming sandstones and various types of mudstone.

The thick sandstone units of the Fall River generally are the most continuous and uniform in texture and structure of any in the Inyan Kara Group. They characteristically weather to a darker, more orange-brown color than the sandstones of the Lakota. The mudstones of the Fall River differ from those of the Lakota in being more uniformly silty, more highly carbonaceous, and rarely calcareous. No ostracodes have been found in Fall River mudstones, and fossils other than poorly preserved plant remains are rare. Fall River rocks are also characterized by significant quantities of muscovite, a mineral that is scarce or lacking in the Lakota.

The thick cliff-forming sandstones of the Fall River Formation, like the fluviatile sandstones of the Chilson Member of the Lakota Formation, have lateral fine-grained equivalents which are dominantly siltstone or interbedded sandstone and siltstone.

Throughout the southern Black Hills, the Fall River Formation can be divided into lower, middle, and upper units. The lower unit in the Flint Hill quadrangle consists principally of laminated carbonaceous siltstone or interbedded carbonaceous siltstone and thin-bedded sandstone. Mudstone and interbedded sandstone and mudstone have been mapped in a few places. The middle unit is most varied, and includes the cliff-forming S_5 sandstone of probable fluviatile origin, as well as mudstone, interbedded sandstone and mudstone, and siltstone. The upper unit of the Fall River Formation consists principally of variegated mudstone, the S_6 sandstone, and locally siltstone or interbedded sandstone and mudstone.

A composite stratigraphic section of the Fall River Formation in Sheep Canyon is given in figure 104. This section is representative of areas in the west-central and southwestern parts of the Flint Hill quadrangle in which both the S_5 and S_6 sandstones are well developed.

LOWER UNIT

The principal rock types in the lower unit of the Fall River Formation are laminated carbonaceous siltstone or interbedded carbonaceous siltstone and thin-bedded sandstone.

The most prominent and most widespread rock type in the lower unit of the Fall River is laminated carbonaceous siltstone (fig. 104). The siltstone is the lowermost rock unit in the Fall River Formation, except where it has been locally removed by scouring and replaced by the S_5 sandstone.

Such scouring has completely removed the carbonaceous siltstone unit in the northern part of sec. 8, T. 8 S., R. 4 E. In this area, the

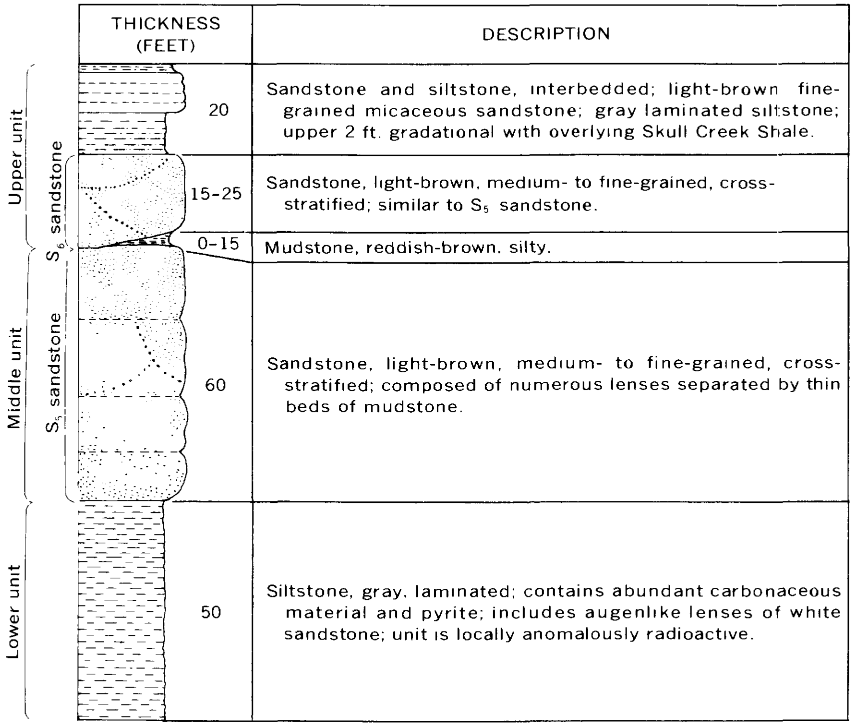


FIGURE 104.—Composite section of the Fall River Formation, Sheep Canyon, sec. 27, T. 8 S., R. 3 E.

S_5 sandstone rests directly on the S_4 sandstone of the Lakota Formation, and the Fall River–Lakota contact is difficult to map. In other areas, variations in the thickness of the carbonaceous siltstone are probably the result of partial scouring of the unit by streams that subsequently deposited the S_5 sandstone. In the Deadhorse Canyon area, in Sheep Canyon, and along the Cheyenne River in secs. 4 and 9, T. 9 S., R. 4 E., it is impossible to show the thin remnants of the carbonaceous siltstone at the scale of the geologic map. In much of the Flint Hill quadrangle, however, the basal carbonaceous siltstone is about 50 feet thick.

Two contrasting facies of the carbonaceous siltstone are found in the Flint Hill quadrangle, but they have not been mapped separately. The most widespread and typical facies consists of gray, irregularly laminated siltstone, with interstratified lenses of thin white or pale-brown sandstone that resemble the augen common in some metamorphic rocks. These sandstone lenses are commonly about one-half inch thick and 3–4 inches long. The unit weathers to a tough yellowish-gray rock with a distinctly rounded or mammillary surface. The siltstone is predominantly quartzose, but contains significant amounts of very finely divided carbonaceous material and scattered flakes of fine white mica along the bedding planes.

Pyritic concretions, which decompose to stain the outcrop brown and produce efflorescent salts, are common in thin very fine grained sandstone or light-colored siltstone beds. The concretions are irregular ellipsoids generally less than 6 inches long, consisting of very fine grained pyrite that fills the interstices between the sand or silt grains. Spectrographic analyses of two concretions from this unit are given in table 4.

TABLE 4.—*Results of spectrographic analysis, mineral determination by X-ray diffraction, and selenium analysis of two pyrite nodules from carbonaceous siltstone in the Fall River Formation*

Percent	Elements detected [1]		Normal abundance in earth's crust [2]
	Sample HB-53	Sample HB-25-55	
Over 10	Fe	Fe	Si
5–10			Al, Fe
1–5	Si	Si	Mg
0.5–1	Al		
0.1–0.5			Mn, Ti
0.05–0.1	Zn, Cu	Ti	
0.01–0.05	Mn, Ti, Mg, Zr	Zn	Zr, Ba, Ni, Cr
0.005–0.01		Cu, Mn, Ni, Al, Zr, Mg	Cu, Zn
0.001–0.005	Ba, Mo, Ni, Pb, Y	Co, Pb, Ba, Mo	Pb, Y, Co
0.0005–0.001	Cr	Sc	
0.0001–0.0005		Cr	Mo, Ag, Sc
0.00005–0.0001	Ag		
0.00001–0.00005			
Mineral determination by X-ray diffraction	Pyrite and quartz	Pyrite and quartz	
Percent selenium in pyrite concentrate	0. 0007	0. 0008	

[1] Results reported by R. G. Coleman, U.S. Geological Survey (written commun., 1956) and by Coleman and Delevaux (1957, p. 520, Nos. 204 and 207).
[2] Goldschmidt (1954, p. 74).

These analyses indicate that copper, zinc, molybdenum, and possibly scandium, in addition to iron, have been preferentially concentrated in the pyritic concretions in amounts exceeding the average abundance of these elements in the crust of the earth (Goldschmidt, 1954, p. 74). Most of these elements behave like copper, which, according to Goldschmidt (1954, p. 185), "can be highly concentrated by accumulation under reducing conditions in sulphide-bearing mud from stagnant anaerobic bottom waters * * *." Molybdenum and, to a certain extent, scandium are concentrated in forest litter and thus may have been derived to some degree from the organic material in these rocks.

The less typical and less widespread facies of the carbonaceous siltstone does not contain the augenlike sandstone lenses, and the outcrop does not weather to a tough rounded surface. In some areas, particularly in the small south-trending canyon in sec. 23, T. 8 S., R. 3 E., this facies of the siltstone contains numerous discontinuous beds of very fine grained sandstone, generally less than 5 feet thick, and some thin beds of gray argillaceous mudstone.

The outcrop of the siltstone unit in the areas where it includes numerous thin sandstone beds is very rough because the sandstone beds are more resistant than the siltstone. The thin sandstone beds are iron stained on the upper surface, ripple marked, and commonly covered with "worm tracks." The ripple marks are irregular in orientation; some are curved, and some are interference ripples or "tadpole nests." The ripple marks have wavelengths that range from 2½ to 5 inches and amplitudes that range from about ⅕ to ½ inch. Many appear symmetrical with sharp crests, but others are flat topped. Small rounded meandering ridges considered to be "worm tracks" commonly occur on the surfaces of thin iron-stained beds, and in many places they are superimposed on the ripple marks. The ripple marks and "worm tracks" probably were formed in shallow water.

Siltstone of this type has a high radioactivity background, and it has been prospected for uranium deposits in several places in the southern Black Hills. The radioactivity is most marked in the upper few feet of the unit, commonly at the contact with the overlying S_5 sandstone. Several uranium ore deposits have been mined from rocks of this unit in the Edgemont NE quadrangle.

The basal carbonaceous siltstone is difficult to identify in parts of the Flint Hill quadrangle where the lower unit is overlain by interbedded sandstone and mudstone and where thick S_5 sandstone is absent. The two units have been mapped together as the basal carbonaceous siltstone unit in the northwestern part of the quadrangle along the west side of Chilson Canyon from the NW¼ sec. 24, T. 8 S., R. 3 E., to sec. 11, T. 8 S., R. 3 E. Similarly, along the Cheyenne River in the south-central part of the quadrangle, the siltstone of the lower unit of the Fall River is difficult to separate from interbedded sandstone and mudstone of the middle unit, and they have been arbitrarily divided.

MIDDLE UNIT

The middle unit of the Fall River Formation comprises the S_5 sandstone as well as stratigraphically equivalent fine-grained rocks that have been mapped variously as interbedded sandstone and mudstone, mudstone, and siltstone. The S_5 sandstone commonly forms the outer hogback or cuesta surrounding the Black Hills, and where the hogback is cut by streams, the S_5 sandstone forms cliffs along the canyon walls. The S_5 sandstone generally lies disconformably on carbonaceous siltstone of the lower unit of the Fall River Formation. In places, such as sec. 8, T. 8 S., R. 4 E., and secs. 9 and 10, T. 9 S., R. 4 E., it rests on the underlying Lakota Formation filling a scour cut completely through the lower unit of the Fall River.

The thickness of the S_5 sandstone averages about 80 feet but changes abruptly from 100 feet or more to zero within a quarter of a mile. Where the sandstone thins abruptly, it fingers laterally into fine-grained rocks.

The S_5 sandstone generally is overlain by variegated mudstone of the upper unit of the Fall River, but locally the S_6 sandstone of the upper unit of the Fall River rests on S_5 sandstone.

Numerous cross-stratified lenses of sandstone commonly separated by beds of siltstone less than a foot thick make up the S_5 sandstone. The sandstone lenses are less than 50 feet thick, and range from a few tens of feet to several hundred feet in width. The cross-stratification consists of either sets up to 3 feet thick of high-angle cross-strata typical of the S_4 sandstone (fig. 103), or thick sets of long gently dipping planar strata.

The beds of siltstone that separate sandstone lenses have been broken up in some places to form discontinuous beds of sedimentary breccia composed of siltstone fragments in a sandy matrix. These breccia beds apparently represent the churned-up remains of mudstone layers that were deposited by the river during periods of slack water.

The S_5 sandstone is light brown to dark yellowish orange, fine grained, well sorted, and predominantly quartzose with less than 5 percent of chert grains and minor quantities of vein quartz and chalcedony. Quartz grains in this sandstone exhibit undulatory extinction, appear to have fewer secondary overgrowths of silica, and appear to be less well rounded than the grains in sandstones from the Lakota Formation. The S_5 sandstone contains more conspicuous heavy minerals than the sandstones of the Lakota Formation; the dominant varieties are euhedral to subhedral zircon and well-rounded brown tourmaline.

Figure 97 shows three histograms representative of the grain size distribution of sandstone from this unit. In general, the S_5 sandstone is better sorted and has a slightly greater median grain size than the S_1 and S_2 sandstone of the Chilson Member of the Lakota Formation.

The S_5 sandstone generally lacks much cement or clay matrix, but there are a few limited areas of abundant calcareous, siliceous, or ferruginous cement. Cements of these types appear to be most common where the S_5 sandstone is less than half its maximum thickness. Siliceous cement is commonly confined to individual beds 10 feet or less thick. The cement is uniformly distributed in a given bed, and the sandstone breaks with a conchoidal fracture through the sand grains. A thin section of the silicified S_5 sandstone from the northwest corner of the quadrangle in sec. 10, T. 8 S., R. 3 E., shows that the quartz and chert grains are cemented by a chalcedonic cement that corrodes the borders of the grains. The chalcedony fibers are oriented normal to the grain boundaries and frequently do not completely fill the pore space, resulting in drusy voids between grains. Patches of silicified sandstone now hold up some of the more prominent topographic high points in the quadrangle such as the knob in sec. 10, T. 8 S., R. 3 E., in the northwestern part of the quadrangle, certain knobs in secs. 7 and 8, T. 8 S., R. 4 E., and the high ground in the northern part of sec. 16, T. 8 S., R. 4 E.

Silica cement is in places associated with calcareous cement in a manner suggesting that the two types may be genetically related and in part controlled by joints. In sec. 7, T. 8 S., R. 4 E., a bed of sandstone broken by conspicuous vertical fractures is cemented by silica. Some of the fractures are partly cemented by calcite that appears to be later than the silica. Sandstone areas between the intensely silicified rock adjacent to the fractures are stained light brown by iron oxide and only lightly cemented by silica, which suggests that the iron oxide was removed from the silicified areas by the process of silicification.

Iron oxide cement is most common at the base of the S_5 sandstone. Much of the iron oxide occurs in the form of thin grain coatings, although in some places iron oxides have thoroughly impregnated the sandstone, forming an ironstone as much as a foot thick. In other places the iron oxides have completely replaced fragments of wood, retaining intact the cellular structure of the wood. Iron oxide concretions are common, and generally occur in groups in medium- or coarse-grained sandstone. They range in diameter from 1/4 to 5 inches, and in shape from rodlike to spherical. Liesegang bands of iron stain or cement commonly parallel joints and extend into the sandstone for several feet.

Calcareous cement is the least abundant type, and generally does not cement large areas of sandstone. It most commonly forms nodular concretionary masses, the nodules of which are generally less than 6 inches in diameter and concentrically banded, the alternating bands being respectively well cemented and poorly cemented. Some concretions are as much as 4 feet in diameter.

Some uranium deposits, especially those in the SW1/4 sec. 10, T 8 S., R 3 E., are associated with concretionary calcite cement in the

S_5 sandstone—an association that may prove valuable for prospecting purposes, as suggested by Gott (1956).

Interbedded sandstone and mudstone forms part of the middle unit of the Fall River Formation where thick S_5 sandstone is absent. This unit is lithologically similar to some of the basal carbonaceous siltstone unit of the Fall River Formation which contains numerous discontinuous sandstone beds and some argillaceous mudstone. It tends, however, to contain more of the argillaceous mudstone. Where extensions of the S_5 sandstone are not present or are not recognizable, the interbedded sandstone and mudstone unit is not easily separated from the basal siltstone unit. Along the Cheyenne River in the south-central part of the quadrangle the units have been arbitrarily divided. Along the west side of Chilson Canyon, however, the basal carbonaceous siltstone unit may contain some interbedded sandstone and mudstone referable to the middle unit of the Fall River Formation. These rocks in Chilson Canyon are generally poorly exposed, and form steep grass- and tree-covered slopes.

The sandstones of this interbedded unit are very different in character from the S_5 sandstone. They are generally less than a foot thick, although they may be as much as 10 feet thick. The sandstone beds are numerous in a given exposure, but extend only a few feet laterally. They commonly overlap one another like shingles on a roof. The thicker beds are either massive or cross-stratified with thin planar strata. The sandstone is light brown and fine grained. Beds less than a foot thick are commonly ripple marked and contain vertical tubes less than one-half inch in diameter generally filled with white clay and probably formed by worms or some other burrowing animal. Fine worm tubes or scolithes tubes also crisscross the ripple marks on the surfaces of the thin sandstones. A minor portion of the sequence is made up of argillaceous mudstone that is generally fissile and dark greenish gray or brown. Some thin beds of lignitic material are also found in this unit.

Gray silty mudstone that is locally carbonaceous forms the whole of the middle unit of the Fall River Formation on Flint Hill and Chilson Mountain. The S_5 sandstone is absent here. The mudstone on Flint Hill and Chilson Mountain grades upward into variegated mudstone of the upper unit of the Fall River Formation.

Siltstone has been mapped in the middle unit of the Fall River Formation in the southern part of the quadrangle. In places this includes some thin interbedded sandstones. The siltstone overlies the S_5 sandstone and is overlain by variegated mudstone of the upper unit. It apparently represents a more silty facies of the mudstone composing the middle unit on Flint Hill.

UPPER UNIT

Variegated silty mudstone (overlying the middle unit in fig. 104) forms a conspicuous part of the upper unit of the Fall River Formation throughout the southern Black Hills. This mudstone was originally used as a marker bed in the Edgemont NE quadrangle by G. B. Gott and R. W. Schnabel (written commun., 1958) and has since been correlated throughout the southern Black Hills by Gott and D. E. Wolcott (G. B. Gott, oral commun., 1964).

The mudstone is moderate reddish brown mottled with greenish gray, is noncarbonaceous, and is considered to be the lowermost part of the upper unit of the Fall River Formation. It rests on the S_5 sandstone or its fine-grained equivalents in the middle unit and is overlain by S_6 sandstone. In much of the quadrangle the mudstone is about 20 feet thick, but in sec. 23, T. 8 S., R. 3 E., it is as much as 40 feet thick. The varied thickness is apparently due to scouring that preceded the deposition of the overlying S_6 sandstone. In the Sheep Canyon–Deadhorse Canyon area, remnants of the variegated mudstone are preserved between sandstones S_5 and S_6 where scouring was not complete. The mudstone is too thin to be shown at the scale of plate 32 in several places in the east-central part of the quadrangle, especially where the relief is great.

Imprints of deciduous leaves are the only fossils found in this mudstone. These were found in a highly ferruginous silty layer near the base of the variegated mudstone in sec. 23, T. 8 S., R. 3 E.

Sandstone S_6 (fig. 104) is the uppermost prominent sandstone in the Inyan Kara Group. This sandstone resembles the S_5 sandstone in color, texture, structure, and cementation, but it is generally thinner, averaging 20 feet or less. Its maximum thickness of 60 feet is attained in sec. 27, T. 8 S., R. 4 E. Slabby sandstone at the top of S_6 is more micaceous than the other sandstones of the Inyan Kara Group. The S_6 sandstone commonly rests on the variegated mudstone described above, but locally lies on the S_5 sandstone. In many places the S_6 sandstone is the uppermost rock unit of the Inyan Kara Group, but it is overlain by laminated carbonaceous siltstone in sec. 15, T. 9 S., R. 4 E., in the southeastern part of the quadrangle.

In some places a thin unit of siltstone or interbedded sandstone and siltstone conformably overlies the S_6 sandstone. These rocks are generally too thin to map, but in sec. 15, T. 9 S., R. 4 E., in the southeastern part of the quadrangle, they are about 20 feet thick. They are lithologically similar to other siltstones or interbedded sandstones and siltstones in the Fall River Formation. They grade upward into the Skull Creek Shale.

DESCRIPTIONS OF DIAMOND-DRILL CORES OF INYAN KARA GROUP

Two diamond-drill cores of the Inyan Kara Group are described below. The holes were drilled in secs. 11 and 14, T. 8 S., R. 3 E., by the U.S. Atomic Energy Commission. The logs of these holes show the complex stratigraphy of the Inyan Kara Group, as well as the difference in the character of the unweathered rock from that exposed at the surface. Holes drilled deeper than 100 feet commonly cut rocks unaffected by weathering. These rocks contain much fresh pyrite, and many of the rocks are gray in contrast to the common red, yellow, and brown colors of weathered rocks.

Correlation of the various rock units from drill hole to drill hole is much more difficult than is correlation between outcrops which are at least partly connected by exposed rocks. Many of the sandstone units are similar in lithology, and the units of interbedded rocks are much alike. Pinchouts of rock units that result from scour and fill are less apparent in drill core than they are on the surface. Some beds that are cut in diamond-drill cores do not crop out. For these reasons the various units are easily confused and the relation of beds seen in drill core to rocks exposed on the surface is often obscure. For example, a sandstone bed about 100 feet thick in the lower part of the Lakota Formation was cut in drill core in the eastern part of sec. 11, T. 8 S., R. 3 E. Outcrops of this bed have not been recognized in the Flint Hill quadrangle, but the bed is shown in section *A–A′*, plate 32.

In general, correlations between drill cores and outcrops can safely be made in small areas close to outcrops that have been carefully mapped. Where drilling is done on a spacing of 1,000 feet or more, only rough groupings of rocks may be correlated with certainty.

Diamond-drill hole RE–14; SW¼ sec. 11, T. 8 S., R. 3 E.

[Collar elevation approximately 4,220 ft]

	Thickness (feet)	Depth (feet)
Fall River Formation (in part):		
Middle unit:		
No core recovered	10	10
S⁵ sandstone, light-gray to light-brown, fine to very fine grained; massive in upper half, some crossbedding and laminations in lower half; some iron stain and clay fragments	40	50
Mudstone, black; numerous very thin sandstone lenses; abundant carbon and pyrite	6	56
Sandstone, gray and dark-red, fine and very fine grained, silty, laminated	22	78
Mudstone and sandstone, very fine grained to silty. Mudstone is dark red; sandstone blue-green	13	91
Sandstone, light-reddish-brown, fine-grained, massive	7	98

Diamond-drill hole RE-14; SW¼ sec. 11, T. 8 S., R. 3 E.—Continued

	Thickness (feet)	*Depth (feet)*
Fall River Formation (in part)—Continued		
Lower unit:		
Siltstone, gray, grading to dark maroon: abundant iron stain	16	114
Thickness of Fall River Formation measured	114	
Lakota Formation:		
Fuson Member:		
Sandstone, gray with some light-brown; fine grained grading to medium grained; sparse crossbedding; abundant green interstitial clay; calcareous	26	140
Mudstone, silty, dark-gray and red, some purplish cast; sparse carbon in lower half	21	161
Sandstone, gray to yellow-brown, fine-grained, massive, soft, friable	18	179
Mudstone, pale-green, sparse carbon and pyrite	10	189
Sandstone, very light greenish gray, very fine grained, well-sorted, well-cemented; sparse interstitial white clay; becomes yellowish gray and fine grained below 195 ft; gradational with bed below	18	207
Mudstone, pale-yellowish-green to pale-yellowish-brown, sandy, friable; one bed very fine grained muddy sandstone	33	240
Sandstone, pale-olive, very fine grained; abundant interstitial clay; some beds of very sandy mudstone	16	256
Chilson Member, unit 2:		
Sandstone, pale-reddish-orange, very fine grained; streaked with pale green	2	258
Mudstone, light-gray	1	259
Sandstone, pale-grayish-orange-pink, very fine grained; contains carbonaceous trash	2	261
Claystone, becomes silty and grades into bed below, carbonaceous	3½	264½
Sandstone, yellowish-gray grading downward to reddish-yellow-orange; very fine grained, somewhat coarser in middle of bed	18	282½
Mudstone, medium- to dark-gray; fissile; sandy and carbonaceous; sparse clots of finely crystalline pyrite	6	288½
Sandstone, grayish-orange-pink to pale-grayish-orange, fine to very fine grained; top marked by thin hematite streak; some finely divided carbonaceous material, white clay grains, some mottled iron stain	20½	309
Mudstone, gray to green; sandy in upper part becoming less sandy below; calcareous from 314 to 331 ft; contains *Metacypris angularis* Peck, *Metacypris persulcata* Peck, "*Metacypris*" sp., *Pseudocypridina inornata* (Peck), *Pseudocypridina* n. sp. A, *Darwinulla* sp., gen. aff. "*Bythocypris*", new genus D, new genus F, *Isaura* sp., fragments of fish bones and scales	27	336

Diamond-drill hole RE-14; SW¼ cec. 11, T. 8 S., R. 3 E.—Continued

	Thickness (feet)	Depth (feet)
Lakota Formation—Continued		
Chilson Member, unit 2—Continued		
Sandstone, light-gray, fine to very fine grained; speckled with abundant black grains	8	344
Siltstone, dark-gray, carbonaceous; some dark-greenish-gray claystone; grades into bed below; between 345 and 351 ft contains *Metacypris angularis* Peck, *Metacypris persulcata* Peck "*Metacypris*" sp., *Pseudocypridina inornata* (Peck), *Pseudocypridina* n. sp. A, new genus F	23	367
Sandstone, light-gray, very fine grained; contains abundant black grains; below 370 ft grades to fine-grained grayish-orange-pink sandstone with white clay grains	46	413
Mudstone, dark-gray, silty, laminated; splits into irregular plates	1	414
Sandstone, light-gray, fine to very fine grained; silty, with some light-greenish-gray clay fragments; calcareous at base	5	419
Mudstone, medium-light-gray to dark-gray, some olive-gray; sandy; some thin fine-grained medium- to light-gray carbonaceous sandstone; somewhat fissile	35	454
Sandstone, pale-grayish-orange-pink, fine-grained, well-indurated; plant remains replaced by hematite	2½	456½
Siltstone, dark-brownish-gray; irregularly laminated; abundant carbonaceous material	15½	472
Chilson Member, unit 1:		
Sandstone, light-red, fine-grained; color derived from clots of interstitial red and white clay; color changes abruptly to yellowish orange at 480 ft, changes at 489 ft to pale red similar to upper part of bed; texture remains unchanged throughout bed	19	491
Siltstone, medium-gray	1½	492½
Sandstone, light-gray to pale-yellowish-gray; very fine grained to silt; concentrations of carbonaceous material along bedding planes, 5 thin beds of carbonaceous mudstone	12½	505
Mudstone, light-gray to dark-brownish-gray; irregularly laminated; carbonaceous; abrupt textural and color changes	5	510
Sandstone, very pale orange to very light gray, fine-grained; local concentrations of carbonaceous material along bedding planes; 2 beds 1½–2 ft thick of dark-brownish-gray carbonaceous mudstone	13	523
Thickness of Lakota Formation	409	
Morrison Formation:		
Claystone, mottled pale-yellowish-green and pale-red, dense, calcareous, subconchoidal fracture, friable, sparse pyrite crystals	4	527
Thickness of Morrison Formation measured	4	

Diamond-drill hole RE–17, SW¼SW¼ sec. 14, T. 8 S., R. 3 E.

[Collar elevation approximately 4,040 ft]

	Thickness (feet)	Depth (feet)
Fall River Formation (in part):		
Upper unit:		
No core recovered	10	10
S_6 sandstone, very pale orange, fine to very fine grained, massive; lower foot crossbedded, base marked by heavy hematite stain and gypsum seam; parallel bedding	4	14
Siltstone, moderate-yellowish-gray, much very fine grained sandstone, micaceous; some jarosite; poor core recovery	8½	22½
Middle unit:		
S_5 sandstone, yellowish-gray, fine-grained, micaceous, well-cemented; below 70 ft dark yellowish-orange to moderate yellowish orange and friable	66½	89
Mudstone, grayish-black, irregularly fissile; grades downward to light-gray laminated mudstone with very fine grained pinkish sandstone	5	94
Sandstone; dark reddish orange at top, yellowish gray below; fine to very fine grained; white clay grains abundant; bed of gray silty carbonaceous mudstone 1 ft thick at 105 ft; grades to bed below	17	111
Lower unit:		
Siltstone, very dark gray grading to medium-light-gray; carbonaceous; fissile at top, massive below; scattered small streaks and particles of hematite in more massive part; below 116 ft grades into very fine grained silty sandstone with less carbonaceous matter	8	119
Thickness of Fall River Formation measured	119	
Lakota Formation:		
Fuson Member:		
Sandstone, yellowish-gray, medium- to fine-grained; sparse white clay grains, some thin gray siltstone lenses at base	6	125
Sandstone, white and moderate-reddish-orange, mottled, fine-grained, friable; abundant white interstitial clay	2	127
Sandstone, moderate-red to moderate-reddish-brown, fine to very fine grained, well-indurated; abundant interstitial material	2	129
Mudstone; light gray and greenish gray with some pale-yellowish-red and grayish-red mottling between 165 and 168 ft; micaceous in upper half; grades to light-greenish-gray very fine grained sandstone with abundant pyrite	67	196
Sandstone, light-greenish-gray; very fine grained grading to fine grained at base, some white interstitial clay, some calcareous zones	14	210
Mudstone, medium- to dark-gray, sandy, calcareous	9	219
Minnewaste Limestone Member:		
Limestone, light-olive-gray, dense; some fractures filled with clear calcite crystals	1	220

Diamond-drill hole RE-17, SW¼SW¼ sec. 14, T. 8 S., R. 3.—Continued

	Thickness (feet)	*Depth (feet)*
Lakota Formation—Continued		
Chilson Member, unit 2:		
Sandstone, light-greenish-gray, very fine grained, calcareous, firmly cemented	7	227
Mudstone, greenish-gray, sandy	17	244
Sandstone, light-olive-gray, very fine grained; grades to underlying mudstone	4	248
Mudstone, pale-olive to medium-light-gray; sandy and pyritic; calcareous interval from 265 to 269 ft contains *Metacypris persulcata* Peck, *Metacypris angularis* Peck, *Pseudocypridina inornata* (Peck), *Cypridea* cf. *C. wyomingensis* Jones, "*Candona*"? sp. A., new genus C, new genus D, new genus F, and internal mold of gastropod that suggests Lioplacodes	23½	271½
Sandstone, light-gray, fine to very fine grained, well-cemented; becomes more argillaceous and carbonaceous downward	5½	277
Mudstone, medium-brownish-gray, sandy; calcareous part contains *Metacypris persulcata* Peck, *Metacypris angularis* Peck, *Pseudocypridina inornata* (Peck), new genus D	2	279
Sandstone, light-gray, very fine grained, well-cemented	3	282
Mudstone and sandstone interbedded; mudstone is dark olive-gray, carbonaceous, pyritic and fissile; at 283 ft contains *Isaura* sp. and ganoid fish scales; at 283½ ft contains *Metacypris angularis* Peck, new genus F; at 289½ ft contains *Metacypris persulcata*P eck, *Pseudocypridina inornata* (Peck), new genus F; sandstone is light gray and very fine grained and in beds 1–4½ ft thick at 284½, 287, 293½, 300, 305½, and 307½ ft; some beds are calcareous and carbonaceous	35	317
Chilson Member, unit 1:		
Sandstone, light-gray, very fine to fine-grained, firmly cemented; white clay grains and carbonaceous material; dark-gray mudstone bed 2 ft thick at 323½ ft; medium-light-gray mudstone bed at 370 ft	59	376
Siltstone, medium-gray to medium-light-gray, laminated; some light-gray very fine grained sandstone in beds less than 6 in. thick; carbonaceous material at base	17	393
Sandstone, light-gray, very fine to fine-grained; top marked by zone of hematite stain 1 in. thick; intensity of stain decreases downward from overlying bed; below 395 ft sandstone mottled moderate orange pink and light gray with some patches of pale-yellowish-green clay cement; bed of medium-gray mudstone 1 ft thick at 459 ft; medium-gray laminated carbonaceous siltstone ½-ft thick at 465 ft; 1 ft of calcareous well-cemented sandstone at base	86	479
Mudstone, medium-gray to dark-gray, fissile; some is silty and irregularly laminated	22	501

Diamond-drill hole RE-17, SW¼SW¼ sec. 14, T. 8 S., R. 3 E.—Continued

	Thickness (feet)	*Depth (feet)*
Lakota Formation—Continued		
Chilson Member, unit 1—Continued		
Sandstone, moderate-pinkish-gray to light-gray; lowest 10 ft moderate orange pink; very fine to fine grained; some thin carbonaceous seams; 4 dark-gray mudstone beds less than 2 ft thick; sandstone above mudstone beds commonly calcareous	51	552
Sandstone, moderate-pinkish-gray, very fine to fine-grained; similar to sandstone above, with some carbonaceous seams, mudstone beds, and pyrite; calcareous cement at base	5	557
Thickness of Lakota Formation	438	
Morrison Formation:		
Mudstone, greenish-gray, dense, calcareous; some pyrite	4	561
Thickness of Morrison Formation measured	4	

SKULL CREEK SHALE

The Skull Creek Shale is present only in the southern part of the Flint Hill quadrangle, where there are good exposures along the Cheyenne River. The Skull Creek Shale conformably overlies the Fall River Formation, and is about 250 feet thick. The lowermost rocks in the formation are a thin sequence of interbedded dark shale and laminated sandstone and siltstone gradational with the underlying Fall River Formation. The Skull Creek is dominantly dark-gray to black fissile marine shale characterized by red silty ferruginous concretions and elliptical cone-in-cone limestone concretions in the lower 20 feet of the formation. Sandstone dikes similar to those common in the Mowry Shale are present in the upper 50 feet of the formation.

NEWCASTLE SANDSTONE

The Newcastle Sandstone, which lies conformably between the Skull Creek and Mowry Shales, forms a conspicuous southwest-dipping hogback in the southwest corner of the quadrangle. Outcrops of the formation are largely on the dip slopes of the hogbacks. The character of the formation is given in the following composite section which was pieced together from scattered outcrops in the east half of sec. 15, T. 9 S., R. 3 E.

Newcastle Sandstone in Sec. 15, T. 9 S., R. 3 E.

[Measured by Henry Bell]

	Approximate thickness (feet)
Newcastle Sandstone:	
Sandstone, light-brown and pale-light-brown, fine-grained; planar bedded, but more massive than lower sandstones	15
Claystone, gray-green and red-brown, mottled; outcrop characteristics suggest presence of swelling clays; silty near contact with overlying sandstone	5
Sandstone, pale-brown, very fine grained; some iron stain and iron concretions; massive weathering	1
Siltstone, yellow-brown and pale-gray, laminated, friable; very sandy; contains laminae of gray mudstone, some carbonaceous material, and white mica flakes	5
Sandstone, pale-brown, very fine grained; sparse calcareous cement	3
Mudstone, medium-gray, silty, fissile, poorly exposed; bed may be discontinuous and varied in thickness	2
Sandstone, pale-brown; weathered surface pale light-brown; very fine grained; very thinly bedded; irregular, discontinuous, somewhat wavy but generally planar; much very finely divided carbonaceous material on bedding surfaces; some very friable zones contain charcoal; small iron concretions with bleached centers	3
Thickness of Newcastle Sandstone	34

MOWRY SHALE

The Mowry Shale is the uppermost formation of the Lower Cretaceous Series in the southern Black Hills. It is about 150 feet thick and consists largely of light-gray to silvery-gray slightly siliceous shale containing local concentrations of amber-colored fish scales.

The contact of the Mowry Shale with the overlying Belle Fourche Shale is difficult to distinguish in the Flint Hill quadrangle, primarily because of the lack of silica in the Mowry. The upper contact is placed at the base of the lowermost thin bentonite bed below the manganosiderite concretion zone in the basal Belle Fourche Shale. This contact corresponds very well with a change in the color of the shale from silvery gray below to dark gray above.

The basal contact of the Mowry Shale is taken in the Flint Hill quadrangle at the top of the Newcastle Sandstone.

Sandstone dikes and irregularly shaped sandstone masses are locally abundant in the Mowry. The sandstone dikes, which can be traced as much as 1,000 feet horizontally, are conspicuous in the lower and middle parts of the formation, whereas the sandstone masses occur within 30 to 50 feet of the top of the Mowry. The sandstone is yellowish gray, fine grained, micaceous, and locally carbonaceous. Bedding, and locally crossbedding, has been found in both the sandstone dikes and the sandstone masses. The shale surrounding the dikes and masses is contorted, probably as a result of compaction around the more competent sandstone bodies.

A study of the sandstone dikes in the southern Black Hills has been made by W. B. Bryan (written commun., 1957), who considers them to have been derived from marine sandstone lenses in the upper part of the Mowry Shale. The sand was emplaced in fractures in the Mowry and Skull Creek Shales either by forceful intrusion or, more probably, by winnowing on the sea floor and deposition in open fractures, thus producing the bedding commonly noted in the dike sandstone.

UPPER CRETACEOUS ROCKS

BELLE FOURCHE SHALE

The Belle Fourche Shale, the lowermost formation of the Upper Cretaceous Series in the southern Black Hills, consists of about 400 feet of soft dark-gray marine shale with a few thin zones of yellow cone-in-cone limestone concretions. The formation crops out only in the extreme southwestern part of the Flint Hill quadrangle.

The Belle Fourche–Greenhorn contact shown on plate 32 was drawn as suggested by G. B. Gott and D. E. Wolcott (written commun., 1958) at the base of a thin limestone they considered to be equivalent to the Orman Lake Limestone Member. This limestone locally forms the base of the Greenhorn Formation in much of the Western Interior (Petsch, 1949; Cobban, 1951).

GREENHORN LIMESTONE

The Greenhorn Limestone is present only in the extreme southwest corner of the quadrangle, where it forms part of a prominent southwest-dipping hogback. The upper part of the formation is grayish-yellow thin-bedded slabby ledge-forming limestone containing abundant molds and casts of the pelceypod *Inoceramus labiatus.*

The lower part of the formation consists of brownish-gray calcareous shale containing several thin limestone and bentonite beds. This is the only part of the formation present in the quadrangle.

TERTIARY(?) DEPOSITS—TERRACE GRAVEL

Three small thin deposits of unconsolidated terrace gravel occur in sec. 15, T. 8 S., R. 3 E. More small deposits similar to these occur to the west and northwest, where they have been described by Gott and Schnabel (1963, p. 169) and Ryan (1964, p. 410). They probably are Tertiary in age and may be equivalent to the basal part of the White River Formation.

QUATERNARY DEPOSITS

TERRACE-GRAVEL DEPOSITS

Rudely sorted gravel deposits consisting of boulders, cobbles, and pebbles of igneous and metamorphic rocks, limestone and sandstone, quartz, chert, and ironstone in a matrix of coarse to fine sand exist at several levels along the Cheyenne River, and are found less abundantly in Chilson Canyon. The relative proportions of the components are varied, but sandstone fragments derived from rocks of the Inyan Kara Group make up a large part of most of the gravel deposits.

The largest and thickest gravel deposits are in the southeastern part of the quadrangle, where the Cheyenne River canyon is widest. Other large deposits exist in secs. 22, 26, and 27, T. 8 S., R. 3 E., between Chilson Canyon and Sheep Canyon.

The most extensive gravel deposits underlie several relatively low terraces that are 50–180 feet above the present drainage. A higher terrace level, 260–310 feet above drainage, includes mostly small deposits.

Chilson Canyon and the canyon of the Cheyenne River are characterized by incised meanders and gravel-covered terraces in contrast to the short straight course of many other canyons in the quadrangle. This incised meandering course suggests that these two canyons were formed at a time when streams were carrying a far greater volume of water than at the present time. The terraces along the Cheyenne River and Chilson Canyon most probably were formed by lateral corrosion and the gravel deposited at the time the terraces were formed.

Since the dissection of the terraces on which the gravels were deposited, some of the gravels have been moved downslope from their original position by slope wash, giving in part an erroneous picture of their original distribution.

LANDSLIDE DEPOSITS

Extensive deposits of landslide debris cover the bottoms of Hell and Falls Canyons in the northeastern part of the Flint Hill quadrangle. They apparently formed as a result of slumping of thick sandstone units (S_2, S_4, and S_5) in the upper part of the Lakota Formation and lower part of the Fall River Formation down over soft, readily erodible mudstone, shale, and friable sandstone in the lower part of the Lakota Formation, the Redwater Shale Member of the Sundance Formation, and the Unkpapa Sandstone. Large-scale slumping of this type probably occurred during a time when the canyons were carrying far greater quantities of water than they are now.

Large blocks of sandstone as much as 500 feet long are included in the slumps. They now dip about 15° into the hillside down which they slid, forming a distinctive landslide topography.

Recent sliding of surficial material on steep slopes underlain by mudstone is indicated by trees which have trunks curved by compensation for the slow movement of the material in which they are rooted.

ALLUVIUM AND COLLUVIUM

Extensive Holocene alluvial deposits are restricted largely to the Cheyenne River and to Chilson Canyon, although small deposits are found also in Hell, Falls and Sheep Canyons. The material has been largely derived from local sources and ranges in size from clay to pebble gravel. The thickness of the alluvium is variable and difficult to determine accurately. It ranges from a thin veneer to probably as much as 60 feet, as shown by recent gullying in some canyons.

Terraces, locally in three levels, have been cut into the alluvium of the Cheyenne River and Chilson Canyon. These may correlate with the three terraces recognized by Leopold and Miller (1954) along the Cheyenne and Powder Rivers and other streams in eastern Wyoming.

The floors of many canyons are covered by fine-grained colluvium derived from the weathering of cliffs and accumulated by gravity and local runoff on the floors of the canyons. Although widely distributed, this material is commonly so thin that it has only been mapped in Chilson Canyon in the west-central part of the quadrangle. There, extensive colluvial fans that overlie terraced alluvium have formed at the base of steep slopes. Deposits of this type are probably still forming.

WINDBLOWN SAND AND SILT

Large areas covered by sand and silt, probably in part of eolian origin, are found south of the Cheyenne River and on the divide between Sheep and Chilson Canyons in the west-central part of the quadrangle. The sediment is probably of local origin, having been derived from alluvium and colluvium and redistributed by the prevailing northwesterly wind. The material commonly has a northwest grain that is indicated by parallel ridges and valleys. In sec. 34, T. 8 S., R. 3 E., at least 8 feet of sand and silt has been exposed in a small pit. South of the Cheyenne River some of the sand possibly is considerably thicker than this, as indicated by the height of dunes in the southwest corner of the Cascade Springs quadrangle.

STRUCTURE

REGIONAL SETTING

The Black Hills is structurally a huge northwest-trending asymmetric anticline with the more steeply dipping limb on the southwest side. Figure 105 is a structure-contour map of the Black Hills modified

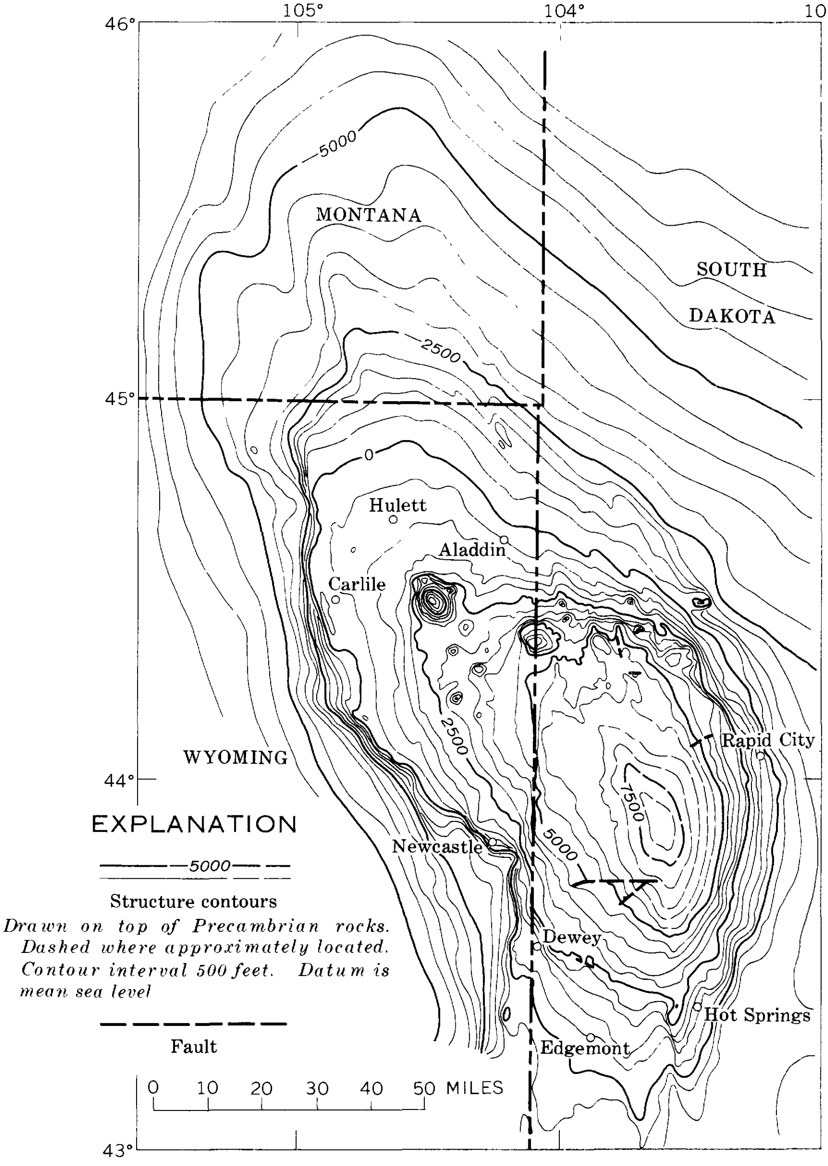


FIGURE 105.—Structure contours on the top of the Precambrian rocks in the Black Hills. Modified from Noble, Harder, and Slaughter (1949).

from Noble, Harder, and Slaughter (1949), who suggested that this anticlinal shape may have been formed by faulting and tilting of two large crustal blocks in the Precambrian basement. According to these authors, the southern crustal block, which has been tilted to the east, trends north with its west edge nearly at the South Dakota–Wyoming boundary. The northern block trends northwest from near Newcastle, Wyo., and underlies the Black Hills in Wyoming and Montana. Presumably it has been tilted to the northeast.

The major anticlinal structure of the Black Hills is modified by secondary northward- and southward-plunging anticlines. These anticlines may be related to zones of structural weakness in the Precambrian core of the Black Hills (Runner, 1943). Some of the anticlines as well as domes in the sedimentary rocks of the northern Black Hills have been formed as a result of the intrusion of stocks, laccoliths, dikes, and sills of alkalic igneous rock during Tertiary time. Igneous rocks of Tertiary age are not known to be present at the surface in the southern Black Hills, however, nor have geophysical investigations by the U.S. Geological Survey found evidence that such igneous bodies are present at depth below any of the secondary structures in this area.

STRUCTURE IN THE FLINT HILL QUADRANGLE

The principal structure in the Flint Hill quadrangle is the Chilson anticline, which trends southward in an arcuate pattern through the center of the quadrangle (pl. 32). The anticline is asymmetric with the steep limb dipping as much as 14° W. Rocks on the eastern limb strike N. 45° E. and dip about 2½° SE. The crest of the anticline is most sharply defined in the area between the Cheyenne River and Chilson Mountain, in sec. 25, T. 8 S., R. 3 E. It is poorly defined both north of Chilson Mountain and south of the Cheyenne River.

Along the west margin of the quadrangle a structural terrace is superimposed on the west limb of the Chilson anticline. The terrace is widest along the north boundary of the quadrangle and narrowest toward the south where it merges with the anticline.

The sedimentary rocks of the Flint Hill quadrangle are strongly jointed. The most persistent and conspicuous set of joints strikes about N. 30° W. and nearly everywhere dips vertically or at very high angles. A second prominent joint set strikes N. 75°–80° E. with dips nearly vertical. These two joint sets are present throughout the quadrangle (fig. 106). They are most conspicuous in the massive sandstone cliffs, but are also visible on the flat intercanyon areas where soil cover is thin. The joints most commonly are uncemented, but in some places, particularly in sec. 18, T. 9 S., R. 4 E., they have been filled with calcareous cement.

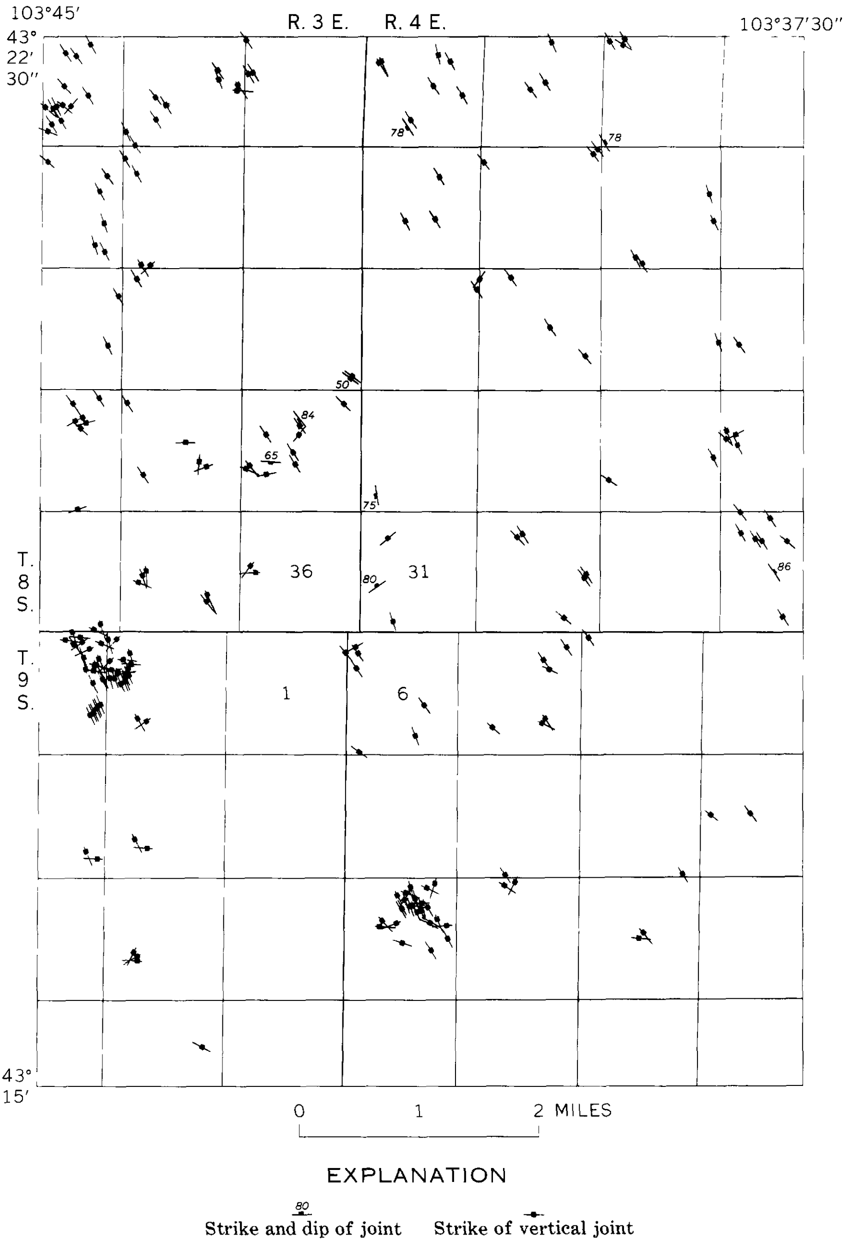


FIGURE 106.—Joint pattern, Flint Hill quadrangle.

The only faults mapped in the Flint Hill quadrangle are minor steeply dipping normal faults that have displacements of less than 25 feet. One was mapped in the Fall River Formation in the northwest corner of the quadrangle, in sec. 10, T. 8 S., R. 3 E., at a uranium prospect; another offsets the S_4 sandstone of the Lakota Formation southwest of Flint Hill in sec. 20, T. 8 S., R. 4 E.

Collapse structures affecting the Sundance and Unkpapa Formations have been noted in Hell Canyon in secs. 17 and 21, T. 8 S., R. 4 E. They most probably have resulted from the solution of gypsum or limestone in underlying Paleozoic formations (Bowles and Braddock, 1963). These features are too small to be shown on the geologic map. The amount of displacement in the collapse structures is not evident because of the brecciated nature of the collapsed material.

In the NW¼SW¼ sec. 19, T. 8 S., R. 4 E., G. B. Gott and D. E. Wolcott mapped a uranium mine in the Lakota Formation in which they noted numerous small faults. They concluded that this mine was at the northwest edge of a collapse structure near the crest of the Chilson anticline (G. B. Gott, oral commun., 1964).

GEOLOGIC HISTORY

The geologic history represented by the rocks exposed in the Flint Hill quadrangle is one of alternating marine and continental environments. The Sundance Formation, which includes the oldest rocks exposed in the Flint Hill quadrangle, is the last product of marine deposition until the time of formation of the Skull Creek Shale. The Jurassic sea, in which the Sundance rocks were deposited, existed principally to the north and west (McKee and others, 1956). After the retreat of this sea, the Morrison Formation was deposited in lakes and marshes that probably contained carbonate-rich fresh to brackish water. The Unkpapa Sandstone is possibly the product of local erosion in a small positive area in northwestern Nebraska (McKee and others, 1956). Its probable contemporaneity with the Morrison Formation and its cross-lamination and local ripple bedding suggest that it was deposited as a shoreline sand marginal to extensive Morrison lakes and marshes.

By the beginning of Cretaceous time, the lakes and marshes in which Morrison rocks were deposited had probably filled in, and the thin highly carbonaceous siltstone locally found at the base of unit 1 of the Lakota Formation represents a time when vegetation flourished in extensive swamps and environmental conditions were favorable for its preservation.

Differential uplift southeast of the Black Hills, probably in central Nebraska and Kansas, resulted in erosion of a sedimentary terrain.

The sediment thus formed was deposited as the S_1 sandstone in channels of aggrading streams that had previously cut into and, in many places, through the extensive swamp deposits. Carbonaceous siltstone contemporaneous with the S_1 sandstone was most probably formed in flood-plain swamps marginal to the principal stream channels, which drained northward, probably toward the retreating Jurassic sea. Local uplift on preexisting structures in older rocks in the southern Black Hills may have influenced the location of early Lakota streams and the degree to which they scoured the underlying deposits. The S_1 sandstone in the central part of the Flint Hill quadrangle fills a trough scoured at least 50 feet deep in places into the Morrison Formation (see fig. 93), yet thicknesses of the Lakota Formation along the crest of the Chilson anticline are less than those on the east flank of the anticline (pl. 33).

Mudstone was deposited contemporaneously with the S_2 sandstone in lakes and swamps marginal to the main streams. Exposures in the east-central part of the Cascade Springs quadrangle indicate that the S_2 streams had considerable erosive power; all but 50 feet of the Unkpapa Sandstone was scoured away in one place prior to the deposition of the thick S_2 sandstone. The thin red sandstone that caps the S_2 sandstone in many places implies a period of subaerial oxidation and dehydration prior to the deposition of the Minnewaste Limestone Member. The relative absence of carbonaceous material in the S_2 sandstone and its mudstone facies, as compared with the S_1 sandstone and associated rocks, also implies that the environment became more oxidizing and thus less favorable for the preservation of organic material.

The lithologic character of the Minnewaste Limestone Member and the Fuson Member of the Lakota Formation suggests the existence of a widespread lake in the southeastern Black Hills. The thickest sections of Minnewaste are in the southeastern part of the Cascade Springs quadrangle, implying that the deepest part of the Minnewaste Lake was in this area. The carbonate content of the lake waters gradually decreased during Fuson time, for the upper part of the Fuson mudstone is noncalcareous in contrast to the lower few feet, which contains limestone concretions and thin calcareous ripple-bedded sandstones.

Differential uplift in the southeastern Black Hills is suggested again by the S_4 sandstone, which in places fills a channel scoured completely through the Fuson mudstones. Some of the coarsest rocks deposited during this period of nonmarine deposition in the southern Black Hills were deposited in the S_4 channel complex. Pebbles containing Pennsylvanian fossils in conglomerates of the S_4 sandstone indicate a source area of Pennsylvanian rocks. During Fuson time very little vegetation was preserved in the rocks, implying that climatic conditions may have changed from those existing during the time when the Chilson Member was deposited. The leached zone recognized by Waagé (1959) at the top of the Lakota Formation may indicate a period of widespread emergence and subaerial oxidation and weathering after the deposition of the S_4 sandstone.

After this period of weathering, there was a recurrence of the conditions in which vegetation flourished. Carbonaceous material derived from lush swamp vegetation was preserved in the carbonaceous siltstone that is characteristic of the lower unit of the Fall River Formation. Waagé (1959) suggested that the Fall River Formation was deposited in a marginal marine environment, including tidal flats, coastal swamps, estuaries, and deltas. The character of the rocks of the Fall River Formation in the Flint Hill quadrangle and the lack of both marine and fresh-water fossils that are typical of the Lakota tend to confirm Waagé's interpretation of the environment. The S_5 sandstone may have formed in either a fluviatile or deltaic environment. The highly carbonaceous siltstones and mudstones into which it fingers laterally may represent coastal swamps. The upper part of the Fall River Formation consists predominantly of mudstone, siltstone, and thin sandstone that presumably formed in marshes and lagoons and perhaps on beaches and bars. The upper few feet of the Fall River represents the last coastal swamp to exist before the recurrence of marine conditions under which the Skull Creek Shale was deposited.

Marine deposition persisted throughout the southern Black Hills area in the remainder of Cretaceous time, producing the thick sequence of shales and thin sandstones and limestone that overlie the Inyan Kara rocks.

During and after the Laramide uplift, vast quantities of rocks were eroded from the Black Hills and from the Rocky Mountains to the west. The White River Formation was deposited in many of the present valleys of the Black Hills, thus indicating that by Oligocene time the present topographic shape of the Black Hills had been formed. Deposits of the White River Formation at high elevations on the Black Hills must mean that at least the lower slopes of the Black Hills were buried by these deposits. Since Oligocene time, erosion has been the dominant geologic process, and it has largely uncovered the topography buried by the White River sediments.

The Chilson Canyon and Cheyenne River canyon in the Flint Hill quadrangle are characterized by incised meanders and extensive terrace gravel deposits. They are probably older than Buck, Wildcat, Hell, Dick, Devil, and Brady Canyons, which are short and relatively straight and which do not breach the hogback.

There is no evidence of Pleistocene glaciation in the Black Hills, although Fillman (1929) suggested that snowfields may have formed in the higher parts of the Black Hills. Runoff from such snowfields may have been partly responsible for exhuming the land surface buried under White River rocks and for cutting the terraces found along the principal streams. Much of the canyon-bottom alluvium and the windblown sand are of Holocene age, although possibly some of the high-level windblown sand and silt is reworked high-level stream alluvium deposited during an early stage of the present cycle of stream erosion.

ECONOMIC GEOLOGY

URANIUM DEPOSITS

Uranium is the most economically important known mineral resource in the Flint Hill quadrangle. The discovery in 1951 of the yellow uranium mineral carnotite in Craven Canyon about 5 miles northwest of the Flint Hill quadrangle prompted intensive prospecting that led to similar discoveries in the Flint Hill quadrangle. Production of uranium ore increased to such an extent by 1953 that an ore-buying station was established at Edgemont by the U.S. Atomic Energy Commission, and in 1956 a mill for processing uranium ore was in operation. The area in the southern Black Hills in which the uranium deposits occur is now known as the Edgemont mining district.

The deposits discovered in the southern Black Hills during 1952 and 1953 contained the yellow uranium minerals carnotite and tyuyamunite as the principal ore minerals. Several of the deposits discovered since 1955 have contained dark unoxidized ore minerals. The deposits containing carnotite and tyuyamunite are near the surface and have been mined from shallow open pits or from short adits.

URANIUM-BEARING FORMATIONS

Anomalous concentrations of uranium have been found in the Black Hills area in the Deadwood Formation, Minnelusa Formation, Spearfish Formation, Newcastle Sandstone, and the Pierre Shale, as well as in several formations of Tertiary age. Uranium ore has been mined only from the Lakota and Fall River Formations, principally in the southwestern and northwestern parts of the Black Hills. The principal rock units from which uranium has been produced in the Edgemont mining district are, in ascending order, (1) the S_1 sandstone and interbedded sandstone and siltstone of the Chilson Member of the Lakota Formation, (2) the S_4 sandstone of the Fuson Member of the Lakota Formation, (3) the interbedded sandstone and carbonaceous siltstone of the lower unit of the Fall River Formation, and (4) the S_5 sandstone of the middle unit of the Fall River Formation. Uranium has been produced from each of these units in the Flint Hill quadrangle, but the major production has come from the S_4 sandstone and the S_5 sandstone.

DISTRIBUTION

All the productive uranium deposits are in the western two-thirds of the Flint Hill quadrangle (pl. 32). The northwest quarter of the quadrangle contains the largest mine, the Gould mine, in addition to other deposits. Small mines are in Wolf and Chilson Canyons in secs. 30 and 31, T. 8 S., R. 4 E., secs. 25 and 36, T. 8 S., R. 3 E., and in sec. 6, T. 9 S., R. 4 E. Other deposits are found in sec. 2, T. 9 S., R. 3 E., and along the Cheyenne River in sec. 11, T. 9 S., R. 3 E. Most of these deposits are in sandstone. The distribution of the major sandstone units in the quadrangle appears to control the distribution of the uranium deposits in both the Lakota and Fall River Formations.

The S_1 sandstone is thickest in the southwestern part of the Flint Hill quadrangle and it fingers northeastward into carbonaceous siltstone (pl. 32; fig. 95). The significant uranium deposits in the S_1 sandstone are in the central part of the quadrangle near the zone of interfingering with carbonaceous siltstone. No deposits have been found in siltstone equivalents of the S_1 sandstone.

The S_2 sandstone is virtually barren of uranium throughout the southern Black Hills. Only one small prospect has been opened in this sandstone. It is in sec. 17, T. 8 S., R. 4 E., on the west side of Hell Canyon, where the sandstone is interlayered with mudstone and has been mapped as an interbedded unit.

The S_4 sandstone is widespread in the Flint Hill quadrangle (pl. 32; fig. 100), but so far it has yielded uranium only in the northwestern part of the quadrangle where the channel sandstone is relatively narrow.

The S_5 sandstone appears to occupy a narrow channel along the west margin of the Flint Hill quadrangle; it is more sheetlike in the southeastern part of the quadrangle, and it is relatively thin or absent in the north-central and northeastern parts. Uranium deposits in the S_5 sandstone occur only in the northwestern part of the quadrangle. One particularly interesting deposit in the S_5 sandstone exists on the east side of Sheep Canyon in sec. 27, T. 8 S., R. 3 E., where erosion has scoured through the variegated mudstone, and the S_6 sandstone of the upper unit of the Fall River Formation rests on S_5.

A relationship between the distribution of uranium deposits and tectonic structure can also be demonstrated. The large uranium deposits in the Flint Hill quadrangle are on the structural terrace on the west flank of the Chilson anticline. Only relatively small deposits are found near the crest of the Chilson anticline, and no deposits have been found far down the east flank of the anticline. The deposits also seem to be preferentially located near areas of abrupt change in dip. Similar relationships between uranium deposits and structure have been noted in other places in the Edgemont mining district (Bell and others, 1956).

The pattern of distribution of uranium deposits is also controlled to some extent by sedimentary structures. Several of the deposits in the lower part of the S_1 sandstone in Chilson Canyon are near the edges of a small northwest-trending scour cut as much as 50 feet into the Morrison Formation (fig. 93). Uranium deposits in the thick sandstone units are also localized along local unconformities at the base of sandstone lenses.

MINERALOLOGY

The uranium deposits of the Black Hills have been classified by Weeks, Coleman, and Thompson (1959) as moderately vanadiferous, resembling the carnotite ores of the Colorado Plateau. Carnotite, $K_2(UO_2)_2(VO_4)_2 \cdot 1\text{–}3H_2O$, and its calcium analog tyuyamunite, $Ca(UO_2)(VO_4)_2 \cdot 5\text{–}8\frac{1}{2}H_2O$, are the most abundant and the most economically important ore minerals mined from deposits in the Flint Hill quadrangle, but metatyuyamunite, $Ca(UO_2)_3(VO_4)_2 \cdot 3\text{–}5H_2O$, corvusite, $V_2O_4 \cdot 6V_2O_5 \cdot xH_2O$, and rauvite, $CaO \cdot 2UO_3 \cdot 5V_2O_5 \cdot 16\ H_2O$, are the major constituents in some deposits. Corvusite and rauvite compose a large proportion of the ore in less-oxidized deposits, but the more completely oxidized deposits contain only the yellow minerals carnotite and tyuyamunite. Uraninite, UO_2, is reported from a few deposits in the Flint Hill quadrangle, and it has been found in larger quantities in the Edgemont NE quadrangle (Gott and Schnabel, 1963), where it is associated with coffinite, $U(SiO_4)_{1-x}(OH)_{4x}$, and haggite, $V_2O_3 \cdot V_2O_4 \cdot 3H_2O$, in unoxidized ore deposits. A few unoxidized deposits have been discovered in the Flint Hill quadrangle since the geologic mapping was completed, but they have not yet been shown to be of economic significance.

The ore minerals occur as coatings on sand grains and joint surfaces and as interstitial and fracture fillings. In some deposits yellow uranium minerals form concentric bands that resemble liesegang bands. Some high-grade deposits of the vanadium minerals show concretionary characteristics. The ore forms both conformable tabular masses and irregular pod-shaped bodies that transgress textural boundaries and structures in the host rocks

Uranium minerals in most of the deposits are associated with carbonaceous material, iron oxide stains, pyrite, and, in some places, carbonate cement.

Many similarities have been noted between the uranium deposits in the Edgemont mining district and those on the Colorado Plateau, particularly those in the Salt Wash Sandstone Member of the Morrison Formation. In the classification of sandstone-type uranium deposits proposed by Botinelly and Weeks (1957), the deposits in the Edgemont mining district would be grouped with those having vanadium-uranium ratio between 3:1 and 1:2; some of the highly oxidized deposits in the S_1 sandstone have a vanadium-uranium ratio of less than 1:1.

The uranium deposits in the Flint Hill quadrangle have produced ore with an average grade of about 0.25 percent U_3O_8 and 0.30 percent V_2O_5. The grade varies, however, from one deposit to another, and within deposits; even samples cut from a piece of ore less than 2 feet square will show variations in grade of as much as 10:1 between samples. This variation is probably due to original irregular distribution of the unoxidized ore minerals plus irregular dispersion of the uranium and vanadium during oxidation.

Analyses of many samples of mineralized rock show that uranium frequently is not in equilibrium with its daughter products. The ratio of uranium to equivalent uranium in the mines in the Flint Hill quadrangle has a wide range, although the average U/eU ratio is about 1:1.

Uranium and vanadium minerals in many deposits are closely associated with carbonaceous material. This is particularly true of those deposits found in thin sandstones interbedded with mudstone. Less carbonaceous material is found in deposits in thick sandstones, and none has been noted at the Gould mine. Only a small part of the total carbonaceous material present in the rocks has formed a locus for the concentration of uranium minerals. Low-grade coal in the Lakota sandstone, for example, contains 0.001 percent equivalent uranium (table 5). The carbon commonly associated with the ore deposits occurs as finely comminuted fragments and films. Some fragments of carbonaceous material clearly represent fossilized plant remains. Other highly lustrous black fragments of unknown origin are also present.

The sandstone that surrounds many of the uranium deposits is pink or reddish in contrast to the normal yellowish gray. This pink color commonly extends both vertically and laterally from the mineralized rock and is a useful guide to ore deposits. The color is caused by a very thin film of hematite that stains the quartz grains. Vickers (1957) pointed out that some uranium deposits in the northern Black Hills occur downdip from pink-stained sandstone, but no such relation to regional or local dip has been recognized in the Flint Hill quadrangle.

Some deposits, notably the deposit at the Gould mine in sec. 11, T. 8 S., R. 3 E. (Cuppels, 1962), are not surrounded by this pink stain.

Mineralized rock is commonly stained various shades of yellow and brown by iron oxides. Iron and uranium minerals are commonly associated, but the uranium minerals are not necessarily confined to areas of abundant iron staining. Much of the most heavily iron-stained rock is barren of radioactivity and uranium. Some of the carnotite ore produced in the Flint Hill quadrangle has a ratio of vanadium to uranium that is inconsistent with the ratio of vanadium to uranium in carnotite and tyuyamunite. Unrecognized vanadium minerals obscured by iron oxide, however, may be present and cause the observed ratios.

Drill core from uraninite deposits in the Edgemont NE quadrangle contains abundant pyrite and some marcasite. Most of the yellow and brown iron oxides in the deposits in the Flint Hill quadrangle probably result from oxidation of pyrite, just as yellow uranium minerals result from the oxidation of uraninite.

Analysis of the ore from the Gould mine has shown the presence of as much as 1,600 ppm arsenic and 100 ppm selenium. The distribution of these elements does not seem to correlate in detail with the distribution of the uranium minerals. Selenium is commonly reported from uranium deposits on the Colorado Plateau, where clausthalite (PbSe) is found associated with galena. Native selenium has been identified from the Edgemont mining district (Thompson and others, 1956). No arsenic minerals have been found in uranium deposits of the Flint Hill quadrangle, and the source of the arsenic in the ore is not known.

The amount of selenium in uranium ore from the Gould mine is low relative to the amount in one of the mines at Carlile in the northern Black Hills and in deposits in the Baggs area, Wyoming (Davidson, 1963, p. C28–C31). Davidson's explanation for the variation is that in the Gould deposit, soluble selenium compounds were removed during the process of oxidation and redeposition of uranium, whereas in the Carlile deposit no migration of elements took place during oxidation of uranium and in the Baggs deposits both selenium and uranium migrated and reprecipitated together.

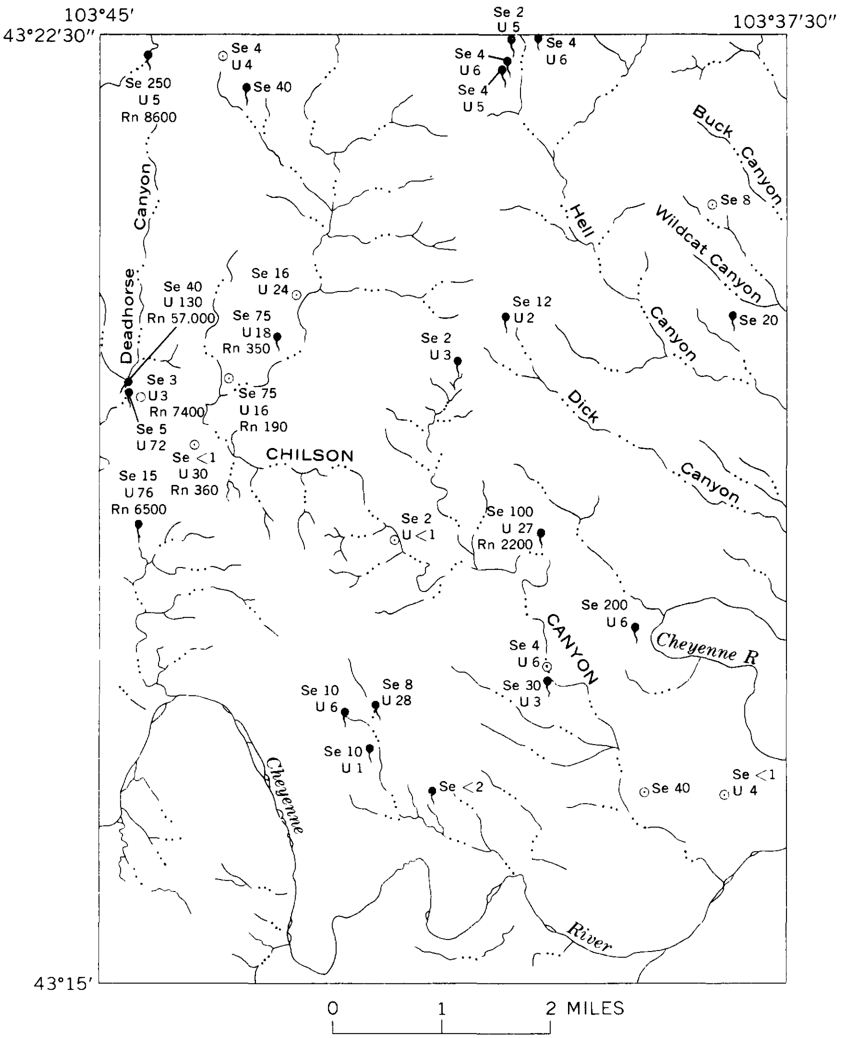
Selenium may be derived from the oxidation of pyrite. Two pyrite nodules from the Fall River Formation in an area some distance from known uranium deposits contain 7 and 8 ppm selenium (table 4). This is considerably higher than the average abundance of 0.6 ppm selenium in shales but well within the range for selenium in iron sulfides from sedimentary rocks (Rankama and Sahama, 1950, p. 754). An average of 33 ppb (parts per billion) and as much as 250 ppb selenium has been found in water from wells and springs in the Flint Hill quadrangle (fig. 107). The water samples were collected in August, September, and October 1955, during a time when precipitation and flow from springs was high and the selenium content probably low. During months when precipitation and flow are low, the selenium content of the water may be greater. At such times water from the springs and from pools below the springs may be toxic to cattle. The ash of an unidentified species of *Astragalus*, found growing near a spring in Hell Canyon, was found to contain 500 ppm selenium.

These values are not extremely high when compared with values for selenium in spring water (as much as 0.4 ppm) and plants (as much as 1,610 ppm in *Astragalus*) as reported by Miller and Byers (1935). Nevertheless, because of the probability that selenium in the terrestrial rocks of the Inyan Kara Group was concentrated in a manner similar to that of uranium, high selenium values should be kept in mind as potential guides to uranium deposits.

Iron- and manganese-rich calcium carbonate occurs in some of the deposits as nodules, interstitial cement, and fracture fillings. In the Lion 1 mine, in sec. 10, T. 8 S., R. 3 E., carnotite and tyuyamunite impregnate porous sandstone between carbonate-cemented nodules. Some of the ore from this mine contained as much as 7 percent calcium carbonate. Ore from deposits other than the Lion 1, however, generally contains less than 1 percent calcium carbonate as reported by the operators of the buying station in Edgemont. Although quantitative data are not avaliable for barren sandstone, its seems likely that calcium carbonate is present in this order of magnitude in most of the cliff-forming sandstones.

The distribution of carbonate-cemented sandstone seems to be related to the distribution of the uranium deposits. A large uraninite deposit has been found in the Edgemont NE quadrangle at the contact between the S_4 and S_5 sandstones. The deposit is in an area that is marginal to S_4 sandstone intensely cemented with carbonate (Gott, 1956). The Gould mine, also in the S_4 sandstone, is in an area free of calcium carbonate cement, but concretionary nodules of calcium carbonate are abundant in the S_4 sandstone less than a mile to the east (fig. 101).

Water samples from 25 springs and wells in the Flint Hill quadrangle (fig. 107) were analyzed for uranium content in the fall of 1955, and some of these springs and wells were subsequently tested for radon. Uranium content of the water ranged from less than 1 to 130 ppb, and 10 of the samples contained 16 ppb or more. By comparison, in the Cretaceous, Tertiary, and Quaternary rocks of western Kansas, eastern Colorado, and the Oklahoma Panhandle, Landis



EXPLANATION

Well

Spring

Se 40
Selenium content of water, in parts per billion

U 6
Uranium content of water, in parts per billion

Rn 360
Radon content of water, in micromicrocuries per liter

FIGURE 107.—Springs and wells in Flint Hill quadrangle sampled during August, September, and October 1955, and results of analyses of water for selenium, uranium, and radon.

(1960) found the average uranium content for spring waters to be 11.3 ppb and that for wells to be 9.5 ppb. These 10 samples of high uranium content from the Flint Hill quadrangle fall in the range characteristic of ground water from uranium-mineralized aquifers noted by Fix (1956, p. 667). Four of the waters with high uranium content are from springs or wells more than half a mile from any known uranium deposit, and may indicate areas where prospecting might be fruitful.

LOCALIZATION OF URANIUM DEPOSITS

It is generally accepted that uranium can be most readily transported in solution as a complex uranyl carbonate ion, and that the principal reaction involved in the precipitation of uranium from solution is the reduction of uranyl ions to uranous ions.

The close association of uranium minerals with carbonate cement, as demonstrated by Gott (1956) and as shown at the Lion 1 mine in sec. 10, T. 8 S., R. 3 E., in the Flint Hill quadrangle, suggests that uranium in the southern Black Hills did migrate in carbonate-rich ground water. Because the most abundant carbonate cement exists in the S_4 channel sandstone of the Fuson Member of the Lakota Formation, this rock unit possibly provided the principal route for the migration of uraniferous ground water through the southern Black Hills.

Uranium minerals commonly are concentrated around a nucleus of organic material. This fact lends support to the thesis that the uranium was precipitated by the reduction of the uranyl ion. The absence of organic material at the Gould uranium deposit suggests that some reducing agents—possibly organic acids, methane, or hydrogen sulfide—migrated some distance from their source and effected the precipitation of uranium without visible evidence of the existence of a reducing agent.

The most obvious sources for reducing agents in the Inyan Kara Group of the Flint Hill quadrangle are the carbonaceous siltstone of the lower unit in the Fall River Formation and the carbonaceous siltstone of unit 1 in the Chilson Member of the Lakota Formation. If the S_4 channel sandstone is considered to be one of the principal routes of horizontal access for uraniferous solutions in the southern Black Hills, then some means of vertical movement for either uranium-bearing fluids or reducing agents must be found. G. B. Gott (oral commun., 1960) has shown that vertical movement and intermingling of uraniferous solutions and reducing agents was possible where the S_5 channel sandstone of the Fall River Formation filled a scour cut through the lower carbonaceous siltstone of that formation into the S_4 channel sandstone of the Lakota Formation. Such a connection, which would have allowed reducing agents formed in the lower carbonaceous siltstone of the Fall River to mingle with uraniferous ground water, may have existed in the northwest corner of the Flint Hill quadrangle where the S_5 channel crosses the S_4 channel. The evidence for such a connection is lacking because of erosion; nevertheless, the largest uranium deposits in the Flint Hill quadrangle occur in this area in the S_4 and S_5 sandstone.

Geologic structures have undoubtedly played a significant role in localizing the uranium deposits of the Flint Hill quadrangle by controlling the direction and rate of flow of ground water. The largest uranium deposits discovered in the quadrangle, especially those in the S_4 and S_5 sandstones, have been found on the structural terrace west of the Chilson anticline, and several smaller deposits have been found, principally in the S_1 sandstone near the crest of the anticline. Few deposits have been found on uniform dip slopes, such as that east of the crest of the Chilson anticline.

COAL

Limited quantities of low-grade coal have been mined from the Chilson Member of the Lakota Formation along the Cheyenne River in the southwestern part of the Flint Hill quadrangle, but the prospects for developing any commercial coal deposits in the area at the present time are slight. Coal has been supplanted as a fuel in the area by fuel oil from nearby oil fields in eastern Wyoming.

Stone (1912) described several thin coal seams along the Cheyenne River in the Flint Hill quadrangle. One, in sec. 24, T. 9 S., R. 3 E., on the north side of the Cheyenne River, is from 6 to 55 inches thick and occurs at the base of a sandstone lens (fig. 96). The change in thickness of the coal takes place in a horizontal distance of 400 feet, across which the elevation of the seam changes about 30 feet. This seam is the largest in the Flint Hill quadrangle and was mined in the past for local use.

The coal in this seam is either massive or laminated. The massive variety is highly lustrous and breaks with a conchoidal fracture. The laminated variety is closely jointed and it breaks with an irregular fracture, and is either highly lustrous or dull with slickensides. Some layers consist of aggregates of rodlike plant remains which resemble pine needles and which are most conspicuous on weathered samples. The term "pine needle" coal is purely descriptive, according to Stone (1912), who reported that the "needles" appear to consist of solid resin, suggesting "that they may have been the filling in some type of stem." Stone described this coal as splint coal with a few inches of bright bituminous coal.

The sandstone overlying the coal seam is light brown, fine grained, and well indurated; the discontinuous irregularly curved bedding is marked by concentrations of carbonaceous material.

The underlying sandstone is white to gray; the gray color is caused by finely divided interstitial carbonaceous material. Most of the carbonaceous material, as in the overlying sandstone, is dull and soft, but some that occurs as flakes, streaks, and spherical particles is hard and highly lustrous. The sandstone is poorly cemented and very friable, which suggests that it has been leached of some of its cementing material. The dull coal contains a few thin lenses of sandstone containing white clay fragments.

Table 5 gives a semiquantitative spectrographic analysis of coal from the north wall of the Cheyenne River canyon, in sec. 2, T. 9 S., R. 3 E., that resembles the "pine needle" coal of Stone.

TABLE 5.—*Semiquantitative spectrographic analysis of coal from the upper part of the Chilson Member of the Lakota Formation on the north side of the Cheyenne River, sec. 2, T. 9 S., R. 3 E., Flint Hill quadrangle*

[Analyst, R. G. Havens, field No. BB-X-53; lab. No. 229678. Looked for but not detected: Ag, As, Au, Be, Bi, Cd, Ce, Co, Dy, Er, Ga, Gd, Hf, Hg, In, Ir, K, La, Li, Mo, Nb, Nd, Os, P, Pb, Pd, Pt, Re, Rh, Ru, Sb, Sc, Sn, Sm, Sr, Ta, Th, Tl, Te, U (percent eU 0.001), V, Y, Zn, and W]

Percent	*Elements present*
x.−	Si
.x	Ca
.x−	Al
.0x+	Na
.0x−	Fe, Mg
.00x	Zr
.00x−	Ba, Cu, Ge
.000x+	Ni
.000x	Cr, Mn
Trace	B, Yb

Germanium is the only element listed in this analysis which is present in an amount greater than its normal abundance in the lithosphere as tabulated by Goldschmidt (1954, p. 74). Germanium, according to Goldschmidt (1954, p. 377), is typically concentrated in coals; it makes up as much as 1 percent of the ash of some coals.

Coke from a coal deposit in the Chilson Member of the Lakota Formation at Cambria, Wyo., contains gold and silver (Stone, 1912). Seven samples of coal from some of the seams along the Cheyenne River in the Flint Hill quadrangle were assayed by Dwight Skinner of the U.S. Geological Survey, but none of these samples showed gold or silver.

No uranium deposits have been found associated with the coal in the Flint Hill quadrangle. None of the seven samples of coal assayed for gold and silver contained more than 0.001 percent equivalent uranium.

OIL AND GAS

Two wildcat wells for oil and gas have been drilled in the Flint Hill quadrangle. The Continental Oil Co. drilled a dry hole on the crest of the Chilson anticline in sec. 36, T. 8 S., R. 3 E., in 1942. This hole was reportedly abandoned in the Pahasapa Limestone when circulation was lost in a cavern.

A dry hole that penetrated the Minnelusa Formation was drilled to a depth of 1,890 feet in the center NW¼NE¼ sec. 26, T. 8 S., R. 3 E., in 1956 by the B. and W. Drilling Co. This hole was reportedly plugged and abandoned in August 1957.

These two dry holes do not preclude the possibility of the discovery of oil on the Chilson anticline, however, because a small amount of oil has been produced from the Minnelusa Formation on the Barker dome in the northwestern part of the Edgemont NE quadrangle (Gott and Schnabel, 1963). Local northward dips in secs. 18 and 19, T. 8 S., R. 4 E., suggest the possibility of closure on the crest of the anticline in the north-central part of the quadrangle, although these anomalous dips may have resulted from collapse due to solution of underlying rocks.

SAND AND GRAVEL DEPOSITS

Sand and gravel in sufficient quantities to meet local demand for road building are available from alluvium of the Cheyenne River and the various terrace-gravel deposits in the Flint Hill quadrangle. The sands and gravels available in the quadrangle probably are not satisfactory for use as concrete aggregate because of their relatively high admixtures of silt and clay, humus and organic matter, and cherty pebbles.

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INDEX

[Italic page numbers indicate major references]

Geology and Uranium Deposits of the Southern Black Hills

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GEOLOGICAL SURVEY

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CONTENTS

[Letters designate the separately published chapters]

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