Geology and Uranium Deposits of the Strawberry Hill Quadrangle, Crook County Wyoming

GEOLOGICAL SURVEY BULLETIN 1127

Prepared on behalf of the United States Atomic Energy Commission

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By ROBERT E. DAVIS *and* GLEN A. IZETT

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GEOLOGY AND URANIUM DEPOSITS OF THE STRAWBERRY HILL QUADRANGLE, CROOK COUNTY, WYOMING

By Robert E. Davis and Glen A. Izett

ABSTRACT

The Strawberry Hill quadrangle is on the northwest flank of the Black Hills uplift a few miles southeast of the monocline that bounds the uplift in this area. Drainage is predominantly north-northwestward and is controlled by the regional dip of the strata, and to some extent by local structural features.

More than 750 feet of sedimentary rocks is exposed within the quadrangle. Exposed units include the Morrison formation of Late Jurassic age, and the Lakota and Fall River formations, Skull Creek shale, and Newcastle sandstone, all of Early Cretaceous age. These rocks consist of sediments that were deposited in a continental environment, typified by rocks of the Morrison and Lakota formations, overlain by sediments deposited in a marginal marine environment, characterized by the more regular sequence of rocks belonging to the Fall River formation, and, finally, sediments deposited under marine conditions, represented by the thick shales of the Skull Creek and the sandstone of the Newcastle. The next younger formation, the Mowry shale, occurs as landslide blocks scattered within the area. Quaternary alluvium partly fills the valleys of the major streams.

The rocks in the area dip gently northwest, away from the main Black Hills uplift. Superimposed upon the regional dip are small folds, joints, and small faults. A set of prominent domes is alined N. 60° E. and N. 20°–25° W.; the parallelism between this alinement and that of certain faults and folds in Precambrian rocks of the central Black Hills suggests that the location of the domes may have been controlled by directions of weakness in the underlying Precambrian rocks.

Concentrations of uraniferous material are largely restricted, so far as is known, to abnormally thick permeable carbonaceous sandy intervals within the upper unit of the Fall River formation. Sedimentary features, the most important of which is abnormal change in thickness of beds, may have been of major importance in localizing uranium deposits.

The Busfield and Vickers mines, near the west-central edge of the quadrangle, were two of the larger uranium producers in the northern Black Hills. Up to October 1957, each of these mines had produced 9,000 tons or more of uranium ore, and the main ore bodies had virtually been mined out. The deposits from which the ore was mined are two separate concentrations of black uranium minerals in or adjacent to an abnormally thick sandstone at the top of the upper unit of the Fall River formation. Coffinite, the principal ore mineral, is intimately associated with carbonaceous material and, locally,

with abundant pyrite. The carbonaceous material is disseminated throughout the sandstone and concentrated in layers oriented along planes of stratification and cross-stratification. The upper part of one of the deposits is oxidized, but owing to a local perched water table, the major part of the deposits is unoxidized.

Uranium probably was carried into the area by ground water and precipitated from solution by decaying organic matter in a reducing environment. Precipitation and localization of uranium were controlled by the lithologic character of the host rock, sedimentary structures, and tectonic structures.

The relations of vanadium-uranium ratios to oxidized and unoxidized mineralized zones strongly suggest preferential leaching and migration of uranium. Also, the disequilibrium of equivalent uranium and chemical uranium as related to the intensity of oxidation of mineralized samples indicates enrichment of the primary uranium deposits. An age determination shows part of the uranium from a sample of unoxidized ore to be about 60,000 years old. This indicates Quaternary deposition of uranium, and we suggest that the deposits are at present in a transitory state.

A bentonite bed in the lower part of the Newcastle sandstone near the northern edge of the quadrangle may be minable. Material from this bed passed the initial test for favorable swelling properties. Locally, scattered landslide blocks of siliceous Mowry shale probably can be used as a limited supply of road metal.

INTRODUCTION

LOCATION

The Strawberry Hill 7½-minute quadrangle in northwestern Crook County, Wyo. (fig. 1), is bounded by latitudes 44°45′ N. and 44°52′30″ N. and by longitudes 104°37′30″ W. and 104°45′ W. No towns or settlements are within the quadrangle; the nearest town, Hulett, is approximately 8 miles by graded dirt road south-southeast. Devils Tower National Monument is approximately 12 miles to the south.

PURPOSE AND SCOPE OF INVESTIGATION

The Strawberry Hill quadrangle is one of four 7½-minute quadrangles in the northwestern Black Hills selected to be mapped in detail because of the occurrence of commercial uranium deposits. Two mines—the Busfield, which was operated by Sodak Uranium and Mining Co., and the Vickers, which was operated by Hilmer-Tessem Uranium Corp.—are near the west edge of the quadrangle, and a third, operated by the Quad Mining Co., is just beyond the west edge. Of the three mines, only the Quad was operating in August 1957, when the fieldwork was completed.

Detailed geologic mapping of the quadrangle and of the Busfield and Vickers mines was undertaken as a possible aid to further exploration for uranium deposits and to determine, insofar as possible, the interrelations among tectonic structures, sedimentary structures, stratigraphy, lithology, and uranium deposits.

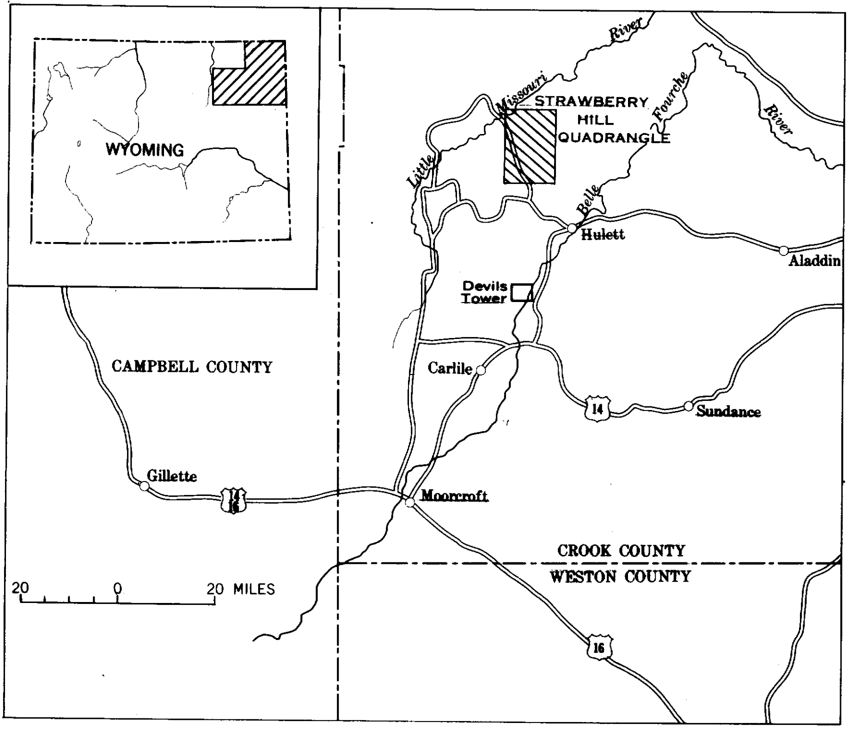

FIGURE 1.—Index map showing location of the Strawberry Hill quadrangle, Wyoming.

During the summer of 1956, the mines and adjacent areas were mapped in detail by planetable by Davis, assisted by C. W. Signor, Jr., and mapping of the quadrangle at a scale of 1:12,000 was begun. Mapping of the quadrangle was completed during the summer of 1957 by Izett, Davis, and M. R. Brock, with the assistance of R. E. Mase and J. L. Gaebel.

The work was done on behalf of the Division of Raw Materials of the U.S. Atomic Energy Commission.

ACKNOWLEDGMENTS

Many people contributed directly or indirectly to this project. The personnel of Sodak Uranium and Mining Co. and Hilmer-Tessem Uranium Corp. gave freely of their time and information and fully cooperated during the mine mapping. Messrs. Wagner, Sheffield, and McLean, owners of the Vickers mine, and Mr. Clyde Boyle, of Sodak Uranium and Mining Co., gave information concerning their respective properties. The local residents were cooperative and helpful in every way possible. The contributions of all these people are gratefully acknowledged.

PREVIOUS INVESTIGATIONS

The geologic features of the northern Black Hills region of South Dakota and Wyoming have been known in a general way for more than half a century. The first systematic and comprehensive work, by N. H. Darton and his coworkers, included papers on individual quadrangles (Darton, 1905; Darton and O'Harra, 1905, 1907) and a general paper on the geology and water resources of the region (Darton, 1909). The geology of the Strawberry Hill quadrangle is discussed in the description of the Devils Tower 30-minute quadrangle (Darton and O'Harra, 1907) as well as in the regional description (Darton, 1909).

Little additional work was done in the region until 1922–24 when W. W. Rubey and others of the U.S. Geological Survey mapped the region that included the northern and western flanks of the Black Hills. Rubey (1929, 1930) has discussed the lithology and origin of certain of the Cretaceous units of the region.

In recent years, Knechtel and Patterson published two papers (1955 and 1956) on the geology of bentonite deposits in the Missouri River Basin. Their mapped area included the extreme northwest corner of the Strawberry Hill quadrangle.

In 1954 and 1955 the mapping of Rubey and others, along with that of Knechtel and Patterson, was integrated, expanded, and locally modified by C. S. Robinson, W. J. Mapel, M. H. Bergendahl, and P. K. Theobald of the Geological Survey. Maps showing the geology and structure of the region have been published (Mapel, Robinson, and Theobald, 1959) and a comprehensive report on the geology is being prepared by Robinson, Mapel, and Bergendahl (written communication, 1957). Certain features of the stratigraphy in both the northern and southern parts of the Black Hills have been studied recently by K. M. Waagé (1959); Waagé has modified some of the previously accepted stratigraphic concepts and a small part of the nomenclature of the Lower Cretaceous rocks.

The Busfield mine was mapped by geologists of the U.S. Atomic Energy Commission (MacPherson, 1956).

TOPOGRAPHY AND DRAINAGE

The geomorphic features of the Strawberry Hill quadrangle are the result of the gentle northwest regional dip of the strata, the local structures that modify the regional dip, and the erosion characteristics of sandstone and shale.

Drainage is through two main systems. Most of the area is drained through three north- and northwestward-flowing creeks—Elkhorn, Tie, and Bronco John—and their subsidiaries. The gentle northwest regional dip controls the direction of this drainage; the creeks flow down the dip-slope of the strata into the Little Missouri River, the valley of which marks approximately the northwest limit of the Black Hills uplift in this region. The remainder of the area, southeast of Goldie Divide and along the east-central edge of the quadrangle, drains through Sourdough Creek and Buck Creek (outside the map area). These creeks flow eastward down the southeast-facing escarpment of sandstone and siltstone to the Belle Fourche River (fig. 1), which has cut its valley in the older claystone and shale.

The location of the northwestward-flowing creeks may have been influenced by local structural features, principally domes, that have been superimposed upon the regional structure. Streams flow through parts of the domes rather than in the structural troughs between them, probably because of more open joint systems in these domed areas.

The configuration of the higher interstream areas, and to some extent that of the streams, is a function of the lithologic character of the bedrock. In a broad sense, the surface is undulating and dips gently to the northwest. Two distinct topographic expressions are present. Where streams have been incised into sandstone beds, canyon and divide topography has formed; where streams drain softer shale areas, as in the northeast part of the quadrangle, a rolling hilly surface has been developed.

The most conspicuous topographic feature in the area is Strawberry Hill, which consists of two steep-sided mesas that rise approximately 250 feet above the surrounding surface. The mesas are composed of soft shale capped by sandstone beds.

Total relief in the area is approximately 835 feet; altitudes above sea level range from about 3,620 feet, along the Little Missouri River in the northwest corner of the quadrangle, to 4,455 feet on top of Strawberry Hill. Local relief is generally 150–200 feet, except along Sourdough Creek, where the upland surfaces stand approximately 400 feet above the creek level.

CLIMATE AND VEGETATION

The regional climate is semiarid, with hot relatively dry summers and cold winters. No weather recording stations are within the quadrangle, but the total precipitation at Hulett in 1953, according to the most recent readily available records, was estimated to be 18.65 inches (U.S. Weather Bureau, 1953). Precipitation in the same year at Devils Tower, 9 miles southwest of Hulett, was about 2 inches above normal; therefore, assuming that precipitation at Hulett was also above normal, the average annual precipitation at Hulett is probably about 16 inches. Most of the precipitation occurs during the late spring and early fall. The average temperature at the Hulett station during 1953 was 46.5° F. Extremes were 101° F, recorded on June 30, and −21° F, recorded on February 20.

Range grasses, sagebrush, and cactuses cover the flat areas. Evergreens commonly form a dense cover on north-facing slopes and along some canyon walls. Except for areas underlain by shale, which support a heavy growth of evergreens, south-facing slopes commonly are grass-covered.

GENERAL GEOLOGY

STRATIGRAPHY

The Strawberry Hill quadrangle is underlain by sedimentary rocks of Late Jurassic and Early Cretaceous ages. Quaternary alluvium covers the valley floors of several of the larger tributary creeks. The exposed sedimentary rocks include five formations with an average aggregate thickness of about 760 feet. These are, in ascending order, the Morrison, Lakota, and Fall River formations, the Skull Creek shale, and the Newcastle sandstone. The areal distribution of these formations is shown on the geologic map (pl. 1).

The sequence of sedimentary rock types represents a gradual change from a continental environment during the Late Jurassic to a marine environment during the Early Cretaceous. The Morrison formation consists of a succession of variegated claystone and a few discontinuous limestone and sandstone interbeds; it is overlain by the Lakota formation which consists of complexly lensing and interfingering variegated claystone, siltstone, and conglomeratic sandstone. The Morrison and Lakota formations form a distinct lithogenetic unit of sediments deposited in a continental environment. Disconformably overlying the Lakota formation is a sequence of carbonaceous clayey siltstone and even-bedded sandstone of the Fall River formation, which was deposited at the margin of an Early Cretaceous seaway. Black greasy slightly silty shale of the Skull Creek conformably overlies the Fall River formation and is the lowermost part of a thick sequence of sedimentary rocks that were deposited in a marine environment. The next younger unit, the Newcastle sandstone, consists of carbonaceous claystone, bentonite beds, siltstone, and sandstone.

UPPER JURASSIC SERIES

MORRISON FORMATION

The Morrison formation, the oldest rock unit exposed in the Strawberry Hill quadrangle, is the uppermost formation of the Upper Jurassic series in the northwestern Black Hills. This sequence of variegated claystone and intercalated thin beds of limestone and sandstone was originally named the "Beulah shales" by Jenney (1899, p.

593). Darton used Jenny's terminology for these beds in his earlier work (Darton, 1901b, p. 188) but later adopted the name Morrison as it had been defined by Eldridge (1896) for the similar sequence of rocks in the Denver Basin.

The Morrison formation is the bedrock along Sourdough Creek in the southeastern part of the quadrangle, but it is exposed at only one place in this canyon—in sec. 14, T. 55 N., R. 65 W. Away from this exposure the Morrison forms gentle slopes commonly covered by grass or by slump blocks and rubble from the overlying Lakota and Fall River formations.

In the outcrop the formation consists of greenish-gray limy slightly sandy claystone containing a few discontinuous beds of dense light-gray limestone less than 1 foot thick. X-ray determination of similar claystone in samples of Morrison rock from the Carlile quadrangle showed that illite, chlorite, and montmorillonite are major constituents of the claystone and that calcite, quartz, and kaolinite occur in minor and trace amounts (Bergendahl, Davis, and Izett, 1961, p. 621).

The base of the Morrison is not exposed in the mapped area but can be seen along the Seely road near where the road crosses Sourdough Creek half a mile east of the quadrangle. In this area light-greenish-gray sandy claystone of the Morrison conformably overlies an orange-brown sandstone, which is the topmost bed of the Redwater shale member of the Sundance formation.

The contact of the Morrison with the overlying Lakota formation is covered everywhere along Sourdough Creek, but where the contact is exposed elsewhere in the northern Black Hills it has been mapped at several different horizons (Waagé, 1959, p. 38). The most conspicuous horizon and the one most expedient for mapping is at the base of the lowest conglomeratic sandstone above the pastel red and green claystone with intercalated dense gray limestone beds, which are undoubtedly Morrison. Where the conglomeratic sandstone is absent or where the claystone slopes below are well exposed, the contact is mapped at the base of the lowest occurrence of dark-gray or black claystone, or, in the absence of the dark claystone, the contact is placed at the top of the highest occurrence of limestone, marlstone, or claystone with nodules of limestone. These horizons may or may not all be present in a single exposed section and almost never coincide with one another stratigraphically, which makes mapping of the Morrison-Lakota contact difficult and inconsistent.

If the exact thickness of the Lakota formation in the area were known, an approximate Morrison-Lakota contact could be shown on the map. Because the thickness is not known accurately, however, and because the character of the contact is not known owing to the colluvial cover, the two units were mapped as one in the Sourdough Creek area (pl. 1).

The Morrison, commonly about 100 feet thick, reaches a maximum of 145 feet in the northwestern Black Hills (Robinson, Mapel, and Bergendahl, written communication, 1957), but is absent locally. In the Sourdough Creek area, the Morrison probably is about 100 feet thick as estimated from measurements east and south of the mapped area. However, in an exploratory hole drilled by the U.S. Atomic Energy Commission, in sec. 2, T. 56 N., R. 65 W., only 29 feet of Morrison was intersected, which emphasizes the variable thickness of the formation.

The age of the Morrison has been controversial for the last half century, but recent opinions strongly favor a Late Jurassic age. Reeside (1952, p. 32) states "It seems to be more generally accepted in recent years that these deposits were laid down in Upper Jurassic time." Darton and O'Harra (1907, p. 3) reported dinosaur bones at many localities. Robinson, Mapel, and Bergendahl (written communication, 1957) report saurian bones, ostracodes, charophytes, and the mollusk *Unio nucalis* Meek and Hayden from the Morrison in the northwestern Black Hills.

Samples from the Morrison formation collected recently by I. G. Sohn and other geologists of the U. S. Geological Survey working in the Black Hills have yielded many identifiable ostracodes. Regarding their identification, Sohn (1958, p. 122) states "The ostracodes in these 50 samples represent species of *Darwinula* Brady and Robertson, 1885, species of the "*Metacypris*"-"*Gomphocythere*" group, species of *Theriosynoecum* Branson, 1936, and species of at least three genera hitherto not described in the United States". Sohn also has found charophytes in association with the octracodes.

Although vertebrate and invertebrate fossils have been found in the Morrison of the Black Hills by many geologists, no identifiable fossils were found in the Strawberry Hill quadrangle.

The environment in which Morrison sediments were deposited is not fully known, but the limy clays and dense limestones suggest that the sediments were deposited in quiet water in lakes and ponds. According to Sohn (1958, p. 122), the association of charophytes and ostracodes "confirms a fresh-water or possibly a brackish-water environment." A description of the Morrison in drill core from sec. 2, T. 56 N., R. 65 W., logged by C. S. Robinson, is given below:

Morrison formation in U.S. Atomic Energy Commission drill hole N.H.R. 152, Bronco John Creek, sec. 2, T. 56 N., R. 65 W., Crook County, Wyo.

[Logged by C. S. Robinson, 1955]

	Feet
Lakota formation (in part):	
Sandstone, grayish-white in upper part to medium-gray in lower part; medium-grained with clay matrix; poorly sorted; upper 2 feet has clay pellets 0.1 mm in diameter; pyrite or marcasite in ¼- to ½-inch thick blebs or stringers in upper foot and in middle; a few seams of carbonaceous shale 1 to 2 inches thick 4 feet from bottom; lower 2 feet conglomeratic with chert and clay pellets ¼ to ½ inch in diameter	16
Morrison formation:	
Claystone, purplish-gray	15
Claystone, sandy; light greenish-gray with purple streaks ½ foot from top; contains seams 1 to 2 inches thick of medium-grained clayey and micaceous sandstone	2
Claystone, mostly purplish-gray with greenish-gray blotches, micaceous	6
Claystone, greenish-gray, sandy, calcareous	1
Claystone, dark greenish-gray, grades to dark purplish-gray near top, noncalcareous	3
Claystone, light greenish-gray to medium-gray, very calcareous	3
Thickness of Morrison formation	30
Sundance formation (in part):	
Redwater shale member (in part):	
Sandstone, medium-gray and light-gray, slightly greenish, very fine grained to silty; clay in chips and thin seams; upper part locally calcareous; sand grains separated from each other by limestone cement	13

LOWER CRETACEOUS SERIES

Lowermost Cretaceous rocks that are above the pastel claystone of the Morrison and below the black Skull Creek shale in the Black Hills were subdivided by Darton (1901a, p. 526–532) into a lower sandstone unit, the Lakota formation; a middle shale unit, the Fuson formation; and an upper sandstone unit, the Dakota formation. On the basis of fossil wood, he considered the lower and middle units, the Lakota and Fuson, to be of Early Cretaceous age and the upper unit, the Dakota, to be of Late Cretaceous age. Russell (1928) suggested that the name "Dakota" should not be applied to rocks in Darton's Dakota sandstone unit because plant remains from this unit were older than those from the Dakota type locality in eastern Nebraska and probably were of Early Cretaceous age; Russell renamed this unit the Fall River formation. Rubey (1930) recognized that the Lakota, Fuson, and Fall River were "extremely variable units" with ill-defined formational boundaries, and proposed that the units be treated as a group. As good exposures of these rocks occur along

Inyan Kara Creek in the northwestern Black Hills, Rubey applied the name "Inyan Kara group."

The discovery of uranium in the Black Hills in the rocks of the post-Morrison and pre-Skull Creek interval prompted detailed stratigraphic studies to determine if any relation between uranium mineral concentrations and lithic variations could be found. Geologists of the U.S. Geological Survey, mapping quadrangles at large scales (1:12,000 and 1:7,200), found that they could not consistently map the ill-defined contacts between the Lakota, Fuson, and Fall River units. K. M. Waagé, working in cooperation with Geological Survey field parties in the Black Hills, has adjusted the nomenclature and subdivision to conform to a twofold lithogenetic division separated by a transgressive disconformity (Waagé, 1959). The lower part of this twofold division, the Lakota formation, is dominantly variegated claystone, sandy claystone, siltstone, and locally conglomeratic sandstone, which are lithogenetically related to the underlying Morrison formation. The Lakota formation as redefined by Waagé includes Darton's Lakota and Fuson formations.

The upper part of the division, the Fall River formation, consists dominantly of silty and sandy sediments of marginal marine origin, which are lithogenetically allied to and gradational with the overlying Skull Creek shale. The upper part as redefined is nearly equivalent to the Fall River formation of Russell. The transgressive disconformity separating the Lakota and Fall River formations is marked by a zone of manganosiderite spherulites in claystone underlying the disconformity. A detailed description of the nomenclatural history and stratigraphy of the Inyan Kara group in the Black Hills has been presented by Waagé (1959).

LAKOTA FORMATION

The Lakota formation is the lowermost unit of the Lower Cretaceous series and the oldest formation of the Inyan Kara group. It was named by Darton (1899, p. 387), and the type locality was designated to be 4 miles northwest of Hermosa, S. Dak., at a grass- and timber-covered knob called Lakota Peak (Darton, 1909, p. 4). Waagé (1959) has redefined the Lakota, and his definition is used in this report. Waagé's standard reference section is in secs. 32 and 33, T. 7 S., R. 6 E., in Fall River Canyon, Fall River County, S. Dak.

In the Strawberry Hill quadrangle, the Lakota crops out along Sourdough Creek in the southeastern part of the mapped area, in a few of the deeper canyons cut into Goldie Divide in the south-central part of the area, and in breached domes along lower Elkhorn Creek and Tie Creek. The Lakota forms moderately steep, commonly grass-covered slopes and ledges; but locally, as in the breached dome in sec. 14, T. 56 N., R. 66 W., it contains a thick sandstone lens that forms a prominent cliff. In the canyon of Sourdough Creek, the Lakota is poorly exposed, and it was not mapped separately from the underlying Morrison formation. Elsewhere in the quadrangle, only several tens of feet of the upper part of the Lakota crops out.

The thickness of the Lakota formation in the northwestern Black Hills ranges from 75 to 300 feet, according to W. J. Mapel (oral communication, 1958). In the Strawberry Hill quadrangle the thickness of the Lakota is not accurately known, but judging from exposures east and south of the quadrangle, we estimate that a thickness of 220 feet probably is representative for the Sourdough Creek area. Near the Busfield mine, a hole drilled by the Atomic Energy Commission penetrated 160 feet of Lakota, and in a drill hole in sec. 2, T. 56 N., R. 65 W., near Bronco John Creek, the Lakota was only 100 feet thick.

The Lakota formation is characteristically an extremely varied succession of three detrital rock types—claystone, siltstone, and conglomeratic sandstone, as well as mixtures of these three which produce a large number of intermediate lithic varieties. Sandy granular claystone, clayey sandstone, silty sandstone, and silty claystone are the more common intermediate rock types. Carbonaceous debris, bentonite, masses of authigenic chert, silicified wood, selenite, and siderite spherulites are minor components that further increase the variety of rock types in the Lakota. Abrupt changes among the many rock types along the strike of the beds make it impracticable to subdivide or correlate units within the Lakota in the area mapped. Elsewhere in the northern Black Hills, the Lakota locally maintains fairly uniform composition, and subdivision is possible; for example, in the Carlile quadrangle the formation has been subdivided into a lower sandstone unit and upper mudstone unit (Bergendahl, Davis, and Izett, 1961).

Silty, sandy, and granular claystones form the bulk of the Lakota throughout the quadrangle. These claystones range from dark gray to light gray, greenish gray, maroon, purple, and yellow. X-ray data from samples of similar claystone in the Carlile quadrangle show that the dominant clay minerals commonly are montmorillonite and kaolinite with trace amounts of quartz and mica (Bergendahl, Davis, and Izett, 1961, p. 627). The claystones are nonfissile and weather to gentle slopes. Swelling clay, which weathers to a characteristic frothy hard surface, is a minor constituent of some claystones. Most of the claystones are semiplastic, but admixtures of silt and sand make them dense and brittle locally.

Red quartzite and gray and black chert pebbles and cobbles that have weathered out of locally conglomeratic, sandy, granular claystone were found in the canyon of Sourdough Creek. Most pebbles are well rounded, some are highly polished, and a few contain silicified fossil fragments.

Locally within the area, thin lenses or beds of light-gray dense siltstone crop out. The siltstone commonly contains finely divided to coarse carbonaceous material disseminated throughout. These beds form thin discontinuous resistant ledges.

The sandstone beds within the Lakota are light gray on fresh surfaces but weather light brown. They consist of more than 95 percent quartz and chert grains and less than 2 percent potassium feldspar and plagioclase grains. The chert-quartz ratio of the sandstones increases markedly with increase in grain size. In NW¼ sec. 28, T. 56 N., R. 65 W., a fine-grained sandstone contains only 5 percent chert, whereas an underlying conglomeratic sandstone lens consists of about 40 percent chert. The quartz grains range from unstrained to strongly strained varieties and contain inclusions of vacuoles, microlites, and dust particles. Tourmaline and zircon are the only identifiable mineral inclusions. Composite quartz grains with sutured contacts are common and were derived probably from a metamorphic terrane. The chert grains consist of cryptocrystalline quartz; some grains contain silicified fossil fragments. A few of the chert grains are coated with a white earthy patina, which has caused them to be erroneously identified by some as weathered feldspar grains.

The sandstone beds commonly are crumbly or friable where they are loosely cemented or bonded by hydrous iron oxides and clay minerals, but locally they form resistant ledges where they are cemented by calcium carbonate. In the carbonate-cemented sandstone, the quartz grains are corroded by the cement.

The sandstone lenses tend to be massive, but high-angle tabular cross-stratification is a prominent feature locally.

Mechanical analyses of four samples of Lakota rocks were made, and cumulative frequency curves were plotted from the data obtained from the weighed sieve fractions. The results of these analyses are shown in table 1, samples G–5715, G–5723, G–5732, and D–571. The detrital fractions range in size from silt to coarse-grained sand, and the median grain size ranges from 6.2 to 0.8 on the Phi scale as used by Folk (1957). The sorting coefficients range from 0.4 to 2.2 and, by Folk's classification, range from well sorted to extremely poorly sorted.

Heavy minerals, separated from the 0.125 to 0.062 mm size fractions, are zircon, tourmaline, staurolite, and rutile in decreasing order of abundance.

TABLE 1.—*Results of mechanical analyses of 23 samples of sandstone, siltstone, and limestone from Lakota, Fall River, Skull Creek, and Newcastle formations*

[Sieve openings: 0.500 mm, 0.250 mm, 0.175 mm, 0.125 mm, 0.088 mm, 0.062 mm; separation of −0.062 mm fraction made by hydrometer analysis. Phi scale and sorting coefficient after Folk (1957)]

Sample No.	Stratigraphic unit	Median grain size, Phi scale	Sorting coefficient
	Lakota formation		
G-5715	Silty limestone	6. 2	1. 8
G-5723	Sandstone	1. 9	. 4
G-5732	Conglomeratic sandstone	. 8	2. 2
D-571	Sandstone	3. 3	. 5
	Fall River formation		
G-571	Sandstone, lower unit	3. 1	0. 4
G-573	do	3. 8	. 8
G-5724	do	2. 9	. 3
G-574	Keyhole sandstone member	2. 9	. 4
G-5725	do	2. 1	------
G-5726	do	2. 7	. 3
G-5754	Keyhole sandstone member, base	3. 3	1. 0
G-5755	Keyhole sandstone member, middle	2. 7	. 4
G-5756	Keyhole sandstone member, top	2. 6	. 4
G-575	Sandstone, upper unit	3. 0	. 3
G-5727	do	3. 0	. 3
D-569	do	3. 2	. 4
D-5634	do	3. 0	. 3
G-5750	Sandstone lens, upper unit, 5 feet above base.	3. 0	. 5
G-5751	Sandstone lens, upper unit, 10 feet above base.	3. 1	. 4
G-5752	Sandstone lens, upper unit, 20 feet above base.	3. 1	. 3
G-5753	Sandstone lens, upper unit, 40 feet above base.	3. 0	. 3
	Skull Creek shale		
G-576	Siltstone	4. 4	1. 1
	Newcastle sandstone		
G-5720	Sandstone at base of formation	2. 9	0. 5

The contact between the Lakota and the overlying Fall River formation is a regional transgressive disconformity that separates a lower (Lakota) unit of continental sediments from an upper (Fall River) unit of marginal marine sediments (Waagé, 1958). A zone of siderite spherulites, which weather to limonite specks, occurs a few feet below the disconformity and helps to locate it. We believe that the term "paraconformity," as defined by Dunbar and Rodgers

(1957, p. 119), more aptly describes this nearly planar surface in the Strawberry Hill quadrangle. A particularly good exposure of the paraconformity occurs in SW¼ sec. 14, T. 56 N., R. 66 W. Here slightly sandy claystone that contains many hollow limonite spheres about one quarter of a millimeter in diameter is sharply overlain by carbonaceous siltstone of the Fall River formation. The siderite spherulites cannot be seen everywhere along Sourdough Creek, but the zone in which they occur is conspicuously marked by a layer, a few inches thick, of brick-red silty claystone, and a change upward from silty and sandy claystone to carbonaceous siltstone marks the paraconformity. The lowermost resistant bed of the Fall River in this area commonly is a dead-white weathering 1-foot thick bed of siltstone about 3 to 4 feet above the paraconformable contact. This bed is of further aid in locating the contact in places where the red claystone zone is covered.

No fossils other than fragments of silicified wood were found in the Lakota within the quadrangle. The Early Cretaceous age of the Lakota formation in other areas has been well established by its contained fossil cycads, ferns, and conifers, which were described by Ward (1894). Recently, Sohn (1958) has described ostracodes from the Lakota in the Black Hills. He found species of the subfamily Cyprideinae in rocks of Inyan Kara age, but found none in the Morrison formation; these species, therefore, may be useful in separating the Inyan Kara rocks from the underlying Morrison formation. Sohn (1958) has presented a brief discussion of the age of the Morrison and Lakota formations relative to the standard European section.

Sediments of the Lakota formation were deposited probably in various continental environments including channel, flood plain, lacustrine, and swamp. Thick sandstone lenses, which commonly are conglomeratic at their base and which pass along their strike into impure claystone, probably represent channel and flood-plain deposits. Local accumulations of carbonaceous debris and thin limestone lenses represent swamp and lacustrine conditions, respectively.

Measured sections, which follow the discussion of the Fall River formation, give details of the lithologic character and thickness of the Lakota within the quadrangle.

FALL RIVER FORMATION

The Fall River formation, of Early Cretaceous age, was named by Russell (1927) and consists of rocks that Darton had assigned to the Dakota formation. Waagé (1959) has redefined the lower contact of Russell's Fall River formation to coincide with the regional transgressive disconformity described above, and his definition of the Fall River is used in this report.

Locally in the northern Black Hills, the Fall River formation can be divided into units, some of which can be traced several miles along the outcrop. In the Carlile quadrangle, Bergendahl, Davis, and Izett (1961) subdivided the Fall River into four units that held fairly constant stratigraphic position and maintained uniform thickness. One of these units, the sandstone unit, was raised to member status by Davis and Izett (1958) and named the Keyhole sandstone member of the Fall River formation.

In the Strawberry Hill quadrangle, the Fall River was informally subdivided into a lower and an upper unit. The top of the Keyhole sandstone member was chosen as the datum for subdividing the formation. This horizon was selected for three reasons. (a) It is a sharp contact in a fairly constant stratigraphic position above the nearly planar Lakota–Fall River paraconformity. The top of the Keyhole member is not a sharp contact in only two areas, one in T. 56 N., Rs. 65 and 66 W. (fig. 5), and the other in parts in secs. 9 and 10, T. 55 N., R. 65 W., along Sourdough Creek. In these two areas, however, the horizon of the top of the Keyhole member could be determined by inference within the accuracy limits of the map. (b) It is exposed throughout a greater area than any other suitable datum within the Fall River formation. (c) It is a consistent and recognizable horizon above and below which lateral lithic variations within units can be compared in different areas of the quadrangle.

For the reasons stated, the top of the Keyhole member not only proved to be the best horizon for subdividing the Fall River formation but also provided an excellent datum for structure contouring throughout the quadrangle.

The Fall River formation forms the bedrock in approximately one-third of the quadrangle. It crops out along the canyons of Elkhorn, Tie, Bronco John, and Sourdough Creeks and is the bedrock across Goldie Divide between Elkhorn Creek and the head of Sourdough Creek. Small isolated areas of Fall River crop out also along tributaries to the main drainages and where erosion has exposed it over structural highs (pl. 1).

For many miles along the major drainages, the more resistant siltstone and sandstone units within the Fall River form ledges and cliffs separating moderately steep slopes formed by less resistant claystone and siltstone. Between these drainages, resistant sandstone beds underlie broad divides covered with soil. The most prominent cliff generally is the massive one formed by the Keyhole sandstone member.

The Fall River formation ranges between 125 feet and 145 feet in thickness within the mapped area, and this range of thickness is consistent with variations elsewhere in the northern Black Hills (W. J. Mapel, oral communication, 1958).

The variations in thickness of the Fall River in different parts of the quadrangle are shown on plate 2. Our observations throughout the quadrangle indicate that these variations have no consistent pattern.

LOWER UNIT

The lower unit of the Fall River formation locally is divisible into three parts: a lower siltstone and thin-bedded sandstone, a medial silty claystone and clayey siltstone, and an upper sandstone—the Keyhole sandstone member. The lower part is probably equivalent to the siltstone unit in the Carlile quadrangle (Bergendahl, Davis, and Izett, 1961); the medial part is probably equivalent to the mudstone unit; and the Keyhole sandstone member is equivalent to the sandstone unit. These three parts of the lower unit were not mapped separately within the Strawberry Hill quadrangle because the contacts between them are gradational and are not consistent from place to place.

The lower part of the lower unit ranges from 20 to 50 feet in thickness and consists of dark-gray carbonaceous siltstone and a few thin-bedded sandstones. The sandstone beds commonly are near the top, and the carbonaceous siltstone beds are near the base. Locally, as along Sourdough Creek and in the southwestern part of the quadrangle, the lower part consists of a massive fine-grained sandstone lens as much as 50 feet thick, and in these areas the underlying carbonaceous siltstone beds are only a few feet thick. Elsewhere in the quadrangle, as in parts of secs. 13, 14, 23, and 24, T. 56 N., R. 66 W., the lower part is only 20 feet thick and consists of one sandstone bed 5 feet thick underlain by 15 feet of interlaminated siltstone and claystone.

The sandstone in the lower part is thin bedded, commonly cross-stratified, micaceous, and very fine to fine grained. Many of the sandstone beds are cemented by iron oxides. Vertical tubes filled with light-gray siltstone, formed probably by soft-bodied organisms, mar the otherwise uniform texture of the sandstone. The sandstone is well bedded, and some thin beds can be followed for several thousand feet along Elkhorn and Sourdough Creeks.

The medial part of the lower unit ranges from about 20 to 40 feet in thickness and consists of dark-gray interlaminated silty claystone and clayey siltstone, which weather to moderately steep slopes. Intercalated thin siltstone beds cemented by iron oxide locally form more resistant ledges. Finely divided carbonaceous debris occurs in most of the siltstone and claystone. The interlaminated siltstone and claystone are not markedly fissile, but some of the more clayey partings could be termed shale.

The Keyhole sandstone member of the Fall River formation, the upper part of the lower unit, ranges in thickness from 0 to a maximum of 35 feet and forms a prominent cliff throughout most of the area. It is particularly well exposed along Elkhorn Creek, where it averages about 25 feet in thickness. The Keyhole appears to be a nearly continuous blanketlike deposit that maintains its relative stratigraphic position; at only two localities, one near the west-central edge of the quadrangle, shown in figure 5, and another in secs. 9 and 10, T. 55 N., R. 65 W., in the canyon of Sourdough Creek, the massive sandstone of the Keyhole member thins laterally by lensing out and interfingering with clayey siltstone and thin-bedded silty claystone. A photograph (fig. 2) taken in the canyon of Elkhorn Creek shows the abrupt thinning of the massive sandstone of the Keyhole member. Plate 2 illustrates the stratigraphic position and changes in thickness of the Keyhole member at various places in the area.

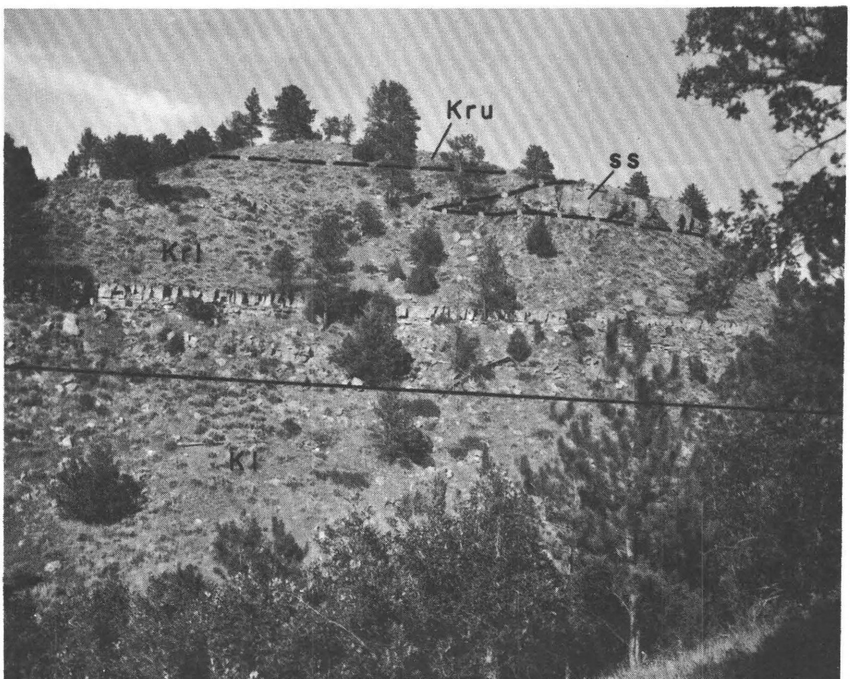

FIGURE 2.—Pinchout of the massive sandstone in the Keyhole sandstone member of the Fall River formation. SE1/4 sec. 25, T. 56 N., R. 66 W., view to northeast; ss, massive sandstone of the Keyhole member; Kru, upper unit of Fall River formation; Krl, lower unit of Fall River formation; Kl, Lakota formation.

The base of the Keyhole member is gradational through 2 to 5 feet with underlying clayey siltstone; the upper part of the Keyhole member commonly is sharply overlain by about 1 foot of carbonaceous claystone or coaly debris, and this sharp contact was mapped as the top of the lower unit. The top of the Keyhole member, where it is overlain by either carbonaceous claystone or coaly debris, is stained dark brown by iron oxides and contains vertical tubes filled with carbonaceous debris, which are interpreted to be fossil root systems.

The Keyhole member is thin bedded near the base and thick bedded in the upper part. Lenticular medium-scale high-angle cross stratification (McKee and Weir, 1953) and parallel ripple marks are common sedimentary structures in the Keyhole.

The sandstone of the Keyhole member is light gray on fresh surfaces but weathers light brown to orange brown. It consists of more than 95 percent quartz with a few percent of feldspar, chert, and white mica. Mechanical analyses were made of 6 samples of sandstone of the Keyhole, and the results are shown in table 1. Samples of the sandstone range from very fine to fine grained with an average median grain size of 2.7 Phi and an average sorting coefficient of 0.5. According to Folk (1957) a sediment with a sorting coefficient between 0.35 and 0.50 is well sorted. By this definition all samples but one are well sorted. The grain size of the sandstone, as shown in table 1, increases from the bottom to the top of the unit.

Heavy minerals, separated from the 0.062 to 0.125 mm size portions, are zircon, tourmaline, staurolite, rutile, garnet, and chloritoid in decreasing order of abundance. R. E. Bergenback and others (written communication, 1957) made a detailed study of the sedimentary petrography of the Inyan Kara group in the Black Hills and have reported a similar suite of heavy minerals.

UPPER UNIT

The upper unit of the Fall River formation consists mainly of slope-forming interlaminated dark-gray silty claystone and clayey siltstone in its lower part, and light-brown ledge- and cliff-forming siltstone and very fine grained sandstone in the upper part. The upper unit ranges between 40 and 55 feet in thickness. Plate 2 shows variations in lithologic character and thickness of the upper unit at several localities in the area.

The silty claystone and clayey siltstone in the lower part of the upper unit are similar to those of the medial part of the lower unit. The siltstone and claystone commonly contain finely divided carbonaceous debris and are subfissile. The uniformity of the slope-forming claystone and siltstone is broken by thin beds of very fine grained sandstone that crop out in the lower part of the unit in NW¼ sec. 7, T. 56 N., R. 65 W. Elsewhere within the quadrangle, thin beds of cross-laminated limy siltstone and iron oxide-impregnated siltstone occur locally in the lower part of the upper unit.

The sandstone beds in the upper part of the upper unit range between 0 and 43 feet in thickness, and in the northern part of the quadrangle they form a nearly continuous blanketlike deposit about 10 to 15 feet thick. The topmost sandstone bed pinches out in SE¼ SW¼ sec. 26, T. 56 N., R. 66 W. The top surface of this sandstone bed is ripple marked, scoured, and uneven; the bed pinches out abruptly into a laterally equivalent, 3-foot bed of carbonaceous debris. In the southern part of the quadrangle, the upper part of the upper unit is not well exposed and it is not known whether the sandstone beds are continuous.

Most of the sandstone is thin bedded, but locally it is thick to very thick bedded. Parallel ripple marks, lenticular medium-scale high-angle cross-stratification, and canoe-shaped scours are common sedimentary structures locally; these features are further described in the section on sedimentary structures (p. 36). Some of the sandstone beds at the top of the Fall River have an uneven surface and contain many burrows and tubes up to 0.3 inch in diameter that were formed probaby by soft-bodied organisms. In the NW¼ sec. 26, T. 56 N., R. 65 W., the burrows are numerous and are filled with light-gray siltstone.

Locally, the sandstone in the upper unit thickens to form lenses, which interfinger with and rest on silty claystone and clayey siltstone. The uranium ore in the Busfield mine area occurs in the thickest and most extensive of these lenses.

The contact between the Fall River formation and the overlying Skull Creek shale is gradational everywhere in the quadrangle. Most commonly the topmost sandstone bed of the Fall River is overlain by a transition zone that ranges in thickness from 1 foot, as observed at the top of the east wall of the Busfield pit, to a probable maximum of about 10 feet, as observed in the west wall of the Vickers pit. The transition zone consists of interlaminated dark-gray silty claystone and clayey siltstone, commonly jarosite-stained, with a few intercalated light-brown siltstone laminae. It is overlain by black greasy Skull Creek shale. Where the topmost bed of the Fall River is something other than sandstone or where exposures are poor, the dark silty claystone and clayey siltstone of the Fall River are difficult to distinguish from the dark shale of the Skull Creek.

No fossils other than the many tubes and burrows filled with light gray siltstone were found in the Fall River formation within the quadrangle. The Fall River is considered to be Early Cretaceous in age, however, because elsewhere in the northern Black Hills Lower Cretaceous cycads are found in the underlying Lakota formation, and Lower Cretaceous marine fossils occur in the overlying Skull Creek shale (Waagé, 1959). Waagé (1959) reports also the Lower Cretaceous zonal guide *Protelliptio douglassi* (Stanton) from the lower part of the Fall River formation along Cabin Creek. Robinson, Mapel, and Bergendahl (written communication, 1957) list other fossils from the Fall River formation, but in general fossil evidence for the age of the Fall River is exceedingly rare. Waagé (1958) has correlated the Fall River, on the basis of lithogenetic similarity, with the lower part of the South Platte formation of the northern Front Range Foothills of Colorado and with the Greybull sandstone member of the Cloverly formation and "Rusty Beds" (Hewett and Lupton, 1917) in the Bighorn Basin of Wyoming.

The environment in which the sediments of the Fall River formation were deposited is not accurately known, but a number of lines of evidence indicate a marginal marine environment. Well-bedded and even-bedded sandstone and the many burrows and casts of soft-bodied organisms indicate that the sediments were deposited at the margin of a seaway, possibly along a tidal flat. The Keyhole sandstone member is a nearly continuous blanketlike deposit—that is, it has one relatively small dimension (thickness) and two large dimensions (length and breadth)—and this characteristic is a significant criterion for recognizing ancient beach deposits (McKee, 1957). The types of stratification in the foreshore and backshore portions also are significant criteria for recognizing beach deposits. The cross-stratification that was seen is mostly high angle and, according to McKee (1957), it cannot be foreshore; moreover, the dip of stratification as recorded in the mapped area closely agrees with dips indicative of backshore beach deposits. We believe that the Keyhole sandstone member may be either a partially reworked ancient beach deposit, thus representing a brief regressive stage of the Early Cretaceous sea, or a deltaic sheet sand, as described by Fisk (1955).

The sandstone lens in the upper unit near the Busfield mine is similar to the cheniers (beach ridges) formed in a marginal deltaic facies of the Mississippi delta, as described by Fisk (1955, p. 392).

In summary, the Fall River formation overlies the continental sediments of the Lakota formation and underlies the marine Skull Creek shale, and in general it represents the transition from continental environment to marine environment.

The following measured sections give details of the variations in lithologic character and thickness of the Inyan Kara group in the quadrangle.

Partial section of the Fall River formation, NW¼ sec. 11, T. 55 N., R. 66 W., Crook County, Wyo.

[Section 8, pl. 2]

	Feet
Fall River formation (in part):	
Upper unit:	
Partly covered; light-brown very fine grained thin-bedded sandstone near base of unit; siltstone in upper 19 feet of unit mostly covered	22
Siltstone, gray, clayey, interlaminated with silty claystone, subfissile; forms slope; thin sandstone bed 7 feet from top of unit forms ledge; concentration of carbonaceous material near base	25
Lower unit:	
Sandstone, light-brown, very fine grained, thin-bedded, cross-stratified, micaceous; forms cliff (Keyhole sandstone member)	18
Siltstone, gray, clayey, interlaminated silty claystone; subfissile; forms slope	45
Sandstone, light-gray, very fine grained, micaceous, cross-stratified, ripple-marked; forms ledge	4
Measured thickness of Fall River formation	114

Partial section of Fall River formation, SE¼ sec. 35, T. 56 N., R. 66 W., Crook County, Wyo.

[Section 6, pl. 2]

	Feet
Skull Creek shale (in part): Partly covered; black silty shale	6
Fall River formation (in part):	
Upper unit:	
Claystone, dark-gray, silty, subfissile; partly covered by float from Skull Creek shale; forms slope	8
Sandstone, light-brown to orange-brown, very fine grained, thin-bedded, cross-stratified; contains some limy beds; friable; forms ledge	11
Siltstone, gray, clayey; interlaminated with gray silty claystone; subfissile; carbonaceous debris at base; forms slope	24
Lower unit:	
Sandstone, light-brown to pink, very fine grained, thin-bedded, cross-stratified; contains some clay galls; carbonaceous near top of unit; forms cliff (Keyhole sandstone member)	20
Siltstone, gray, clayey; forms slope	31
Measured thickness of Fall River formation	94

Partial section of Lakota and Fall River formations, NW¼ sec. 5, T. 55 N., R. 65 W., Crook County, Wyo.

[Section 14, pl. 2]

	Feet
Fall River formation (in part):	
Upper unit:	
Sandstone, light-brown, very fine grained, micaceous, friable; forms ledge	13
Siltstone, gray, clayey; intercalated with silty claystone; 2-foot sandy siltstone ledge near base of unit; forms slope	14
Claystone, dark-gray, silty, carbonaceous; forms slope	1
Lower unit:	
Sandstone, light-brown, very fine grained, thin-bedded; silty near base of unit; high-angle medium-scale cross-stratification; ironstone concretions in lower part of unit; forms cliff (Keyhole sandstone member)	19
Siltstone, gray, clayey; interlaminated with silty claystone; subfissile, carbonaceous; forms slope	26
Sandstone, light-gray, fine-grained, thin-bedded; medium-scale high-angle cross-stratification; micaceous; forms ledges	28
Partly covered; siltstone, gray, clayey; interbedded thin silty claystone and silty sandstone beds; forms slope	10
Measured thickness of Fall River formation	111
Lakota formation (in part):	
Partly covered; mostly sandy claystone; forms slope	9
Sandstone, light-gray, medium-grained; high-angle cross-stratification; forms ledge	8
Measured thickness of Lakota formation	17

Partial section of Lakota and Fall River formations, NW¼ sec. 16, T. 55 N., R. 65 W., Crook County, Wyo.

[Section 15, pl. 2]

	Feet
Fall River formation (in part):	
Upper unit:	
Partly covered; sandstone, light-brown, very fine grained, thin-bedded friable; forms ledge	3
Siltstone, gray, clayey; interlaminated with silty claystone; fissile; forms slope	3
Sandstone, light-brown to pink, very fine grained, thin-bedded, ripple-marked, cross-stratified; forms ledge	6
Siltstone, gray, clayey; interlaminated with silty claystone; subfissile; forms slope	29
Lower unit:	
Sandstone, light-brown, very fine grained, thin-bedded, ripple-marked; some interbedded siltstone; forms ledge (Keyhole sandstone member)	11
Mostly covered; interlaminated silty claystone and clayey siltstone; forms slope	30

Fall River formation (in part)—Continued	
Lower unit—Continued	*Feet*
Sandstone, light-brown, very fine grained, thin-bedded, medium-scale high-angle cross-stratification; forms ledges	19
Siltstone and claystone; light- to medium-gray and light-brown; fissile to very thin bedded; unit is progressively coarser from bottom to top; forms slope	23
Measured thickness of Fall River formation	124
Lakota formation (in part):	
Siltstone, gray to buff, iron-stained; contains siderite spherulites near top of unit; forms slope	14
Sandstone, light-gray, fine-grained; high-angle tabular cross-stratification; some silty claystone partings; thin-bedded; forms ledges	13
Measured thickness of Lakota formation	27

Partial section of Lakota and Fall River formations, NW¼ sec. 28, T. 56 N., R. 65 W., Crook County, Wyo.

[Section 13, pl. 2]

Fall River formation (in part):	*Feet*
Upper unit:	
Partly covered; sandy soil; top of hill capped by iron oxide-cemented siltstone; forms slope	8
Sandstone, gray, very fine grained, iron oxide-stained; weathers brown; forms rounded ledges	4
Partly covered; siltstone, gray, clayey, and silty claystone, subfissile, laminated; forms slope	27
Claystone, dark-gray, subfissile, carbonaceous; in sharp contact with underlying unit; forms slope	1
Lower unit:	
Sandstone, gray, very fine grained, slightly micaceous; silty near base; paper-thin clayey siltstone seams in lower part; thin bedded in lower part becoming thick bedded in upper part; top surface of unit pitted and contains fossil root systems; weathers light brown; forms cliff (Keyhole sandstone member)	30
Partly covered; intercalated light-gray clayey siltstone and silty claystone; subfissile; becomes more silty near top of unit; forms slope	34
Sandstone, gray, very fine grained, micaceous, carbonaceous, thin-bedded, slabby; weathers brown; forms ledge	6
Partly covered; intercalated laminated clayey siltstone and very fine grained sandstone; forms slope	8
Sandstone, gray, very fine-grained, micaceous, thin-bedded; top surface iron oxide-cemented; weathers brown; forms ledge	4
Siltstone, buff, micaceous, laminated, clean; contact with unit below sharp and marked by ¼ inch iron oxide-cemented siltstone lamina; forms slope	6
Measured thickness of Fall River formation	128

	Feet
Lakota formation (in part):	
Claystone, gray, sandy, silty; top of unit contains a few siderite spherulites; forms slope	7
Siltstone, light-gray, slightly carbonaceous, structureless; forms slope	3
Partly covered; light-gray siltstone, carbonaceous; forms slope	6
Siltstone, light-gray, carbonaceous, dense; forms ledge	2
Mostly covered; gray sandy claystone; forms slope	63
Sandstone, brown, coarse-grained; conglomeratic in upper foot with large fragments of chert, quartz, and quartzite; limy in lower part; medium-scale high-angle cross-stratification	17
Measured thickness of Lakota formation	98

Partial section of Fall River formation, SW¼ sec. 16, T. 56 N., R. 65 W., Crook County, Wyo.

[Section 12, pl. 2]

	Feet
Skull Creek shale (in part): covered.	
Fall River formation (in part):	
Upper unit:	
Covered	2
Siltstone, light-brown; limy at base with pimply surface; massive; forms cliff	13
Partly covered; siltstone, light-gray, clayey; laminated in lower part; iron oxide-cemented near top; forms slope	19
Sandstone, gray, micaceous along bedding planes, thin-bedded, carbonaceous; contains some paper-thin claystone seams; iron oxide-cemented; weathers brown; forms ledge	3
Claystone, dark-gray, carbonaceous in lower part; subfissile; grades upward into light-gray claystone; forms slope	4
Lower unit:	
Sandstone, gray, very fine grained, slightly micaceous in upper part; thin-bedded in lower part; progressively thicker bedded upward; top surface iron oxide-cemented; weathers brown; crops out along creek bottom (Keyhole sandstone member)	11
Measured thickness of Fall River formation	52

Partial section of Fall River formation, NE¼ sec. 17, T. 56 N., R. 65 W., Crook County, Wyo.

[Section 11, pl. 2]

	Feet
Fall River formation (in part):	
Upper unit:	
Partly covered; sandstone, very fine grained; contains a few thin limy beds; forms slope	6
Sandstone, light-brown, very fine grained, thick-bedded, micaceous; forms cliff	2
Siltstone, light-brown, thin-bedded; forms cliff	3
Siltstone, light- to dark-brown, clayey, subfissile; iron oxide-cemented in part; forms slope	17
Sandstone, gray, very fine grained, carbonaceous, micaceous; forms slope	2
Siltstone, gray, carbonaceous, micaceous, friable; forms slope	3
Claystone, light-gray, silty, very carbonaceous; forms slope	2

Fall River formation (in part)—Continued

Lower unit:	*Feet*
Sandstone, light-brown, very fine grained, micaceous; thin-bedded at base becoming thick-bedded near top; forms cliff (Keyhole sandstone member)	21
Measured thickness of Fall River formation	56

Partial section of Fall River formation, sec. 11, T. 56 N., R. 65 W., Crook County, Wyo.

[Section 10, pl. 2]

Fall River formation (in part):

Upper unit:	*Feet*
Covered slope; sandy soil	6
Sandstone, gray, very fine grained, slightly micaceous, thick-bedded, massive; medium-scale low-angle cross-stratification; iron oxide-cemented nodules ½ inch in diameter along planes of cross-stratification; top surface of unit stained brown; weathers buff; forms ledge	5
Sandstone, gray, very fine grained, slightly micaceous, thin-bedded; intercalated with variegated red and gray fissile siltstone; forms slope	5
Sandstone, gray, very fine grained, micaceous, friable, thick-bedded; medium-scale low-angle cross-stratification; some 2- to 3-foot interlaminated siltstone units; oscillation ripple marks; weathers buff; forms cliff	7
Siltstone, dark-gray; some intercalated fissile claystone near middle of unit; forms cliff along creek bottom	29
Claystone, dark-gray, carbonaceous, subfissile; forms slope	1
Lower unit:	
Sandstone, gray, very fine grained, micaceous, very thick bedded, massive; cross-stratified near base; in sharp contact with underlying thin-bedded siltstone unit; some thin beds of siltstone less than 1 inch thick near top of unit; top surface weathers rough and contains fossil root systems; weathers buff; forms massive cliff (Keyhole sandstone member)	33
Siltstone, gray; beds are as much as 1 foot thick; even-bedded, thin-bedded; forms slope	8
Measured thickness of Fall River formation	94

Partial section of Fall River formation, sec. 14, T. 55 N., R. 66 W., Crook County, Wyo.

[Section 9, pl. 2]

Fall River formation (in part):

Upper unit:	*Feet*
Sandstone, light-brown, very fine grained, thin-bedded; forms ledges	12
Siltstone, light-brown to light-gray, thinly laminated; forms slope	22
Mostly covered; siltstone, gray, clayey, and silty claystone; carbonaceous zone at base	13

Fall River formation (in part)—Continued	
Lower unit:	*Feet*
Sandstone, light-brown, fine-grained, thin-bedded to thick-bedded; medium-scale high-angle cross-stratification; forms ledges (Keyhole sandstone member)	24
Covered	19
Sandstone, light-gray, very fine grained, slightly micaceous, thin-bedded; medium-scale low-angle cross-stratification; friable; forms ledge	21
Siltstone, clayey, thinly laminated, carbonaceous; vertical tubes or burrows; forms cliff	13
Measured thickness of Fall River formation	124

Partial section of Lakota and Fall River formations, sec. 2, T. 55 N., R. 66 W., Crook County, Wyo.

[Section 7, pl. 2]

Fall River formation (in part):	
Upper unit:	*Feet*
Mostly covered; siltstone, light-brown, thin-bedded; forms slope	8
Siltstone, light-brown, micaceous, laminated; medium-scale low-angle cross-stratification; forms ledge	6
Mostly covered; siltstone, light-brown to light-gray, carbonaceous, thinly laminated; forms slope	20
Claystone, black, carbonaceous; forms slope	1
Lower unit:	
Sandstone, light-brown, very fine grained, thin-bedded to thick-bedded; medium-scale high-angle cross-stratification; forms cliff (Keyhole sandstone member)	23
Siltstone, dark-gray, clayey, fissile; interlaminated with silty claystone that becomes progressively more silty upward; carbonaceous; forms slope	27
Sandstone, light-gray, very fine grained, thin-bedded, slabby; forms ledges	30
Siltstone, light- to medium-gray, slightly carbonaceous, thinly laminated; forms recesses between ledges	7
Siltstone, gray, thinly laminated, carbonaceous; forms ledges	9
Siltstone, gray, carbonaceous, dense; weathers white; massive; forms ledge	1
Siltstone, dark-gray, clayey, carbonaceous, fissile, jarosite-stained; upper 6 inches very carbonaceous; sharp contact with overlying unit; forms slope	3
Measured thickness of Fall River formation	135
Lakota formation (in part):	
Claystone, gray, silty, structureless, iron oxide-stained; contains weathered siderite spherulites in upper part; contact with overlying unit is sharp; forms slope	9
Measured thickness of Lakota formation	9

Partial section of Fall River formation, SE¼ sec. 25, T. 56 N., R. 66 W., Crook County, Wyo.

[Section 5, pl. 2]

	Feet
Fall River formation (in part):	
Upper unit:	
Sandstone, gray, very fine grained, micaceous; pock-marked weathered surface; small- and medium-scale low-angle cross-stratification; carbonaceous trash along planes of cross-stratification; weathers light brown; forms cliff and top of knob	37
Partly covered; siltstone, gray, clayey; interlaminated silty claystone; bottom foot is dark-gray carbonaceous claystone	17
Lower unit:	
Sandstone, gray, very fine grained, micaceous, thick-bedded; cross-stratified on small scale; weathers orange-brown; forms cliff (Keyhole sandstone member)	20
Siltstone, gray, micaceous, ripple-marked on top surface; forms cliff	2
Siltstone, dark-gray, clayey, fissile; forms slope	1
Siltstone, yellowish-brown, micaceous, thin-bedded, cross-laminated; iron oxide-cemented in part; forms ledge	1
Partly covered; siltstone, dark-gray, clayey; carbonaceous matter abundant along stratification planes; thinly laminated; forms slope	6
Partly covered; claystone, dark-gray, silty, subfissile; contains a few iron oxide-cemented nodules 2 to 3 feet above base; forms slope	25
Sandstone, light-gray, very fine grained, micaceous, carbonaceous, thin-bedded; iron oxide-stained on weathered surfaces; forms blocky ledge	10
Measured thickness of Fall River formation	119

Partial section of Fall River formation, S½ sec. 24, T. 56 N., R. 66 W., Crook County, Wyo.

[Section 4, pl. 2; Units marked with asterisk(*) were used to compile section 4, figure 3, which is a composite section]

	Feet
Fall River formation (in part):	
Upper unit:	
*Partly covered; siltstone, brown, laminated	13
*Siltstone, light-brown, very micaceous, laminated to thin-bedded, limy; forms ledges and slope	6
*Partly covered; clayey siltstone; carbonaceous at base	20
Lower unit:	
*Sandstone, gray, very fine grained, micaceous, thick-bedded, massive; poorly cross-stratified on medium scale; top 6 inches contains fossil root systems; weathers orange-brown; forms cliff (Keyhole sandstone member)	22
Siltstone, light-brown, laminated to thin-bedded, cross-laminated; gray claystone at top of unit; forms slope	2
Measured thickness of Fall River formation	63

Partial section of Fall River formation, SE¼ sec. 24, T. 56 N., R. 66 W., Crook County, Wyo.

[Section 4, pl. 2; Units marked with asterisk (*) were used to compile the lower part of section 4, figure 3, which is a composite section]

	Feet
Fall River formation (in part):	
Lower unit:	
Sandstone, gray, very fine grained, micaceous, thick-bedded, massive; oscillation ripple marks near base; medium-scale low-angle cross-stratification; slightly carbonaceous; weathers buff; forms cliff (Keyhole sandstone member)	9
Sandstone, gray, very fine grained, micaceous, thin-bedded, intercalated with some gray siltstone partings; weathers buff; forms ledge (Keyhole sandstone member)	11
*Claystone, dark-gray to medium-gray; slightly silty becoming more silty toward top; forms slope	17
*Siltstone, iron oxide-cemented, forms ledge	.5
*Siltstone, gray, clayey, slightly carbonaceous; intercalated clayey siltstone; forms slope	17
*Siltstone, light-brown, clayey, micaceous; forms ledge	.5
*Siltstone, gray, subfissile; intercalated brown siltstone and clayey siltstone; forms slope	3
*Sandstone, gray, very fine grained, slightly micaceous, thick-bedded; vertical tubes and burrows; forms ledge	6
Measured thickness of Fall River formation	64

Partial section of Fall River formation, sec. 24, T. 56 N., R. 66 W., Crook County, Wyo.

[Section 3, pl. 2]

	Feet
Fall River formation (in part):	
Upper unit:	
Sandstone, gray, very fine grained, friable, thick-bedded; weathers brown; forms rounded knobs	17
Mostly covered; gray clayey siltstone and silty claystone	20
Claystone, dark-gray, carbonaceous; forms slope	.5
Lower unit:	
Sandstone, gray, very fine grained, slightly micaceous; contains clay galls; medium-scale low-angle cross-stratification; thick-bedded, massive; thin interbedded siltstone seams near base of unit; sharp contact with underlying slope; weathers orange-brown; forms cliff (Keyhole sandstone member)	18
Measured thickness of Fall River formation (rounded)	55

Partial section of Fall River formation, NE¼ sec. 14, T. 56 N., R. 66 W., Crook County, Wyo.

[Section 1, pl. 2]

	Feet
Fall River formation (in part):	
Upper unit:	
Covered; sandy soil	6
Siltstone, light-brown, micaceous, sandy, thin-bedded; forms	7
Siltstone, light-brown and gray, clayey; interlaminated fissile silty claystone; forms slope	5
Siltstone, gray, limy; forms ledge	.5
Siltstone, gray and light-brown; interlaminated silty claystone; forms slope	19
Claystone, dark-gray, carbonaceous, subfissile; forms slope	3
Lower unit:	
Sandstone, light-gray, very fine grained, micaceous, thick-bedded; medium-scale cross-stratification; joint surfaces stained black; top surface is iron oxide-cemented; forms cliff (Keyhole sandstone member)	24
Measured thickness of Fall River formation (rounded)	65

Partial section of Lakota and Fall River formations, SE¼ sec. 14, T. 56 N., R. 66 W., Crook County, Wyo.

[Section 2, pl. 2]

	Feet
Fall River formation (in part):	
Upper unit:	
Sandstone, light-brown, very fine grained; silty and limy near base; medium-scale low-angle cross-laminated; upper surface knotty rough weathering; forms cliff	15
Siltstone, light-gray, clayey, interlaminated with some silty claystone in beds less than 2 inches thick; becomes sandy toward top; forms slope	8
Siltstone, gray, limy; thinly laminated along curved planes; forms ledge	.5
Siltstone, gray, clayey; interlaminated siltstone and silty claystone in beds less than 2 inches thick; contains carbonaceous fragments along stratification planes; forms slope	17
Sandstone, yellowish-brown, very fine grained, carbonaceous, friable; intercalated with silty medium-gray claystone; forms slope	2
Claystone, dark-gray, slightly silty, fissile; gradational with underlying unit; forms slope	.5
Claystone, light-gray, silty; stained reddish near contact with underlying unit; forms slope	2
Lower unit:	
Sandstone, gray, very fine grained, slightly micaceous, thick-bedded; medium-scale low-angle cross-stratification; joint surface is stained black; top surface is even and in sharp contact with overlying unit; contains oscillation ripple marks 4 inches in wave length; weathers orange-brown; forms cliff (Keyhole sandstone member)	24

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	Feet
Fall River formation (in part)—Continued	
Lower unit—Continued	
Mostly covered; dark-gray and light-gray silty claystone and siltstone, subfissile; forms slope	39
Sandstone, light-gray, very fine grained, micaceous, thin-bedded; vertical tubes and burrows; forms ledge	5
Partly covered; siltstone, light-brown, micaceous, thinly laminated; slightly carbonaceous along bedding planes; intercalated with medium-gray clayey siltstone; forms slope	15
Measured thickness of Fall River formation	128
Lakota formation (in part):	
Claystone, variegated in maroon, light-gray, orange, and brown; slightly sandy; contains fresh and partly weathered siderite spherulites; claystone is overlain in sharp contact by gray thinly laminated carbonaceous siltstone; forms slope	1
Claystone, variegated in light-gray and maroon; sandy; contains some clayey sandstone in lower part; forms slope	18
Partly covered; sandy claystone and clayey sandstone; forms slope	6
Sandstone, light-gray, fine-grained; contains chert, quartzite, and quartz grains; very thick bedded; medium-scale high-angle cross-stratification; becomes finer grained upward; forms cliff	40
Measured thickness of Lakota formation	65

SKULL CREEK SHALE

The Skull Creek shale, of Early Cretaceous age, is the oldest marine unit of the Lower Cretaceous series in the Black Hills. It was named by Collier (1922, p. 79) and defined as the lowest member of the Graneros shale. Later, Reeside (1944) proposed that the Skull Creek, along with the younger Newcastle, Mowry, and Belle Fourche members, be raised in rank to formations, and since then the term "Graneros shale" has not been used in the Black Hills.

The Skull Creek shale is the bedrock in the bulk of the quadrangle, and it underlies gentle pine-covered slopes throughout much of the area. The thickness of the Skull Creek is not accurately known throughout the quadrangle, but is 240 feet at Strawberry Hill and probably varies but little from this elsewhere in the quadrangle. Elsewhere in the Black Hills the formation ranges in thickness from 230 feet to 270 feet (Robinson, Mapel, and Bergendahl, written communication, 1957).

In the mapped area, the lower 40 to 50 feet of the Skull Creek is dark-gray silty shale with some intercalated laminae of brownish-black siltstone. The sequence weathers to bare brownish-black slopes. The lower part contains iron oxide-impregnated siltstone lenses, ellipsoidal manganosiderite masses as much as 10 feet long, and small limy siltstone concretions that weather bluish-black. The lower part also contains thin bentonite beds, and a few beds of bentonitic shale.

Near the bentonite beds small tablet-shaped calcite fragments have weathered out of the shale, along with some reddish-brown iron oxide-impregnated siltstone chips. The lower 40 to 50 feet of silty shale is consistent enough to be mapped as a subunit in the T. L. Creek quadrangle, which adjoins the Strawberry Hill quadrangle on the west (C. S. Robinson, oral communication, 1958), but lack of outcrop in the Strawberry Hill quadrangle made the separation of this unit impracticable.

The upper 190 to 200 feet of the Skull Creek consists of black greasy flaky shale, which weathers dark gray to black. Near the top of the formation, cone-in-cone concretions are common, as are small limy siltstone concretions similar to those occurring in the lower part. Although the Skull Creek is nearly all shale and silty shale, locally, as in S½ sec. 7, T. 56 N., R. 65 W., a light-gray very fine grained sandstone approximately 6 inches thick crops out near the middle of the formation.

The Skull Creek shale is overlain by the Newcastle sandstone. At Strawberry Hill the contact is gradational from black shale of the Skull Creek to sandy siltstone and interbedded silty shale of the Newcastle and is thus typical of the nature of the contact elsewhere in the northwestern Black Hills (Robinson, Mapel, and Bergendahl, written communication, 1957). The upper contact of the Skull Creek is exposed at only one other place within the quadrangle—in sec. 4, T. 56 N., R. 65 W.—where it is sharp; the slightly silty shale of the Skull Creek is overlain by very fine grained carbonaceous sandstone of the Newcastle.

Fossils reported by Robinson, Mapel, and Bergendahl (written communication, 1957) from the Skull Creek shale in the northern Black Hills include short-necked plesiosaur bones, fish teeth and bones, and a meager assemblage of pelecypods and brachiopods. Waagé (1959) reports arenaceous Foraminifera, linguloid brachiopods, one unidentifiable ammonoid fragment, gastropods, a fragment of *Inoceramus*, and bones of crocodiles and short-necked plesiosaurs. In the Strawberry Hill quadrangle, we found fragmentary vertebrae and other bones which were identified by G. E. Lewis, U.S. Geological Survey, as plesiosaur bones.

In a recent description of the Lower Cretaceous Foraminifera of the Black Hills, Skolnick (1958a and 1958b, p. 275) lists as one of his collecting localities a section of Skull Creek shale and Newcastle sandstone "along section road 7.5 to 8.0 miles northeast of New Haven, Crook County, Wyo., secs. 11 and 14, T. 56 N., R. 66 W." These land sections are wholly within the Strawberry Hill quadrangle, but we are unable to locate the collecting area from this description. Skolnick found the following arenaceous Foraminifera: *Ammobaculites altilis* (Skolnick), *Ammobaculites impolitus* (Skolnick), and *Haplophragmoides paralius* (Skolnick). These Foraminifera were found in zones approximately 19, 110, and 158 feet above the base of the Skull Creek shale. A fourth faunal zone is listed for this locality as "184.4 feet above the base of the Skull Creek shale, in basal shale of the Newcastle sandstone" (Skolnick, 1958b, p. 276).

Mapping in the Strawberry Hill and T. L. Creek quadrangles and a general knowledge of the adjacent areas indicate that the nearest outcrop of Newcastle sandstone to this fossil-collecting locality is about 2 miles north of the Little Missouri River and beyond the northern boundary of the quadrangle. Furthermore, mapping has shown that the minimum thickness of the Skull Creek shale in this region is about 230 feet. We believe that the uppermost faunal zone referred to at this locality, rather than being in basal Newcastle, is in either a silty shale zone in the lower part of the upper third of the Skull Creek or a shaly zone of the upper unit of the Fall River formation, which crops out in the southwest corner of sec. 11 and the northwest corner of sec. 14, T. 56 N., R. 66 W.

The Skull Creek shale was deposited in a marine environment, but, according to Waagé (1959), only the upper part is "normal" marine. The lower part probably was deposited before the appearance of a "normal" marine fauna.

The following sections give details of thickness and lithic variations within the Skull Creek shale.

Section of Skull Creek shale, SE¼ sec. 28, T. 56 N., R. 65 W., Crook County, Wyo.

	Feet
Newcastle sandstone (in part): Claystone, dark-gray, carbonaceous, silty; forms slope	9
Skull Creek shale:	
Shale, black, greasy; cone-in-cone concretions near the base of this unit; forms slope	76
Covered	22
Shale, black; limy siltstone and manganosiderite concretions in this interval; forms slope	86
Shale, brownish-black, silty; tablet-shaped calcite fragments weather out of shale; contains limy siltstone concretions, also vertebrate bones near base of unit; forms slope	50
Siltstone, dark-brown, iron oxide-cemented; forms minor ledge	.3
Bentonite, greenish-white; contains biotite near base; forms slope	.3
Shale, brownish-black, slightly silty; siltstone laminae are common; forms slope	7
Measured thickness of Skull Creek shale (rounded)	242

	Feet
Fall River formation (in part):	
Upper unit:	
Siltstone, light-brown, clayey; intercalated with gray clayey siltstone and silty claystone; forms slope	3
Sandstone, light-brown, very fine grained, micaceous, ripple-marked; forms ledge	3
Measured thickness of Fall River formation	6

Partial section of Fall River formation and Skull Creek shale, sec. 15, T. 56 N., R. 65 W., Crook County, Wyo.

	Feet
Skull Creek shale (in part):	
Shale, black; color contrasts markedly with underlying unit; forms slope	65
Shale, brownish-black; contains a few scattered siderite concretions; slightly silty; weathers brown; forms slope	38
Shale, brown, bentonitic; carbonate laths weather out; weathers to popcornlike surface; forms slope	1
Shale, brownish-gray, slightly silty; selenite weathers out; contains manganosiderite concretions 3 feet in diameter; contains plesiosaur bones; forms slope	9
Measured thickness of Skull Creek shale	113
Fall River formation (in part):	
Upper unit:	
Siltstone, gray, subfissile; interbedded with iron oxide-cemented siltstone; jarosite-stained; forms slope	2
Mostly covered; sandy soil	7
Sandstone, gray, very fine grained, micaceous; carbonaceous along bedding planes in lower part; thin-bedded to thick-bedded; weathers brown; forms cliff	11
Siltstone, light-brown, micaceous, thin-bedded, lenticular; interlaminated with clayey siltstone; forms ledges	3
Siltstone, dark-gray, fissile, clayey; interlaminated with silty claystone and light-brown siltstone; forms slope	20
Measured thickness of Fall River formation	43

Partial section of Skull Creek shale, NE¼ sec. 21, T. 56 N., R. 65 W., Crook County, Wyo.

	Feet
Skull Creek shale (in part):	
Shale, black; forms slope	10
Shale, brownish-gray to black, silty; forms slope	34
Bentonite, yellowish-brown; weathered surface littered with lath-shaped carbonate fragments; poor quality bentonite; weathers to popcornlike surface	1
Siltstone, reddish-brown; weathers into small chips; forms slope	1
Shale, brownish-gray to black; some interbedded siltstone in lower part; forms slope	14
Measured thickness of Skull Creek shale	60

NEWCASTLE SANDSTONE

The Newcastle sandstone of Early Cretaceous age overlies the Skull Creek shale. The formation was named by Hancock (1920, p. 38–40) for exposures near Newcastle, Weston County, Wyo. Reports by Summerford and others (1949, 1950) and by Crowley (1951) describe the lithologic character and thickness of the Newcastle sandstone at various localities in the Black Hills.

Outcrops of the Newcastle sandstone are confined to the top of Strawberry Hill and two small mesas in the NW¼ sec. 4, T. 56 N., R. 65 W. Resistant sandstone beds in the Newcastle form ledges between nonresistant claystone, siltstone, and carbonaceous beds and form the mesa caprock. A complete thickness of the Newcastle sandstone is not present in the area. Approximately 50 feet of Newcastle caps Strawberry Hill and 25 feet caps the two small mesas in sec. 4, T. 56 N., R. 65 W. In the adjoining T. L. Creek quadrangle, C. S. Robinson (oral communication, 1958) reports that the total thickness ranges from 40 to 65 feet. Elsewhere in the northern Black Hills the Newcastle ranges from 0 to 65 feet in thickness.

The Newcastle sandstone is a succession of complexly interbedded claystone, siltstone, and sandstone with admixtures of carbonaceous debris and bentonite. The claystone commonly is dark gray to black and contains some silt, sand, and carbonaceous debris; some of the claystone is bentonitic and weathers to a hard frothy popcornlike surface. Beds of nearly pure bentonite occur locally; in NW¼ sec. 4, T. 56 N., R. 65 W., a 5-foot-thick bed of light-greenish-gray bentonite, which contains biotite near its base, occurs 6 feet above the base of the formation; and at the most easterly point of Strawberry Hill, a nearly white to gray bentonite bed 6 inches thick crops out near the base of the Newcastle.

The siltstone and sandstone range from light gray through brown to dark shades of gray, depending upon the amount of carbonaceous debris in the rock. The sandstone commonly is very fine to fine grained, thin bedded, and locally is cemented by calcium carbonate. The detrital portion of the sandstone consists of more than 95 percent quartz and a few percent of chert, feldspar, and white mica. In the adjoining T. L. Creek quadrangle, C. S. Robinson (oral communication, 1958) reports that sandstone of the Newcastle locally contains highly polished black phosphate pebbles, but none were found in the Strawberry Hill quadrangle.

The Early Cretaceous age of the Newcastle is well established by marine fossils. Mollusks collected by W. W. Rubey from various localities in the Black Hills were identified by J. B. Reeside, Jr., as *Corbula subtrigonalis* Meek and Hayden, *Viviparus* sp., and unidentifiable species of the genera *Protocardia*, *Thracia*, *Tellina*, and *Mactra* (Robinson, Mapel, and Bergendahl, written communication, 1957). No fossils were found in the Newcastle in the Strawberry Hill quadrangle.

The Newcastle was deposited probably in a shallow-water nearshore marine environment. The following measured sections of the Newcastle give details of the lithic variations and thickness in the area:

Partial section of Newcastle sandstone, SW¼ sec. 34, T. 56 N., R. 65 W., Crook County, Wyo.

	Feet
Newcastle sandstone (in part):	
Sandstone, light-brown, very fine grained, slightly carbonaceous and silty, thin-bedded; forms ledges	3
Sandstone, light-gray, very fine grained, friable, carbonaceous; forms ledge	1
Claystone, medium- to dark-gray, silty; interlaminated silty claystone and clayey siltstone; fissile near base; forms slope	12
Claystone, dark-gray to slightly greenish gray, silty; forms slope	3
Sandstone, medium- to dark-brown, very fine grained, silty, carbonaceous; grades upward into siltstone; froms slope	2
Claystone, greenish-gray to black, silty to slightly sandy; slightly iron stained locally; carbonaceous; shaly in upper part; forms slope	4
Bentonite, nearly white to gray; slightly iron stained locally	.5
Siltstone, dark greenish-gray, sandy, laminated; weathers dark brown; contains dark-gray silty shale near base and numerous brown weathering iron-stained layers of siltstone forms slope	5
Measured thickness of Newcastle sandstone (rounded)	31

Skull Creek shale (in part): Shale, black, slightly silty; forms slope.

Partial section of Newcastle sandstone, NE¼ sec. 33, T. 56 N., R. 65 W., Crook County, Wyo.

[Measured by C. S. Robinson, 1955]

	Feet
Newcastle sandstone (in part):	
Sandstone, grayish-white and light yellowish-gray, fine-grained, noncalcareous, micaceous, well-sorted; beds less than 1 inch to 3 feet thick; crossbedded, ripple-marked; carbonaceous in top 3 feet; contains wavy small salmon-colored specks in lower half; forms ledge	14.5
Shale, brownish-gray to black, carbonaceous; contains a bed 2 feet thick of coaly shale about 3 feet above the base	10
Sandstone, grayish-white to yellowish-brown, fine-grained, well-sorted, carbonaceous, noncalcareous; in beds 1 to 4 feet thick; locally crossbedded; forms ledge	14.5
Partly covered; mostly interbedded dark-gray shale and grayish-white fine-grained sandstone	2
Shale, grayish-black, contains a few laminae of brown limonitic sandy shale and fine-grained sandstone	6
Measured thickness of Newcastle sandstone	47

Partial section of Newcastle sandstone, NW¼ sec. 4, T. 56 N., R. 65 W., Crook County, Wyo.

	Feet
Newcastle sandstone (in part):	
Sandstone, light-gray, very fine grained, clayey, limy; laminated near base becoming thin bedded at top; forms ledge that caps top of hill	6
Claystone, dark-gray, slightly silty, structureless; gradational through 2 inches with underlying unit; forms slope	4
Lignite, black, jarosite-stained; forms slope	4
Bentonite, greenish-gray near base becoming greenish-white at top; biotite very common at base, absent in upper part; weathers to popcornlike surface; forms slope	5
Shale, black; contains carbonaceous fragments along stratification planes; sand grains occur mixed with shale; sharp contact with overlying unit; forms slope	.7
Sandstone, light-brown, very fine grained, carbonaceous near base; friable; contact with underlying Skull Creek shale is sharp; forms steep slope	6
Measured thickness of Newcastle sandstone (rounded)	26
Skull Creek shale (in part): Shale, black, greasy, slightly silty; contains cone-in-cone concretions	20

QUATERNARY SYSTEM

ALLUVIUM

Quaternary alluvial deposits of clay, silt, and sand fill the valley of the Little Missouri River in the northwestern part of the area and extend for several miles up the canyons of Elkhorn and Tie Creeks. The deposits are thin; in Elkorn and Tie Creeks they probably are no thicker than 20 feet, but in the valley of the Little Missouri River they probably are at least 30 feet thick. A thin deposit of alluvium occurs also along Sourdough Creek.

SEDIMENTARY STRUCTURES

A preliminary study of the uranium deposit near the base of a thick sandstone lens at the Busfield mine, along with studies of uranium deposits elsewhere in the northwestern Black Hills (Bergendahl, Davis, and Izett, 1961; C. S. Robinson, oral communication, 1958; Robinson and Gott, 1958), indicated that sedimentary structures probably were of major importance in localizing uranium deposits in this region. We therefore directed our efforts toward studies of primary sedimentary structures, including thickness relations among sandstone beds in the Fall River formation, particularly in areas adjacent to the mine. Prominent sedimentary features include cross-stratification, ripple marks, scours, knobs, and sandstone lenses and bars. Each of these features is described below.

CROSS-STRATIFICATION

Cross-stratification is a prominent feature of most sandstone beds in the Fall River formation, as well as in parts of the Lakota formation. Two distinct types of cross-stratification were observed, both of which range from small scale to medium scale and from thinly cross laminated to thinly crossbedded. These two types are briefly described below, using definitions and classifications proposed by McKee and Weir (1953).

The first and more common type is associated with very fine grained sandstone and consists of simple high-angle cross-stratification; each set is lenticular, concave, and plunging. In the sandstone studied at the Busfield mine, where this type is very well exposed, planes of cross-stratification commonly are occupied by thin seams of carbonaceous debris.

The second type is associated with fine-grained or coarser sandstone and seems to be rare in the Fall River formation, although it is observed commonly in Lakota rocks. This type consists of high-angle cross-stratification; each set is tabular and is bounded by planar surfaces. A good example of this type was observed in the lower 15 feet of the Fall River formation, along Tie Creek, in sec. 21, T. 56 N., R. 65 W.

RIPPLE MARKS

Ripple marks are a feature commonly preserved in sandstone beds of the Fall River formation, but are rare in most other rock units in the quadrangle. The ripple marks are similar to those described by McKee (1954) as the parallel ripple mark type, which consists of nearly parallel crestal ridges that may or may not be symmetric in cross section. The ripple marks in the Fall River are all nearly symmetric in cross section and have wave lengths of approximately 5 inches. The index (ratio of wave length to amplitude) ranges between 8 and 12. According to McKee, various geologists believe that this range is indicative of water current action rather than wind action. A few secondary crests have been formed in the troughs between the larger crests. Evans (1943, p. 35–37) believes that such secondary crests are a response to decreasing wave size where the reciprocatory movement on the bottom is about half that which formed the original ripples.

Figure 3 is a rose diagram showing the strike frequency, in percent, of the ripple marks in sandstone beds of the Fall River formation. The greatest frequency of strikes occurs at N. 60°–70° E., but the group of readings falling into this interval is not a high enough proportion of the total to be statistically representative of the strike trend.

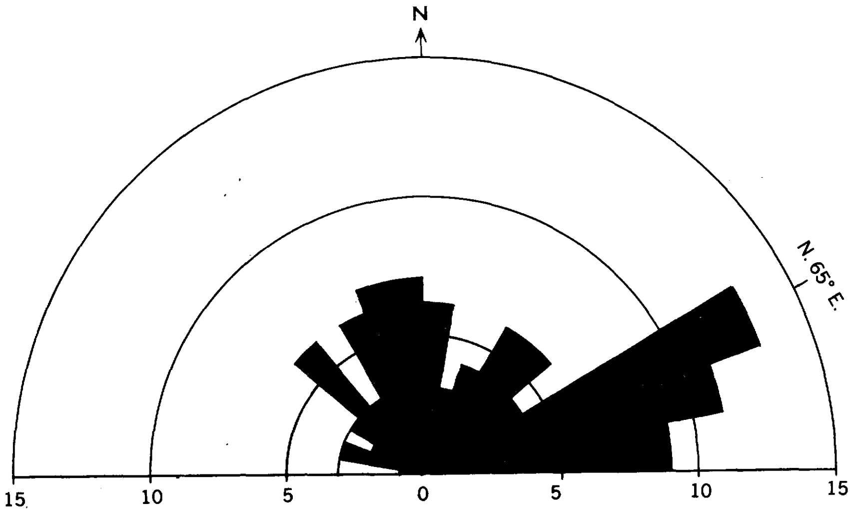

FIGURE 3.—Rose diagram showing strikes of ripple marks in sandstone beds of the Fall River formation.

Because the parallel ripple marks are very nearly symmetric and do not have large wave lengths, they probably were formed in areas of shallow water far enough removed from the Early Cretaceous seaway to be unaffected by tides or other strong currents. The random orientation of the strikes of the ripple marks indicates alternating directions of wave action, possibly in response to changing wind directions.

SCOURS

Scours on the top surface of the uppermost sandstone bed of the Fall River formation were observed at several places within the quadrangle. The general shape of the scours is similar to the shape of the hull of a canoe, except that the scours have rounded ends. The scours are as much as 40 feet long and attain a width of nearly 10 feet. The surfaces of the scours are covered with ripple marks, which are generally transverse to the long dimension of the scour. The surfaces commonly are frosted with a veneer of iron oxide-impregnated siltstone—the erosion remnant of the material which previously filled the scour. Figure 4 shows part of a ripple-marked scour partially filled with siltstone. We have not found any previous description of this type of scour, but we believe that the scours probably were cut into sand bars by strong currents and that oscillation ripple marks subsequently were formed by wave action on the scoured surfaces.

FIGURE 4.—View of a canoe-shaped scour cut into the top sandstone bed of the Fall River formation showing the rough surface of the sandstone bed and oscillation ripple marks which are transverse to the length of the scour. Hammer indicates scale. NE¼ sec. 27, T. 56 N., R. 65 W.

SANDSTONE KNOBS

A rare sedimentary structure seen only in the NW¼ sec. 28, T. 56 N., R. 65 W., on the top surface of the Keyhole sandstone member, consists of small rounded knobs of sandstone 2 to 3 feet in diameter and 1 to 2 feet high. The sandstone knobs commonly have associated arcuate depressions that appear to be the inverse counterpart of the knobs. C. S. Robinson (oral communication, 1958) has found excellent exposures of these sandstone knobs along Dinky Creek in the T. L. Creek quadrangle. The overlying silty claystone and clayey siltstone were deposited over the knobs, but the doming of these sediments dies out a few feet above them. The origin of the knobs is unknown.

SANDSTONE LENSES AND BARS

Abnormally thick parts of the sandstone in the upper unit of the Fall River formation have proved to be both lenses and barlike features, which give rise to an irregular upper surface on the sandstone.

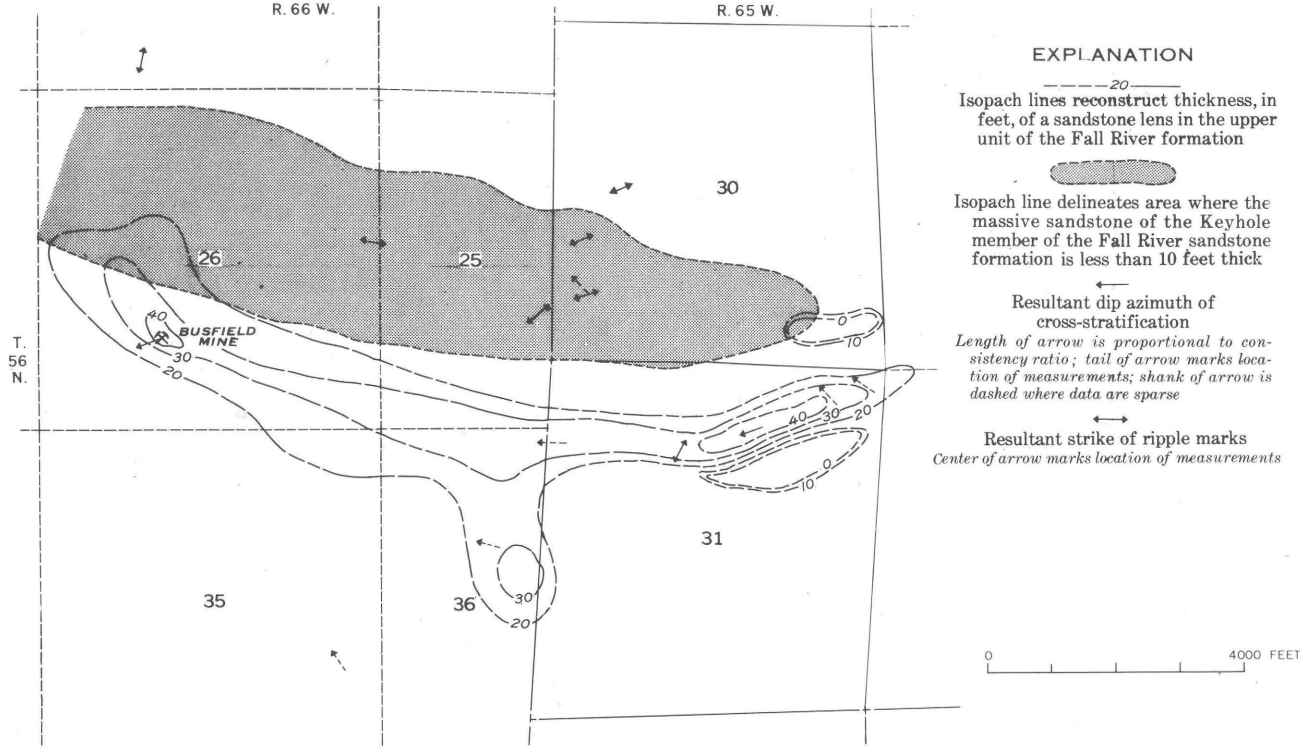

Figure 5.—Map showing abnormal changes in thickness of two sandstone beds in the Fall River formation, T. 56 N., Rs. 65 and 66 W., Crook County, Wyo. See page 41 for definition of consistency ratio.

The Busfield mine is located at the west end of the largest of the lenses. Figure 5 shows the configuration of this lens and its spatial relation to the thinned area of the Keyhole sandstone member adjacent to the north.

The 20-foot isopach line approximately delimits the lens, because elsewhere in the quadrangle the sandstone in the upper unit is rarely more than 12 feet thick. The lens is roughly arcuate in plan and extends from the west edge of sec. 26, T. 56 N., R. 66 W., eastward 2.5 miles to the east edge of sec. 31, T. 56 N., R. 65 W. In the NW¼ sec. 31, T. 56 N., R. 65 W., the lens is only 800 feet wide, but it attains a maximum width of 3,500 feet in sec. 36, T. 56 N., R. 66 W. The lens has a maximum thickness of 43 feet near its west end (at the Busfield mine) and is of comparable thickness near the east end. Where the lens is thickest it rests nearly on the top of the Keyhole sandstone member.

The sandstone within the lens is very fine grained and is well sorted, as shown in table 1 (samples G–5750, G–5751, G–5752, and G–5753). It is light gray on fresh surfaces but weathers light brown, and it commonly forms a prominent ledge along the canyon rims. The sandstone generally is thin bedded but locally, where it is thickest, it is thick to very thick bedded. It consists of more than 95 percent quartz grains and minor amounts of chert, feldspar, and white mica. Heavy minerals identified from the 0.062 to 0.125 mm size fractions are, in decreasing order of abundance, tourmaline, zircon, chloritoid, garnet, staurolite, and rutile.

Cross-stratification and ripple marks are not uncommon features of the sandstone in the lens, and the attitudes of these sedimentary structures are shown on the isopach map (fig. 5) by arrows. The shank of each arrow points in the dip direction of the cross-stratification and the length of the shank is proportional to the consistency ratio as defined by Reiche (1938).[1] The shank of each double-pointed arrow indicates the strike direction of the ripple marks and the length is proportional to the consistency ratio. The shanks of the arrows are dashed where not enough readings were obtained to reach the flatness point, that is, the point at which one additional reading will not change the resultant vector more than 5° (Reiche, 1938). Exposures of cross-stratified sandstone that would yield a sufficient number of readings to be statistically reliable are sparse, but at the few scattered localities where measurements were made, the data indi-

[1] The consistency ratio is an expression of the consistency of dip direction of a group of readings at a given locality. If all readings of dip direction were the same, the grouping would be perfect and the consistency ratio would be unity; if there were no grouping of readings, the consistency ratio would approach zero as the number of readings increases.

cate that the currents which deposited the sand in the lens were dominantly from the east. Most of the resultant strike directions of the ripple marks north of the sandstone lens nearly parallel the axis of elongation of the lens. In the one area within the lens where data are obtainable, however, the resultant strike direction of ripple marks is nearly transverse to the elongation.

The shaded portion on figure 5 shows the area in which the massive sandstone of the Keyhole member is absent or where it is less than 10 feet thick. A photograph (fig. 2) shows the thinning and apparent pinching out of the massive sandstone at the edge of the thinned area. The axis of thinning of the massive sandstone in the Keyhole member nearly parallels the axis of elongation in the sandstone lens of the upper unit, but the relation, if any, between the thinning in the massive Keyhole sandstone and the thickening of the upper unit, other than the axial parallelism, is unknown.

The origin of the sandstone lens in the upper unit of the Fall River is not clearly known. Field data suggest that the lower surface of the lens is gradational with the underlying silty claystone of the upper unit. Nowhere does the sandstone lie on a scoured surface of silty claystone. Furthermore, the thick-bedded sandstone nearly everywhere grades laterally into thin-bedded sandstone, which in turn interfingers with silty claystone. Only in the NW¼ NE¼ sec. 31, T. 56 N., R. 65 W., could a sharp contact between fine-grained sandstone and structureless claystone be seen. The structureless gray claystone adjacent to the sandstone lens grades upward into the shale of the Skull Creek.

Because the sandstone lens does not lie on a scoured surface of silty claystone, it probably does not represent a river channel deposit. The symmetric parallel ripple marks are a further indication that strong tidal or river currents were not operating in this area at the time of deposition.

Similar elongate sandstone lenses called cheniers have been described by Fisk (1955, p. 392). The cheniers and the sandstone lens at the Busfield mine have several characteristics in common. Both are relatively thin and narrow as compared to their length, and lie on silty claystone. Both consist of well-sorted cross-stratified sandstone, and both are doubly convex or flat bottomed in cross section. Fisk believes that the cheniers are ancient beach ridges that have resulted from the progradation of the gulf shore in a marginal deltaic environment. We believe that the lens at the Busfield mine might be the result of deposition under somewhat similar near-shore bar-forming conditions, but probably not in an area of open seaway.

Elsewhere within the quadrangle, isolated outcrops show dipping strata of thin-bedded sandstone and siltstone on an irregular surface of thicker-bedded sandstone in the upper unit of the Fall River. Figure 6 illustrates one such outcrop. We believe that the irregularities over which the dipping strata have been deposited represent either small barlike sedimentary structures, or erosional features on the otherwise regular upper surface of the sandstone bed.

STRUCTURE

GENERAL FEATURES

The Strawberry Hill quadrangle lies on the northwest flank of the Black Hills uplift just west of its northwest axis and a few miles from the northward- and northwestward-trending monoclines that delimit the uplift in this area (pl. 3). The edge of the exposed Precambrian core of the uplift is approximately 40 miles southeast of Strawberry Hill, and the thickness of sedimentary rocks exposed in the interval between the Precambrian surface and the Newcastle sandstone on top of Strawberry Hill is about 3,750 feet, or about half the thickness of

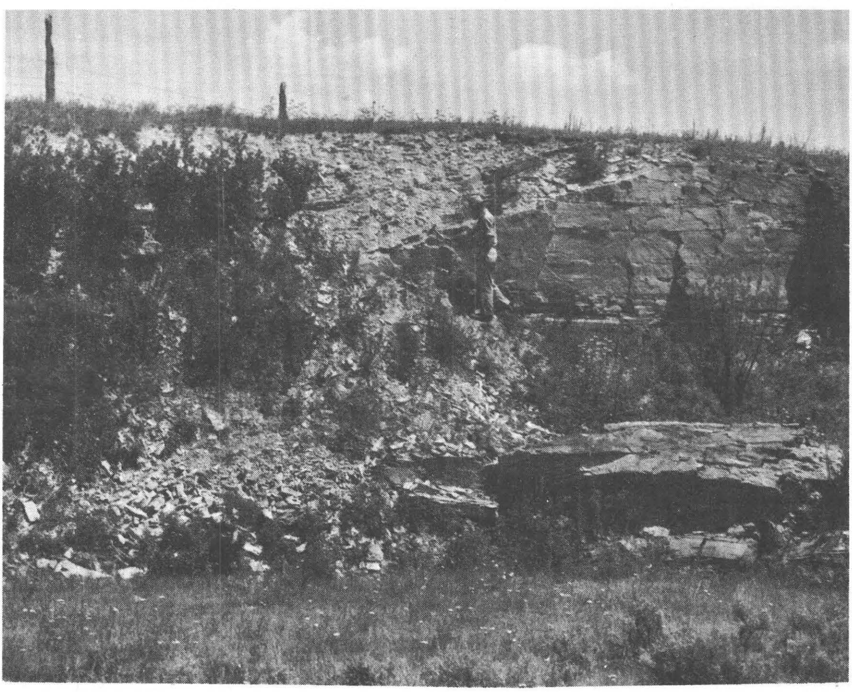

FIGURE 6.—View of dipping strata of very thin bedded sandstone and siltstone covering irregular surface in upper unit of the Fall River formation. N½N½ sec. 2, T. 55 N., R. 66 W.

the sedimentary blanket that overlay the Precambrian at the time of major uplift. The regional dip of the rocks in the Strawberry Hill area is about 1° to the northwest, resulting in a total structural relief within the quadrangle of approximately 1,100 feet.

The nature of the tectonic forces that produced the elongate dome that constitutes the Black Hills uplift has been a subject of some discussion. The two major hypotheses are (a) that uplift was caused by forces acting vertically, probably the result of Tertiary batholith intrusion (Noble and others, 1949; Noble, 1952) and (b) that uplift was caused by compressional forces, probably originating from the southwest, that acted against the foreland of the Rocky Mountain geosyncline and resulted in the upward movement of blocks (Chamberlin, 1945). In both hypotheses, the zones along which vertical movement took place and which controlled the final shape of the uplift are thought to have been previously established zones of weakness in the basement rocks.

The structure within the Strawberry Hill quadrangle is shown by the structure contours on the geologic map (pl. 1). The datum for contouring is the top of the Keyhole sandstone member of the Fall River formation. Structure contours on this datum show not only the tectonic features but also the "apparent structure," that is, irregularities on the structural datum that are nontectonic in origin. Variations in thickness of the lower unit of the Fall River formation indicate that apparent structure has been introduced by pre-Fall River erosion, by pre-Keyhole depositional irregularities, or by post-Keyhole compaction of sediments, or perhaps by some combination of these factors.

The contour interval of 20 feet was chosen because of an apparent spatial relation between the localization of uranium minerals and minor structural features, which could not be depicted as accurately with a larger contour interval. In many areas control points on the datum are abundant enough so that minor complexities in structure, whether due to tectonic forces or to sedimentary irregularities, can be shown rather accurately at this interval. In other areas, however, owing to lack of outcrops of the datum, the structure contours are generalized.

The general-structure of the quadrangle and its relation to the structure of surrounding areas is shown by the tectonic map of the Devils Tower 30-minute quadrangle (pl. 3). Much of the Strawberry Hill quadrangle is on a wide, northeastward-trending, rudely terraced area. To the southeast and northwest, the strata dip on a regional scale a little more steeply and more uniformly to the northwest.

FOLDS

Folds are the dominant structural features in the area. Superimposed upon the broadly terraced area previously mentioned are many subordinate folds, the most conspicuous of which are the prominent domes shown by the structure contours (pl. 1). At least five of the domes are well defined, measuring about a mile across and having closures ranging from about 50 to more than 140 feet.

All the domes are approximately circular in plan but some are slightly elongated in an east-west or northeast-southwest direction; each has steep sides and a relatively flat broad top. Domes along Elkhorn, Tie, and Bronco John Creeks have been breached, and the change in dip between the steep sides and flat tops of the structures can be readily observed.

The structural irregularities in secs. 30 and 31, T. 56 N., R. 65 W., are more apparent than real. They consist of two small domes and an adjacent depression. In this area the massive sandstone of the Keyhole member thins abruptly from the top, and the depression reflects the decrease in altitude of the datum over the thinned area. The domes, however, are south of the thinned area and probably are tectonic in origin.

All the domes, along with similar structures both east and west of the quadrangle, have definite alinements in two directions nearly at right angles to one another, N. 60° E. and N. 20°–25° W. The two directions of alinement are approximately parallel to certain faults and folds in the Precambrian rocks in the central and southern parts of the Black Hills (J. J. Norton and J. A. Redden, oral communication, 1958).

It is not known if any of the domes in this area have cores of igneous rock, for none of them has been deeply drilled. Outside the area several drill holes have cut porphyry masses, perhaps sills, and to the south and southeast, porphyry of Tertiary age crops out in the Missouri Buttes, Devils Tower, and Bear Lodge Mountains. It is our opinion that these domes probably are the result of the forcible intrusion of small igneous plugs into the sedimentary sequence from depth and that the location of these small plugs was controlled by intersecting zones of weakness in the Precambrian rocks through which they were intruded. The intrusion of small stocklike bodies of igneous rock and the resultant doming that has occurred in the Black Hills have been briefly summarized by Noble and others (1949, p. 338–340).

The age relation between the major uplift and the emplacement of dikes, sills, stocklike bodies, and so-called laccoliths has been discussed by several workers (Jaggar, 1904, p. 29–30; Noble and others, 1949,

p. 348). Field studies by these geologists have shown that the Tertiary intrusive rocks were emplaced probably in succession over a period of time and that the intrusions accompanied or followed the major uplift. The domes that we have studied in the Strawberry Hill quadrangle are, as a general rule, somewhat steeper and have a greater structural relief on the north or northwest sides. These features are interpreted as evidence that doming followed the regional tilting in this area.

Between the larger domes are areas of irregular structural relief, consisting of synclines, domes, noses, and terraces. These subordinate features are the response to a combination of the forces that caused regional uplift and the later vertical forces that produced the several larger domes. Apparent structure, thickening of sedimentary units rather than deformation of the units, also is reflected to an unknown but lesser extent.

FAULTS

Faults are of minor importance in the area; they are few in number, and the vertical displacement on each is small. In general, faults are detected only where exposures show offsets in competent sandstone beds; only rarely can a fault be detected in silty or clayey units. More faults probably exist in the area than are shown on the geologic map. Most of the faults mapped are of such small magnitude that offsets of a sandstone bed across covered areas might well go unrecognized or, where a distinct difference in elevation of a given horizon is noted, such difference might be erroneously interpreted as a fold or an irregularity in the surface of the sandstone bed. Faults probably occur also in the soft shale of the Skull Creek, but none have been recognized because of poor exposures and the lack of marker beds.

With a few exceptions, the faults strike northeast; none have a vertical displacement greater than 20 feet, and none can be traced along strike for more than about 1,500 feet. All faults or fault groups can be explained as gravity faults produced either in response to tension in a generally northwest-southeast direction or, locally, to a tensional component acting nearly at right angles to this general direction. G. B. Gott and R. W. Schnabel (written communication, 1958) suggested that faults of this magnitude observed in the southern Black Hills might be due to subsidence in response to the solution of certain of the underlying rocks.

Two of the faults, one on the north side of Sourdough Creek, in the SW¼ sec. 11, T. 55 N., R. 65 W., the other on the east side of Elkhorn Creek in the southernmost part of sec. 13, T. 56 N., R. 66 W., are spatially related to major domes and may be genetically related to them. No other faults were found in the major domed areas.

Although faults are few in number in this quadrangle, they are common and are of greater magnitude in the area immediately to the west, apparently because of proximity to the bifurcation of the monocline (pl. 3).

JOINTS

Joints are conspicuous in most of the rocks in this area. Two prominent sets of vertical joints that strike approximately at right angles to one another can be seen along some of the canyon walls, and impart a large-scale sawtooth appearance to the exposed edges of sandstone beds. The joints in sandstone beds commonly are not continuous through overlying and underlying nonresistant siltstone and shale.

Joints, in conjunction with the large domes, have helped fix the location of the northwestward-flowing streams and thereby have contributed to the development of the present topographic features. Figure 7 is a rose diagram showing the strike frequency of joints in the area. Most joints observed dip within about 5° of vertical. Strong maximums occur at N. 40°–50° E. (about 13 percent) and at N. 40°–50° W. (about 19 percent), and on either side of these maximums are additional concentrations of strike directions. A few other smaller clusters occur, as can be seen in the diagram. The general rectangular pattern of the joints is rotated slightly from the rectangular alinement of the major domes.

The degree to which joints are open or closed is dependent upon their relation to the topography. Along canyon walls joints in sandstone beds underlain by nonresistant units tend to open if they parallel the drainage, whereas those transverse to the drainage remain closed and less conspicuous. Using relative openness as a criterion, the tension and shear joints cannot readily be distinguished in the field, and from place to place, depending upon the direction of the drainage and grain of the topography, different sets of joints are open and thus superficially appear to be tension sets. Because of the predominance of northeastward-trending gravity faults, the northeastward-trending joints probably are of tensional origin, and the concentrations of joints adjacent to the N. 40°–50° E. maximum might be due to related shears. The same reasoning might be applied to the N. 40°–50° W. maximum and the adjacent concentrations, except that there is less evidence, in the form of gravity faulting, that this maximum represents a group of tension joints.

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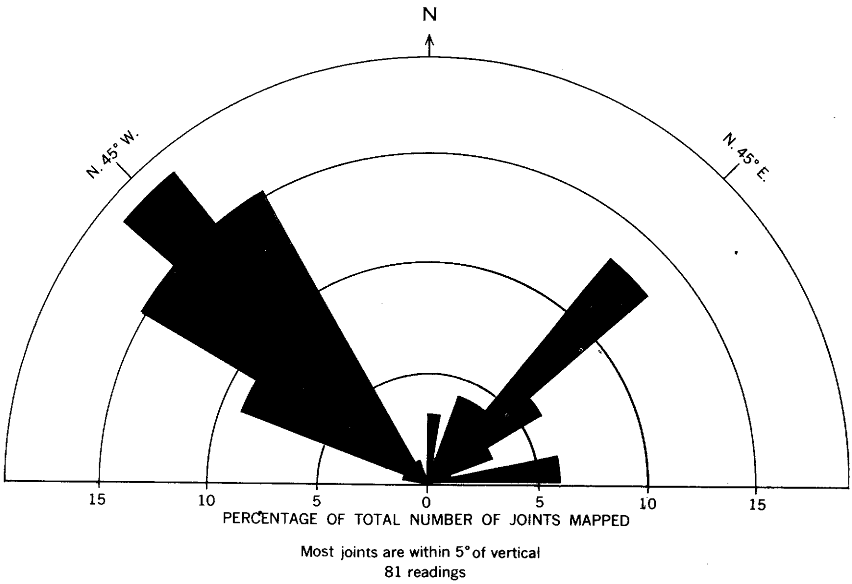

FIGURE 7.—Rose diagram showing strikes of joints in sandstone beds in the Strawberry Hill quadrangle, Wyoming.

If the two groups of joints represented by the concentrations shown in figure 7 are conjugate joint sets, each consisting of a tension set and two related shear sets, they can be explained either by compressional forces acting in a northeast-southwest direction or by vertical forces that caused stretching of the sedimentary blanket in both a northwest-southeast direction and a northeast-southwest direction. Analysis of joint readings taken in the T. L. Creek quadrangle to the west shows the same general joint and fault relationship within that area, but the joint pattern is rotated slightly counterclockwise relative to the pattern in the Strawberry Hill quadrangle (C. S. Robinson, oral communication, 1958).

LANDSLIDES

Landslides, which range in size from small scattered blocks up to irregular masses several hundred feet in length and width, occur at several localities in the mapped area.

In the canyon of Sourdough Creek, blocks of sandstone from the Lakota and Fall River formations are strewn over the lower slopes. Several large masses consisting predominantly of sandstone of the Fall River occur in the southeastern corner of the mapped area. They are irregular bodies with hummocky surfaces, which have apparently slumped down across the nonresistant claystone of the Lakota formation and now rest on slopes of the Lakota and Morrison formations.

At places around Strawberry Hill small landslide blocks (none of which were mapped) of Newcastle sandstone are scattered on the slopes of the Skull Creek shale. One larger landslide block of Newcastle was mapped in sec. 4, T. 56 N., R. 65 W., near the north boundary of the quadrangle.

The Mowry shale of Early Cretaceous age, which normally overlies the Newcastle sandstone, occurs at several places within the quadrangle as isolated masses some of which rest on Skull Creek shale within 10 to 15 feet of the Fall River-Skull Creek contact. These anomalous occurrences of Mowry shale are shown on plate 1. One small mass of Mowry in SE¼ sec. 20, T. 56 N., R. 65 W., consists of hard gray siliceous shale that contains many fish scales concentrated along the planes of fissility. Local ranchers have used small amounts of the shale for surfacing roads that cross areas of gumbo soil of the Skull Creek shale.

These isolated blocks of Mowry shale are probably slump blocks that have slid down over the Newcastle sandstone, where it is thin or nonresistant, onto the Skull Creek. The evidence suggesting this origin includes: (a) blocks of mixed Newcastle and Mowry were found at two localities; (b) in sec. 4, T. 56 N., R. 65 W., a block of Newcastle was found downslope from a Newcastle outcrop, and farther downslope, a block of Mowry shale with a few scattered Newcastle blocks was found; (c) a close spatial relation exists between ridges of Skull Creek and the patches of Mowry shale; and (d) no evidence of structure such as faults or distorted beds was observed in the bedrock underlying the blocks of Mowry.

STRUCTURAL HISTORY

The small size of the mapped area relative to the entire Black Hills region precludes any generalization regarding the origin of the regional structure. Events in the structural history of the Black Hills have been summarized by Darton (1909, p. 76–77), Noble and others (1949), and later by Noble (1952).

Noble (1952) cities evidence for post-Precambrian deformation in or near the Black Hills region prior to the period of major uplift which produced the present Black Hills. Major uplift began in latest Cretaceous or early Tertiary time and was accompanied or followed by igneous intrusions with attendant doming.

It has been suggested by Chamberlin (1945) and Noble (1952) that the Black Hills uplift may owe its present configuration and general structural features to lines of weakness established in the Precambrian basement or even deeper-seated rocks before the major Laramide deformation. The alinement of the domes in the Strawberry Hill quadrangle indicates a possible control by Precambrian structure. On the other hand, the pattern of joints and folds other than the domes apparently developed independently of preexisting lines of weakness and may indicate more closely the direction of Laramide stress.

The major uplift was completed and configuration of the Black Hills established before Oligocene time. Darton (1909) postulates several thousand feet of uplift since Oligocene time, as evidenced by the wide vertical distribution of Oligocene sediments, but Noble and others (1949, p. 349) present evidence which indicates that little, if any, uplift has occurred in the Black Hills since Oligocene time.

ECONOMIC GEOLOGY

Uranium in minable quantities is the most recently discovered of the useful materials that occur locally within the sedimentary rocks in the northern Black Hills region. Other materials that have long been known to occur in exploitable concentrations include bentonite, coal, oil, and rock suitable for use as road metal. Each of these materials, except coal, is presently being produced on a commercial scale within the region. Within the Strawberry Hill quadrangle, however, only uranium has been produced commercially.

URANIUM

Two uranium-ore deposits occurred within the Strawberry Hill quadrangle. The Busfield mine and the Vickers mine were developed on these deposits and became two of the larger productive uranium mines in the northern Black Hills.

Concentrations of uranium minerals occur at several localities elsewhere in the northern Black Hills. Some are of commercial size and grade, whereas others are small mineralized areas of anomalous radioactivity, a few of which might be marginal ore deposits. Up to 1958, less than a dozen deposits in the region had been mined commercially. Other large productive deposits, in addition to the Busfield and Vickers, have been the Carlile, which has been described by Bergendahl, Davis, and Izett (1961), the Hulett Creek group, and the Quad, both of which have been described by C. S. Robinson (written communication, 1958).

All commercial uranium production in the northern Black Hills has come from sandstone beds of the Lakota and Fall River formations; the Carlile deposits were in a lenticular sandstone bed near the top of the Lakota formation (Bergendahl, Davis, and Izett, 1961), and the other deposits are in sandstone beds in the upper unit of the Fall River formation. Other occurrences of uranium minerals and areas of anomalous radioactivity are mainly in the conglomeratic sandstone near the base of the Lakota formation, in silty sandstone near the bottom of the Fall River, and, rarely, in the sandstone of the Newcastle. A small occurrence of uranium minerals was observed just south of the quadrangle in the Keyhole sandstone member where the massive sandstone thins to considerably less than its normal thickness. Vickers (1957) has described small occurrences southwest of Belle Fourche, S. Dak., in a 6- to 10-foot thick sandstone bed in the Fall River. We believe that this sandstone also is the Keyhole member in an area of abnormal thinning. It seems significant that the only known uranium occurrences in the generally thick, clean, well-sorted sandstone of the Keyhole member are in areas where the massive sandstone has become abnormally thin.

The uranium deposits fall into two main categories—oxidized deposits which occur above the ground-water table and consist principally of carnotite and tyuyamunite, and unoxidized deposits which occur below the tops of perched ground-water tables and consist mainly of coffinite and possibly some uraninite. All deposits are associated with carbonaceous debris, either as finely divided fragments disseminated throughout the sandstone host rock or concentrated in thin layers along planes of stratification or cross-stratification. The deposits are all tabular, commonly irregular in plan, and concordant with the gross stratification of the host rock. The size of individual deposits varies markedly; horizontal dimensions range from tens to hundreds of feet. The thickness rarely is greater than 6 feet and averages probably about 4 feet. Similar deposits in the southern Black Hills have been described by Bell and Bales (1955).

Production of uranium from mines in the northern Black Hills through September 1957 was approximately 50,000 tons of ore with an average content of about 0.2 percent U_3O_8.

BUSFIELD AND VICKERS MINES

The Busfield mine and the Vickers mine have been two of the larger productive uranium mines in the northern Black Hills. Up to October 1957, according to the records of the Atomic Energy Commission, the Busfield mine had produced approximately 9,000 tons of ore containing 0.17 percent U_3O_8, and the Vickers mine had produced between 9,000 and 10,000 tons of ore containing 0.18 percent U_3O_8. Because the two mines are within half a mile of one another and the geology of both is similar, they will be discussed together.

The mines are near the west edge of the quadrangle in sec. 26, T. 56 N., R. 66 W.; the Busfield mine is in the SW¼ and the Vickers mine is in the NW¼ (pl. 1). The mine area lies west of Elkhorn

Creek near the east base of a ridge of Skull Creek shale the top of which is 80 to 100 feet above the ground surface at the mines. The few square miles that lie west of Elkhorn Creek and east of the Skull Creek ridge are here referred to as the Elkhorn Creek mining area.

According to B. A. MacPherson (1956) of the Atomic Energy Commission, anomalous radioactivity at the Busfield deposit was discovered in 1952 by airborne reconnaissance by the Commission. Messrs. William and Richard Busfield staked claims shortly thereafter in the area which included the deposit. In 1954 the Commission drilled 6 holes which indicated that ore-grade material was present in the area. The Sodak Uranium and Mining Co. of Hot Springs, S. Dak., then leased the property from the Busfields and carried out an intensive drilling program that outlined the ore body. After the initial opencut was made to the ore zone, mining progressed underground and the mine was worked until December 1955.

In the spring of 1956, the Sodak Uranium and Mining Co. decided that because of the blanketlike configuration of the ore body and the possibility of caving because of the open joints in the sandstone overlying the ore body, an open-pit operation would be faster, safer, and more economical. During the summer of 1956, the overburden was stripped, and the ore was mined by open-pit methods. Removal of the ore body was completed and the mine closed down in 1957. The outline of the opencut as it was in September 1956 is shown on the geologic map of the mine area (pl. 4). When the mine was revisited during the summer of 1957, several feet of water in the pit prevented us from entering two small drifts that had been driven into the pit walls.

The Vickers deposit, half a mile to the northwest, was discovered after the Busfield deposit. Messrs. Sheffield and McLean in the spring of 1956 discovered ore-grade material in a drill hole. No surface indications of an ore body had been noted. The ground was leased and an intensive drilling program begun by an organization that later became the Hilmer-Tessem Uranium Corp. Stripping was begun in August 1956, and by mid-winter the major part of the ore body had been mined out. The outline of the open pit as it was in September 1956 is shown on plate 4. By the summer of 1957, the pit had been nearly doubled in size and another small pit had been opened over an area of high radioactivity to the northeast (pl. 4) just east of the Kay 5 west-side claim line. These pits contained several feet of water and were inaccessible in the summer of 1957. It has been reported that another operator worked the mine on a small scale during the winter of 1957–58.

GEOLOGY

STRATIGRAPHY

Rocks exposed in the area adjacent to the Busfield and Vickers mines consist of siltstone, silty claystone, thin- to thick-bedded sandstone, and black shale belonging to the lower and upper units of the Fall River formation and to the lower part of the Skull Creek shale (pl. 4). Bottoms of small stream valleys commonly are covered with a few feet of alluvial sand and silt.

Exposures generally are poor, except along stream cuts, and rarely is a complete section from stream level to the top of a cut exposed. The most nearly complete section observed in the area is at the intersection of two stream cuts 1,900 feet directly east of the Vickers mine. The section measured at this point follows.

Section of parts of the lower and upper units of the Fall River formation, N½ sec. 26, T. 56 N., R. 66 W., Crook County, Wyo.

Fall River formation (in part):	
Upper unit:	*Feet*
Sandstone, light- to medium-brown, very fine to fine grained, thin-bedded, sparsely micaceous, somewhat carbonaceous, interbedded with shaly siltstone; contains a few thin interbeds of shaly, silty claystone and hard iron oxide-cemented sandstone; beds range from less than 6 inches to about 1 foot thick; unit capped by 2–3 inches hard very dark brown iron oxide-cemented very fine grained sandstone; top of hill	5.8
Sandstone, light- to medium-brown, very fine grained, well bedded, interbedded with light-brown siltstone and light-brown to gray shale; beds as much as 1 foot thick; contains abundant mica and carbonaceous fragments along bedding planes; top 3 feet forms ledge; ledge locally mottled reddish-orange; this unit is the ore-bearing sandy interval at the Vickers mine	9.0
Siltstone, gray to medium-brown, thin-bedded to shaly, and shaly claystone; hard iron oxide-cemented siltstone bed 6 inches above base	3.6
Claystone, predominantly gray, slightly silty; contains a few 1-inch beds of medium-brown silty claystone	3.8
Siltstone, light- to medium-brown, shaly to thin-bedded, and shaly silty claystone; 6 inches from top is iron oxide-cemented 4-inch bed of siltstone	4.3
Claystone, gray to light-brown, shaly, slightly silty; contains several 1-inch beds of siltstone and very fine grained sandstone	2.6
Siltstone, and very fine grained sandstone, light- to medium-gray, thin-bedded; contains abundant mica and carbonaceous fragments along bedding planes; contains many clay shale and silt shale interbeds and partings; 4-inch bed of dark-brown iron oxide-cemented sandy siltstone 1.5 feet above base	4.0
Claystone, gray to light-brown, shaly, slightly silty; contains several thin (1 inch maximum) beds of medium-brown silty claystone	9.2

Fall River formation (in part)—Continued	
Upper unit—Continued	*Feet*
Claystone, medium- to dark-gray, shaly, very slightly silty; extremely fissile and brittle; breaks into tiny thin plates; contains several thin (generally less than ¼ inch) beds of dark-brown, iron oxide-stained siltstone that weather to a distinctive purplish-maroon color	4.0
Lower unit:	
Sandstone, gray and medium- to light-brown, very fine grained, thinly laminated; a few laminae are darkly iron stained; topmost bed of Keyhole sandstone member	.5
Sandstone, light- to medium-gray, mostly very fine grained, micaceous, somewhat carbonaceous, thin-bedded (1.5 feet maximum); contains thin silty interbeds; thin iron oxide-cemented siltstone beds at bottom and about 4 feet up from bottom; surfaces of iron oxide-cemented beds weather to clusters of small round concretions	8.4
Siltstone and sandstone, gray to brown, very fine grained, thin-bedded, and interbedded shaly claystone and shaly siltstone; a few beds are pinkish. Bottom of Keyhole member is within this unit	2.5
Siltstone and sandstone, very fine grained, light-gray to medium-brown, thin-bedded; contains numerous thin silty claystone interbeds and partings	4.5
Claystone, medium- to dark-gray, silty, shaly	9.3
Siltstone and very fine grained sandstone, medium-brown, very thin bedded; somewhat micaceous and carbonaceous; contains a few dark-gray silty claystone interbeds	1.7
Siltstone, medium-gray, very thin to thin bedded; hard, iron oxide-cemented; weathers dark brown; rough knotty surface; slightly micaceous and carbonaceous	.7
Siltstone, gray, clayey, micaceous, carbonaceous; in stream bottom	----
Measured thickness of Fall River formation (rounded)	74

The measured thickness of the upper unit of the Fall River formation is approximately 46 feet, a thickness commensurate with the 45–50 feet measured elsewhere in the vicinity, so it seems certain that the top of the section probably is within a few feet of the top of the Fall River here. The cliff-forming sandstone of the Keyhole member is thin, and the lower contact of the Keyhole member is rather indistinct, but the contact between the top of the Keyhole and the upper unit is clearly marked by the overlying gray shale containing purplish-weathering siltstone layers. This contact is recognizable nearly everywhere in this area, even where the thin edge of the Keyhole member is indistinct or is covered by concentrations of small purple siltstone plates.

The lower unit of the Fall River formation, of which only the upper 10 feet or so is recognizable as the Keyhole sandstone member, is exposed along streams in the central and northeast parts of the area, and in the stream bottom in the southwest corner of the Kay 17 claim and northeast part of the Busfield 8 claim (pl. 4). This latter exposure probably is due to upward thickening of the Keyhole member rather than to faulting or folding because it is approximately on the edge of the area within which the Keyhole is abnormally thin (fig. 5).

In the central and northeastern parts of the area, the Keyhole member consists mainly of brown thin-bedded sandstone with some interbedded siltstone. The top of the Keyhole commonly is marked by a 2- to 4-foot ledge of dark-brown iron oxide-stained sandstone, which is overlain by gray slightly silty fissile claystone generally containing thin laminae of purplish-maroon weathering siltstone.

The outcrop in the extreme southwest corner of the Kay 17 claim is the top of a rounded mass of light- to medium-brown fine-grained to very fine grained clean sandstone similar to that of the Keyhole member; moreover, the outcrop weathers more like a massive sandstone than like a thin-bedded unit. We believe this outcrop to be the top of the Keyhole sandstone member, despite the fact that the upper contact is not marked by the scattered purplish siltstone plates at this place.

The upper unit of the Fall River formation averages about 50 feet thick within this area. At the Busfield mine nearly the entire thickness is occupied by the sandstone lens, which has been described previously. North of the mine the sandstone lens fingers out into thin-bedded sandstone, siltstone, and silty claystone. Along some of the canyon walls, two distinct ledges of sandstone, each rarely more than 7 or 8 feet in thickness, crop out on an otherwise unbroken slope. The two ledges are separated by several feet of thin-bedded siltstone. The upper of the two ledges seems to be nearly continuous throughout the area and commonly crops out along the upper rims of the stream cuts. It consists of very fine grained to fine-grained light-brown locally red-mottled massive sandstone containing sparse mica and carbonaceous material. It weathers to a rounded ledge and is generally capped by several inches of hard iron oxide-cemented siltstone or very fine grained sandstone. From north to south, toward the Busfield mine, the ledge thickens at both the top and bottom, and although it was not actually seen to connect with the sandstone lens at the mine, it is certainly the lateral extension of the upper part of the lens.

The lower sandstone ledge crops out discontinuously along the canyon walls. It generally consists of thin-bedded light-brown sandstone, which contains considerable mica, particularly along bedding planes. The sandstone in this ledge may not be a continuous bed across the area from north to south, but could be two or more thin lenses in about the same stratigraphic position. Disregarding this possible discontinuity, the sandstone in the lower ledge also thickens southward toward the lens at the Busfield mine, and the siltstone interval separating the upper and lower sandstone ledges becomes sandier. We believe that the upper and lower sandstone ledges coalesce, probably in the area north of the mine where good exposures are lacking, and merge with the main body of the lens.

The isopach lines on plate 4 show the approximate thickness of sandstone in the upper unit of the Fall River formation. Information in areas where streams do not cut through the lens was obtained from drillers' notes and from our observations of drill cores. The isopach lines do not represent the thickness of a single sandstone bed but rather depict the total thickness of the interval which is predominantly sandstone and which is underlain by dense shaly siltstone or silty claystone. In its thickest part, at the Busfield mine, the sandy interval is the lens that occupies nearly the entire thickness of the upper unit. In its thinner parts, away from the long axis of the lens, the sandy interval generally forms only the uppermost part of the upper unit, which indicates that most of the thinning of the lens is upward from the bottom. Field observations show that the lens thins also, but to a lesser extent, downward from the top.

The Skull Creek shale overlies the upper unit of the Fall River formation in relatively sharp contact at the Busfield mine and in transitional contact at the Vickers mine. At both mines some beveling of the sandstone beds can be seen but the contact is essentially conformable. At the Busfield mine 1.3 feet of banded light- and dark-gray interbedded shaly carbonaceous silty claystone and siltstone separates fine-grained sandstone of the Fall River from black nonsilty clay shale of the Skull Creek. At the Vickers mine, the contact was drawn at the base of the lowest zone of black slightly silty shale, but above this bed, which is 5 to 6 feet thick, are two zones of hard siltstone each of which is overlain by black shale containing reworked fragments of the underlying siltstone. The entire 10 feet including the lowest shale zone and the overlying shale-silt zones might be considered a transitional interval between undoubted Fall River and undoubted Skull Creek. The lowest shale zone is separated from the underlying sandstone and siltstone of the Fall River by a 1-foot layer of mixed shale and silt.

The Skull Creek shale consists of black silt-free clay shale to dark-gray somewhat silty clay shale and contains massive manganosiderite concretions and a few thin beds of bentonite and bentonitic shale; joint surfaces commonly are covered with selenite crystals.

SEDIMENTARY STRUCTURES

The most pronounced sedimentary structure is the thick sandstone lens the bottom few feet of which contained the Busfield ore deposit. This lens, as seen at the Busfield mine, is the westernmost part of the larger feature shown by isopach lines on figure 5. The lens attains its maximum thickness in this area at and near the site of the Busfield pit. Because the sandstone interval in the upper unit of the Fall River rarely exceeds a thickness of about 12 feet throughout most of the quadrangle, the lateral margin of the lens is outlined by the 15-foot line on plate 4, or by the 20-foot line on figure 5.

Although the thickened interval of sandstone in the vicinity of the Vickers pit is shown as an extension of the main lens, none of the characteristics of the lens observed at the Busfield pit, such as the massive bedding and the prominent sweeping cross-stratification, was seen in the Vickers pit. In the walls of the Vickers pit, the sandstone is somewhat thicker than normal, ranging from about 12 to 15 feet thick, but it is thinly and uniformly bedded and contains numerous thin siltstone interbeds as shown on the sketch of the west wall (pl. 5). Drilling indicates that the sandstone attains a maximum thickness of little more than 20 feet in the vicinity of the pit. In the southwest corner of the Vickers pit several feet of sandstone and siltstone, dipping about 15° SW., cuts across the horizontal beds and is beveled off across the top. This tilted sequence may be a group of foreset beds. No other distinct cross-stratification was seen in the pit.

In both pits the ore-bearing sandstone interval is underlain by a layer of black dense shaly clayey siltstone. This shaly layer is important to the preservation of the ore, for it forms a relatively impervious bottom to the thick sandstone and holds up a perched body of ground water in this area which is at least 100 feet above the permanent regional water table.

Another sedimentary feature in the area is the abrupt change in thickness of the massive sandstone in the Keyhole member. This change in thickness may have had a local effect on the rate or direction of ground-water flow, and thus would have been a factor contributing to the favorableness of this area as a site for mineral accumulation.

STRUCTURE

The extent and intensity of deformation in the mine area are not accurately known, owing to the complexities introduced by sedimentary structures and to lack of exposures of a good structure datum in critical areas. The top of the Keyhole sandstone member is not a suitable datum for structure contouring here, because the area lies along the margin of abrupt thinning of the massive sandstone of the Keyhole member, and structure contours drawn on this datum would reflect in large part this sedimentary irregularity.

Contouring on the Fall River–Skull Creek contact gives only an approximation of the tectonic structure, because the Skull Creek has been stripped from large areas and because some apparent structure is introduced at this datum by the upward thickening of the sandstone lens in the upper unit of the Fall River, as mentioned previously. Figure 8 is a generalized representation of the structure as contoured on the Fall River–Skull Creek contract.

Folds.—The principal structural feature in the mine area is an irregular fold with a broad nose that plunges gently northeastward.

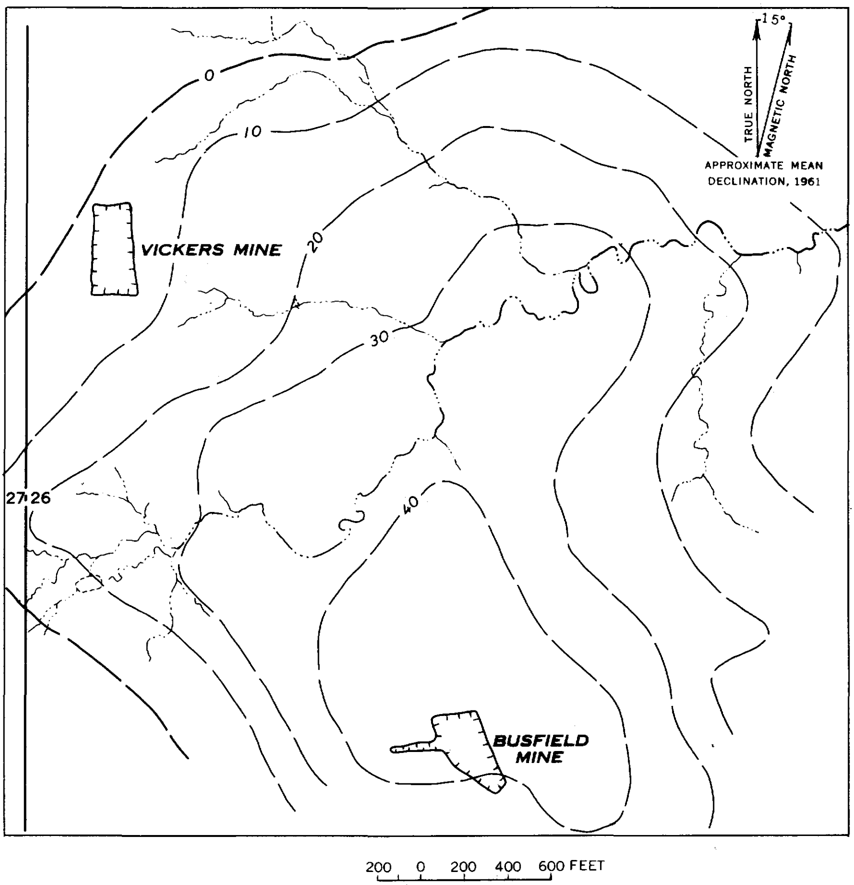

FIGURE 8.—Map showing generalized structure in part of the Elkhorn Creek uranium mining area.

As depicted with 20-foot contour lines on plate 1, the fold is flat-topped and shallow and might be considered nearly a terrace in relation to the surrounding structural features. In detail, however, the feature is seen to be a dome with a total structural relief of a little more than 40 feet on its northwest side (fig. 8). The edge of the dome, as approximately shown by the 0-foot contour line in figure 8, is north and northwest of the Vickers mine; the top of the dome includes the Busfield mine and extends about 1,200 feet north of the mine. The highest part of the dome includes the thickest part of the sandstone lens, and the general shape of the central part of the dome is similar to the general shape of the lens as shown by the isopach lines on plate 4. We believe that about 15 feet of the structural relief of the dome, as measured from its top to its northwest edge, is apparent structure, attributable to the upward thickening of the sandstone lens; the remaining 25 feet of structural relief is due to a combination of the local fold and the regional dip of the rocks.

Joints.—Joints are well developed in the sandstone in both the Busfield and the Vickers pits, but are not as conspicuous in these areas as in the thickly bedded sandstones elsewhere in the quadrangle.

Northwestward-trending joints range in strike predominantly from N. 40°W. to N. 70°W., with a slightly greater concentration in the N. 50°–60°W. range. Northeastward-trending joints have a wider range in strike from N. 30°E. to N. 70°E., with a strong concentration in the N. 50°–60°E. range. Nearly all joints are essentially vertical. In general, joints cannot be observed passing from one sandstone bed to another through intervening nonresistant units. Even in the massive sandstone beds at the Busfield mine, some joints are offset through thick and thin beds.

Rather strongly developed joints were observed in the silty shale of the Skull Creek in the Vickers pit. These joints caused some difficulty during stripping of the pit because of rock slides that occurred as the shale dried out on exposure to the air.

Faults.—A few faults of small magnitude were mapped in the area, but only where exposed by stream cuts or in the open pits. Other minor faults probably occur, but are covered by soil or are obscure because they occur in shale.

Two faults were mapped in the Vickers pit. Both strike northeast and dip northwest. On each fault the relative movement has been down on the hanging wall. Displacement on the northern fault is only about 4 inches and could not be recognized in the shale in the upper part of the wall, for neither the bentonite bed nor any other marker bed is exposed there. Movement on the southern fault is less than 1 foot.

Four small faults were mapped in the Busfield pit. The faults strike essentially northeast and their dips are shown on the map. On each fault the hanging wall has moved relatively down, with a maximum displacement of less than 2 feet.

A group of small faults was mapped in the Busfield 8 and 9 claims. These faults strike northwest, but their dips are not known. Relative movement appears to be as shown on the map. The actual amount of vertical displacement is not known, because the sandstone beds could not be correlated across the faults, but the Fall River–Skull Creek contact shows the displacement to be a maximum of about 7 feet.

ORE DEPOSITS

GENERAL FEATURES

The ore deposits at the Busfield and Vickers mines consisted of lenses and pods of sandstone impregnated with uranium minerals in the lower part of the sandstone interval in the upper unit of the Fall River formation. The lenses and pods at the Busfield mine occurred at the bottom of the thickest part of the sandstone lens and those at the Vickers mine occurred in a nearly normal thickness of sandstone but adjacent to an abnormally thick lens. Outlines of the open pit workings, as they were in September 1956, are shown on plate 4.

The principal ore minerals are coffinite, a uranous silicate (Stieff and others, 1956; Fuchs and Gebert, 1958; Garrels and Christ, 1959), and possibly some uraninite, which are intimately mixed with fragments of carbonaceous material concentrated in thin layers or as disseminated particles. Pyrite is present locally. At the Busfield mine the upper part of the sandstone lens has been oxidized and now contains some pods, disseminations, and joint coatings of carnotite, metatyuyamunite, and perhaps a mixture of meta-autunite and hydrogen-autunite. No oxidized uranium minerals were observed at the Vickers mine.

Uranium content of the mineralized areas ranges from considerably less than ore grade (ore grade as referred to here is a minimum of 0.10 percent U) to 1.63 percent U at the Busfield mine and from less than ore grade to 0.84 percent U at the Vickers mine. Small samples selected for maximum uranium content have run as high as several percent uranium. The V_2O_5 content of samples collected ranges from less than 0.05 percent to 1.63 percent at the Busfield deposit and from less than 0.05 percent to 0.54 percent at the Vickers deposit.

Small areas of anomalous radioactivity have been found in holes drilled between the main deposits, but they are of small extent and probably of no commercial value.

Semiquantitative spectrographic analyses were made of 30 samples from the area, 28 of siltstone and sandstone of the Fall River and 2 of siltstone and shale of the Skull Creek, in an effort to determine whether or not a systematic relationship exists between minor elements and uranium minerals. The results of these analyses are shown in table 2.

The samples as shown in this table and in table 3 are arranged in six groups. Group 1 consists of miscellaneous samples of sandstone and siltstone of the Fall River away from the main deposits; group 2 consists of samples of sandstone and siltstone of the Fall River within or immediately above the ore zone in the Busfield mine arranged in order of increasing percentage of uranium as determined by chemical analyses; group 3 is of samples from the Busfield mine for which no chemical uranium determinations were made, with the exception of D–56–37 (not shown in table 2), which was taken from a carbonaceous seam several feet above the ore zone; group 4 consists of samples from the Vickers mine arranged in order of increasing percentage of uranium as determined by chemical analyses; group 5 is of samples from the Vickers mine for which no chemical uranium determinations were made; and group 6 consists of samples of Skull Creek rocks from the Vickers mine.

A study of the table indicates that no apparent correlation exists between minor element content and the content of uranium in these samples.

BUSFIELD DEPOSIT

The Busfield open pit, the outline of which is shown on plates 4 and 6, is approximately 175 by 250 feet in the stripping area at the bottom. The pit was opened in such a way as to expose the widest, thickest, and highest-grade part of a lenslike ore body which lay at the bottom of the sandstone lens in the upper unit of the Fall River formation. The ore body, as delimited by company drilling, was a very irregularly shaped deposit the longest dimension of which extended from about the center of the west side line of the Busfield 5 claim east-southeast about 700 feet and roughly corresponded to the axis of the thickest part of the sandstone lens. The west half of the body was the widest, attaining a maximum width of about 200 feet. In the vicinity of the easternmost corner of the pit it narrowed abruptly to an average of about 50 feet. The bottom of the ore zone corresponds essentially to the bottom of the sandstone lens, which is a gently rolling irregular surface. The sandstone is directly underlain by a dense shaly siltstone. The top of the ore zone, which generally corresponds to the bottom of the zone of oxidation in the sandstone, is much more irregular. The thickness of the mined-out part of the ore zone ranged from 2 to 10 feet and averaged between 4 and 5 feet. The ore zone thins as it narrows in an easterly direction.

TABLE 2.—*Semiquantitative spectrographic analyses of 30 samples of siltstone and sandstone from Fall River and Skull Creek formations, Strawberry Hill quadrangle, Crook County, Wyo.*

[All values are in percent. Values for semiquantitative analyses are reported to the nearest numbers in the series 7, 3, 1.5, 0.7, 0.3, 0.15, etc. M, major constituent—greater than 10 percent; 0, looked for but not detected; ----, not looked for. Elements looked for in all samples but not detected: P, As, Au, Bi, Cd, Dy, Er, Eu, Gd, Hf, Hg, Ho, In, Ir, Li, Lu, Os, Pd, Pr, Pt, Re, Rh, Ru, Sb, Sn, Sm, Ta, Tb, Te, Th, Tl, Tm, W, Zn. Elements not looked for: Cs, F, Rb. See text for explanation of groups. Analysts: J. C. Hamilton and R. G. Havens]

Field No.	Serial No.	Formation	Rock type	Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn	Ag	B	Ba	Be	Ce
Group 1																	
D-56-3	253641	Fall River	Siltstone	M	7	3	0.3	0.15	0.7	3	0.7	0.03	Trace	0.007	0.03	0	0
-1	253639	do	Sandstone	M	3	3	.15	.15	.3	.7	.7	.015	0.003	.007	.03	0	0
-2	253640	do	do	M	1.5	1.5	.07	.15	.15	.7	.15	.015	.0003	.003	.015	0	0
BUSFIELD MINE Group 2																	
D-56-16	253648	Fall River	Siltstone	M	M	3	0.7	0.3	0.3	3	0.7	0.15	0	0.015	0.03	0.00015	0.03
-8	253580	do	Sandstone	M	.7	.3	.07	.03	.15	0	.7	.007	0	.003	.015	0	0
-10	253582	do	do	M	.7	.15	.07	.03	.15	0	.3	.0015	0	.003	.015	0	0
-34	253656	do	do	M	1.5	.15	.03	.03	.15	0	.3	.003	0	.003	.015	0	0
-14	253646	do	do	M	3	.7	.07	.03	.3	.7	.3	.007	0	0	.015	0	0
-11	253644	do	do	M	.7	.3	.03	.03	.07	0	.3	.0015	0	.007	.015	0	0
-6	253642	do	do	M	.7	.7	.03	.03	.15	0	.3	.0015	Trace	0	.015	0	0
-7	253643	do	do	M	1.5	.7	.03	.03	.15	0	.3	.0015	0	.003	.015	0	0
-15	253647	do	do	M	3	.15	.07	.07	.3	.7	.3	.003	0	.003	.015	0	0
-9	253581	do	do	M	.7	.3	.07	.07	.15	0	.3	.007	0	.007	.015	0	0
Group 3																	
D-56-13	253645	Fall River	Sandstone	M	7	3	0.3	0.15	0.3	3	0.7	0.07	0	0.015	0.03	0	0.015
-35	253657	do	do	M	.7	3	.03	.03	.15	0	.3	.15	0	.003	.015	0	0
-36	253658	do	do	M	.7	.3	.03	.03	.15	0	.3	.0015	0	.007	.015	0	0

VICKERS MINE

Group 4																	
D-56-33	253655	Fall River	Siltstone	M	M	3	0.7	0.3	0.3	3	0.7	0.3	0	0.015	0.03	0	0.015
-23	253583	do	Sandstone	M	.7	.3	.15	.07	.3	.7	.3	.015	0	.007	.03	0	0
-27	253587	do	do	M	3	1.5	.15	.15	.15	.7	.3	.07	0	.003	.015	0	0
-24	253584	do	do	M	3	.7	.3	.07	.3	1.5	.3	.03	0	.007	.03	0	0
-25	253585	do	do	M	M	1.5	.7	.15	.3	3	.7	.03	0	.015	.03	.00015	Trace
-28	253588	do	do	M	3	3	.3	.15	.3	1.5	.3	.15	0	.007	.03	0	0
-30	253653	do	do	M	3	1.5	.15	.15	.3	.7	.3	.07	0	.007	.03	0	0
-26	253586	do	do	M	3	3	.3	.3	.3	1.5	.3	1.5	0	.003	.03	0	0
-29	253589	do	do	M	3	3	.3	.15	.3	1.5	.15	.15	0	.003	.03	0	0
Group 5																	
D-56-19	253649	Fall River	Siltstone	M	1.5	7	0.3	0.7	0.3	0.7	0.15	0.7	0	0	0.015	0	0
-21	253651	do	do	M	M	1.5	.7	.3	.7	3	.7	.07	0	.015	.03	.00015	.015
-22	253652	do	do	M	M	3	.7	.3	.7	3	.7	.07	0	.015	.03	0	0
Group 6																	
D-56-20	253650	Skull Creek	Shale	M	M	3	1.5	0.3	0.7	3	0.7	.07	0	0.015	0.03	0.00015	0.015
-32	253654	do	Siltstone	M	M	3	1.5	1.5	.7	3	.7	.3	0	.007	.07	0	.015

TABLE 2.—*Semiquantitative spectrographic analyses of 30 samples of siltstone and sandstone from Fall River and Skull Creek formations, Strawberry Hill quadrangle, Crook County, Wyo.*—Continued

Field No.	Co	Cr	Cu	Ga	Ge	La	Mo	Nb	Nd	Ni	Pb	Sc	Sr	U	V	Y	Yb	Zr
Group 1																		
D-56-3	0.003	0.003	0.007	0.0007	0	0.003	0	0.003	0	0.003	0.003	0.0015	0.03	0	0.007	0.003	0.0007	0.03
-1	.0003	.0015	.0015	0	.003	.003	.0015	.0015	0	.0007	.015	.0007	.007	0	.07	.003	<.001	.07
-2	.0003	.0007	.0015	0	0	0	.0015	.0015	0	.0007	0	0	.0015	0	.007	0	.00015	.015
BUSFIELD MINE Group 2																		
D-56-16	0.003	0.007	0.007	0.0007	0	0.015	0.0007	0.003	0.015	0.007	0.0015	0.0015	0.015	0.03	0.015	0.007	0.0007	0.07
-8	0	.0007	.0007	0	0	0	0	.0015	0	0	0	0	.0007	0	.007	.003	.0003	.07
-10	0	.0007	.0007	0	0	0	0	.003	0	.0003	0	0	.0003	.07	.015	0	0	.015
-34	.0003	.0007	.0007	0	0	0	0	.0015	0	.0007	0	0	.00015	.03	.007	.0015	.00015	.015
-14	.0003	.0007	.0015	0	1	0	0	0	0	.0007	0	0	.0007	.03	.015	0	.00015	.015
-11	<.001	.0003	.0015	0	0	0	0	.0015	0	0	0	0	.00015	.7	.07	0	<.001	.03
-6	<.0007	.0003	.0007	0	0	0	0	0	0	0	0	0	.00015	.15	.3	0	<.001	.03
-7	<.0007	.0015	.003	0	0	0	0	.0015	0	0	.0015	0	.0015	.15	.03	.0015	.0003	.07
-15	<.001	.0015	.0015	0	0	.007	0	.0015	.007	.0015	0	0	.0015	.3	.03	.003	.0003	.015
-9	<.007	.0015	.0015	0	<.005	0	0	.0015	0	.0007	.0015	0	.0007	.7	.03	.0015	---------	.03
Group 3																		
D-56-13	0.003	0.003	0.007	0.0007	0	0.007	0	0.003	0.007	0.007	0.0015	0.0015	0.007	0.07	0.03	0.007	0.0007	0.07
-35	.0007	.0007	.0015	0	0	0	0	.0015	0	.003	0	.0007	0	0	.03	.0015	.0003	.015
-36	<.0007	.003	.0007	0	0	0	0	.003	0	0	0	0	.00015	.15	.03	0	.00015	.03

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VICKERS MINE

Group 4																		
D-56-33	0.003	0.007	0.007	0.0007	0	0.015	0.03	0.003	0.015	0.007	0.0015	0.0015	0.015	0	0.007	0.007	0.0007	0.07
-23	.0007	.0015	.0015	0	0	0	0	.0015	0	.0007	0	0	.0015	0	.0015	.0015	.0003	.03
-27	.0007	.0015	.003	0	0	0	0	Trace	0	.0015	0	.0007	.0015	0	.003	.003	.0003	.03
-24	.0015	.0015	.0015	0	0	0	0	.0015	0	.0015	0	0	.0015	0	.007	.0015	.0003	.03
-25	.003	.007	.003	.0015	0	.007	0	.0015	Trace	.003	.0015	.0015	.007	.15	.015	.007	.0015	.03
-28	<.007	.003	.003	.0003	<.005	0	0	.0015	0	.003	.0015	.0007	.003	.3	.015	.003	.0007	.03
-30	<.001	.0015	.0015	0	0	0	0	.0015	0	.0015	0	0	.0015	.7	.007	.0015	.0003	.03
-26	<.007	.003	.0015	0	<.005	0	0	.0015	0	.003	.003	.0007	.003	.7	.015	.003	.0007	.03
-29	<.007	.003	.003	.0003	<.005	.003	0	.0015	0	.003	.003	.0007	.003	.7	.15	.003	---------	.015
Group 5																		
D-56-19	0.0007	0.0015	0.003	0	0	0	0	0.0015	0	0.0015	0	0	0.0015	0	0.015	0.003	0.0003	0.03
-21	.0015	.007	.007	.0015	0	.007	0	.003	.015	.003	.0015	.0015	.007	0	.007	.007	.0007	.07
-22	.003	.007	.007	.0015	0	.003	.03	.0015	.007	.003	.003	.0015	.015	0	.015	.003	.0003	.03
Group 6																		
D-56-20	0.003	0.007	0.015	0.003	0	0.007	0	0.0015	0.007	0.007	0.003	0.003	0.015	0	0.015	0.007	0.0007	0.03
-32	.0007	.007	.003	.0015	0	.003	0	.0015	.007	.003	.003	.0015	.015	0	.015	.007	.0007	.03

The host sandstone at the Busfield mine is predominantly thick-bedded to massive, cross stratified, fine grained to very fine grained, somewhat micaceous, and ranges from slightly carbonaceous to very carbonaceous. The sandstone, which totals about 43 feet thick in the pit, can be divided into two zones: an oxidized zone about 37 to 38 feet thick and an underlying unoxidized zone commonly 5 to 6 feet thick. The unoxidized zone is preserved by a local body of ground water, perched on the dense shaly clayey siltstone that underlies the sandstone. The ore body, defined here as that part of the deposit which was mined, mixed, and shipped, lay almost entirely within the unoxidized zone.

The oxidized zone is characterized by its light-brown to medium-brown color, lenses and pods of dark-brown iron oxide-stained sandstone and siltstone and, locally, by yellow to yellow-green oxidized uranium minerals. The unoxidized zone is medium gray to very dark gray or black, depending upon the amount of carbonaceous material present, and contains considerable pyrite locally and no oxidized uranium minerals. The contact between the unoxidized zone and the underlying shale locally is marked by pyrite nodules as much as 4 or 5 inches in diameter. Between the distinct oxidized and unoxidized zones is a thin transition zone, commonly about 6 inches thick, in which the gray sandstone becomes progressively more brownish upward and which locally contains a mixture of unoxidized and oxidized uranium minerals. This is the zone through which the top of the perched body of ground water fluctuates.

Carbonaceous material occurs both as disseminated particles and concentrated in branching and coalescing layers, as much as 1 foot thick, that are arranged predominantly along planes of cross-stratification. In general, the amount of carbonaceous debris in the entire sandstone interval increases downward; the coalified wood fragments become larger, up to half an inch or more in length, and more abundant, and the frequency of carbonaceous layers increases. Pyrite also becomes progressively more abundant downward through the unoxidized zone.

The host rock in the oxidized zone is a very fine grained, well-sorted quartzose sandstone containing a few percent of plagioclase and white mica; clayey siltstone seams and micaceous laminae are not uncommon, and carbonaceous material is abundant locally. The sand grains are bonded or loosely cemented by clay minerals and by brown iron oxides. Uranium minerals occur in carbonaceous layers, as small isolated pods or disseminations, and as thin films on joint surfaces. Within each concentration the minerals occur largely as coatings on sand grains or as cement and as fine aggregates or crystalline fragments between sand grains. Oxidized uranium minerals in samples from the Busfield deposit have been identified by E. J. Young of the Geological Survey as carnotite and possibly a mixture of meta-autunite and hydrogen-autunite. According to MacPherson (1956), carnotite and metatyuyamunite have been recognized. Because the occurrences of oxidized minerals are sporadic, the oxidized part of the deposit has not been mined.

The sandstone in the unoxidized zone, which is the ore zone, is very fine grained, fairly well sorted, and is composed of angular quartz grains and minor amounts of plagioclase and mica. Clay minerals, pyrite, and carbonaceous material fill the interstices. Many quartz grains have irregular grain boundaries, which may indicate that they have been corroded by mineralizing solutions. Black uranium minerals occur in thin black layers or seams. Commonly, though apparently not in all instances, the layers are carbonaceous, and not uncommonly they are associated with pyrite.

No discrete uranium minerals were seen under the microscope. Coffinite and uraninite, which were identified by X-ray diffraction methods by E. J. Young and J. W. Adams of the Geological Survey, apparently occur in thin black layers or in disseminated fragments of carbonaceous material, some of which has been largely replaced by very finely granular pyrite. Some fragments of carbonaceous debris show a cellular structure accentuated by fine-grained pyrite outlining tiny thin slivers of black opaque material that may be an extremely fine grained intimate mixture of organic material and uranium minerals. Coffinite and uraninite probably occur also as intimate mixtures with the finely granular pyrite.

Table 3 shows the results of chemical analyses for uranium, V_2O_5, selenium, and arsenic made on selected samples and shows also equivalent uranium determinations on all the samples listed in table 2. Groups 2 and 3 are samples from the Busfield mine. Disregarding sample D–56–16, which is from the shaly siltstone that directly underlay the ore zone, the samples in group 2 are arranged in order of increasing uranium content.

The grade of mineralized rock as determined from chemical analyses ranges from 0.003 percent to 1.63 percent uranium, and from less than 0.05 percent to 1.63 percent V_2O_5. Equivalent uranium is greater than chemically determined uranium in only 4 of the samples for which chemical determinations were made. These samples, D–56–8, –10, –11, and –7, are from the oxidized zone, and the analyses show equivalent uranium in excess of uranium in amounts ranging from 27 to 133 percent (eU-U ratios from 1.27 to 2.33). All samples from the ore zone and 3 additional samples from the oxidized zone—

TABLE 3.—*Chemical analyses of mineralized samples from the Fall River formation for uranium, V_2O_5, selenium, and arsenic, their states of oxidation, and equivalent uranium-uranium and vanadium-uranium ratios*

[Equivalent uranium analyses given for all samples shown in table 2. Analysts: C. G. Angelo, J. P. Schuch, H. H. Lipp, G. T. Burrow, Claude Huffman, and E. J. Fennelly]

Field No.	Laboratory No.	Formation	Type of rock	eU (range-percent)	U (percent)	V_2O_5 (percent)	Se (ppm)	As (ppm)	State of oxidation	eU:U	V:U
				Group 1							
D-56-3	253641	Fall River	Siltstone	<0.001							
-1	253639	do	Sandstone	.009							
-2	253640	do	do	.031							
				BUSFIELD MINE **Group 2**							
D-56-16	253648	Fall River	Siltstone	0.026-0.030					Unoxidized		
-8	253580	do	Sandstone	.007	0.003	<0.05	.5	<5	Oxidized	2.33	*2.3:1
-10	253582	do	do	.047	.037	.05	3	<5	Partially oxidized	1.27	1:1.3
-34	253759	do	do	.021- .026	.040	<.05	1	10	Unoxidized	.60	*1:5.7
-14	253755	do	do	.031- .036	.044	<.05	3	10	Partially oxidized	.77	*1:3
-11	253754	do	do	.034- .17	.047	.10	4	10	Oxidized	2.17	1.2:1
-6	253752	do	do	.027- .031	.050	.85	3	74	do	.58	9.4:1
-17	253757	do	do	.065	.080	<.05	1	10	Unoxidized	.81	
-7	253753	do	do	.14 - .19	.12	.05	15	315	Oxidized	1.42	1:4.3
-15	253756	do	do	.13 - .16	.27	.05	3	20	Unoxidized	.54	1:9.6
-9	253581	do	do	.41	.69	.10	4	55	do	.59	1:12.5
				Group 3							
D-56-13	253645	Fall River	Sandstone	0.056							
-35	253657	do	do	.012							
-36	253658	do	do	.051							
-37	253760	do	Carbonaceous sandstone	1.1	1.63	1.63	12	245	Oxidized	.67	1:1.8

VICKERS MINE

Group 4

D-56-33	253655	Fall River	Siltstone	0.014-0.015	------	------	------	------	------	------	------
-23	253583	do	Sandstone	.003	0.002	<0.05	.5	5	Slightly oxidized	1.50	*1:1.3
-27	253587	do	do	.005	.006	<.05	<.5	5	do	.83	*1:2
-24	253584	do	do	.022	.021	<.05	15	95	Very slightly oxidized	1.05	*1:3
-25	253585	do	do	.091	.099	<.05	.5	100	do	.92	*1:6.6
-28	253588	do	do	.21	.30	<.05	3	110	Unoxidized	.70	*1:20
-30	253758	do	do	.23-.29	.36	.05	2	42	do	.72	1:13
-26	253586	do	do	.48	.67	.05	5	120	do	.72	1:24
-29	253589	do	do	.60	.84	.54	20	150	do	.71	1:2.8

Group 5

D-56-19	253649	Fall River	Siltstone	0.001	------	------	------	------	------	------	------
-21	253651	do	do	.001	------	------	------	------	------	------	------
-22	253652	do	do	.001	------	------	------	------	------	------	------

Group 6

D-56-20	253650	Skull Creek	Shale	0.001	------	------	------	------	------	------	------
-32	253654	do	Siltstone	.004	------	------	------	------	------	------	------

*Calculated using percent V as determined by semiquantitative spectrographic analyses.

D–56–14, –6, and –37—show uranium in excess of equivalent uranium in amounts ranging from 23 to 80 percent (eU-U ratios from 0.81 to 0.54). The three additional samples from the oxidized zone contain uranium in excess of equivalent uranium because the black uranium minerals are only partially oxidized and therefore the uranium has been only partially leached, owing either to the proximity of the samples to the transition zone between oxidized and unoxidized sandstone or to the impervious nature of the material in which the uraniferous carbonaceous material occurs.

The vanadium content of the mineralized material is low; vanadium-uranium ratios range from a high of 9.4:1 to a low of 1:12.5, as determined from the 7 samples in which the V_2O_5 content is 0.05 percent or greater. The average vanadium-uranium ratio in these samples is 1:4.4. No low-valent vanadium minerals were recognized in thin sections. The variations in vanadium content bear no relation to variations in uranium content except in sample D–56–37, in which the V_2O_5 content is high but the vanadium-uranium ratio is only 1:1.8. A general parallel between oxidized minerals and a higher vanadium-uranium ratio may be shown. The general lack of vanadium in the ores and the low-valent state of the uranium suggests that this deposit might fall into type 2 (low-valent ores) of group 3 (uranium associated with minor amounts of other metals) in the mineralogic classification set up by Botinelly and Weeks (1957).

The contents of selenium and arsenic were also determined. Selenium content ranges from 0.5 to 15 parts per million, or from 0.00005 to 0.0015 percent, and bears no apparent relation to uranium content. Arsenic content ranges from less than 5 to 315 parts per million, or from less than 0.0005 to 0.0315 percent, and has a systematic relation to uranium content and the oxidation state of its environment. Within the oxidized samples, arsenic ranges from less than 5 to 315 parts per million and increases, roughly, as uranium increases. In the unoxidized samples arsenic ranges from 10 to 55 parts per million, again increasing roughly as uranium increases. The arsenic-uranium ratios, then, are generally higher in the oxidized zone than in the unoxidized zone.

VICKERS DEPOSIT

The outline of the open pit of the Vickers mine, as it was in September 1956, is shown on plates 4 and 5. The stripping area at the bottom of the pit at that time was approximately 150 feet east-west by 130 feet north-south, although the full thickness of the ore zone was exposed only in the west part of the pit. Since the pit was mapped, its area was doubled by extension to the west, and a smaller pit was opened to the northeast. The pits were located in such a way as to uncover several lenses of ore, which had been delimited by closely spaced drill holes; an isorad map based on the company's Babbel counter probe readings is shown on plate 4. The isorad lines show the pockety nature of the ore body, which consisted of several rather closely spaced lenses of high concentrations of uranium minerals.

Collectively, the lenses constitute an ore zone between 4 and 5 feet in thickness the bottom of which lies at or near the bottom of the sandstone in the upper unit of the Fall River in and near abnormal thicknesses of the sandstone. As at the Busfield deposit, the bottom of the ore zone commonly is in sharp contact with dense black shaly siltstone. Both bottom and top of the ore zone are somewhat irregular but apparently are not so irregular as at the Busfield deposit.

Oxidation at the Vickers deposit is much less intense than at the Busfield, because the sandstone is overlain by at least 20 feet of relatively impervious, though jointed, shale of the Skull Creek. The slight oxidation is marked by the slightly brownish tint of the gray sandstone beds in the upper three-fourths of the sandstone interval. The top of the ore zone corresponds roughly to the contact between unoxidized sandstone and slightly oxidized sandstone (pl. 5). The top of the ore zone is difficult to determine visually and the ore body was mined virtually on an assay boundary as determined by radiometric survey.

The ore-bearing sandstone is a medium- to dark-gray thin-bedded alternating sequence of fine grained to very fine grained, somewhat micaceous, locally very carbonaceous sandstone and rather dense, somewhat shaly clayey siltstone. Carbonaceous debris occurs as disseminated fragments or concentrated in layers, rarely more than a few tenths of an inch thick. The carbonaceous layers parallel the bedding and are found both in beds of sandstone and of siltstone. The layers are more regular and less sporadic than those in the Busfield deposit. The sandstone interval in the pit ranges from about 13 feet to a little less than 15 feet in thickness. The sandstone-siltstone section, as observed in the west wall of the pit, is shown on the sketch map (pl. 5).

Black uranium minerals occur in association with carbonaceous debris, and locally, fine-grained pyrite is disseminated throughout the sandstone. The sandstone consists predominantly of angular quartz grains with several percent of plagioclase, mica, and other accessory minerals. Some of the quartz grains are slightly etched or corroded. Bonding material is mainly clay minerals. The topmost siltstone bed, immediately beneath the Skull Creek shale, is a very hard carbonate-cemented sandy siltstone containing abundant pyrite. No other beds contain carbonate cement.

Ore-mineral determinations made by E. J. Young show coffinite to be the principal uranium mineral. No uraninite was identified. Discrete grains of coffinite were not observed, but the mineral probably is concentrated within the carbonaceous material and is commonly associated with concentrations of pyrite.

Table 3, groups 4 and 5, shows the results of analyses for equivalent uranium, uranium, V_2O_5, selenium, and arsenic of selected samples from the Vickers mine. Sample D–56–33 is of the siltstone under the ore zone, and comparison of its equivalent uranium analysis (0.014 to 0.015 percent) with equivalent uranium analyses of the overlying unoxidized sandstone (0.21 to 0.60 percent) illustrates the abrupt decrease in uranium from the ore zone to the relatively barren siltstone below. The remaining eight samples of sandstone of the Fall River are arranged in order of increasing uranium content. Samples D–56–23, -27, and –24 are from above the top of the ore zone in the slightly oxidized zone.

Equivalent uranium is in excess of uranium in only 2 of the samples in group 4, D–56–23 and D–56–24; the range is from 5 percent to 50 percent (eU-U ratios from 1.05 to 1.50). Both these samples are from the slightly oxidized zone. Uranium is present in excess of equivalent uranium in the remaining samples in the group, all but one from the ore zone, in amounts ranging from 9 to 43 percent (eU-U ratios from 0.92 to 0.70), with a consistent disequilibrium of about 40 percent (eU-U ratios of 0.71 and 0.72) in samples D–56–28, –30, –26, and –29.

V_2O_5 was present in amounts of 0.05 percent or greater in only 3 samples. In these samples the vanadium-uranium ratios range from 1:2.8 in sample D–56–29 to about 1:24 in sample D–56–26. The ore probably would fall into type 2 of group 3 in the mineralogic classification of Botinelly and Weeks (1957).

The selenium content ranges from less than 0.5 to 20 parts per million. No systematic relation exists between uranium content and selenium content.

Arsenic content ranges from 5 to 150 parts per million and, in a general way, increases with increasing uranium content.

ORIGIN OF THE DEPOSITS

Evidence bearing upon the source of uranium in deposits in Wyoming, Montana, and the Dakotas is scant, particularly so with reference to the Black Hills deposits. Several workers, including Denson and Gill (1956, p. 416), Coleman and Delevaux (1957, p. 525), and Gruner (1956, p. 515), have supported the premise that the uranium in some areas was derived from overlying sediments, in particular from the tuffs of the White River formation of Oligocene age. They believe that uranium and associated elements have been leached from the tuff beds by downward and laterally percolating ground waters and transported to zones in the underlying rocks where conditions were favorable for their deposition and concentration. Others have suggested that the uranium and associated elements in some deposits were present as original constituents in the sediments and that these deposits were derived by redistribution of the original constituents (Sharp and others, 1956, p. 374).

Studies of the Busfield and Vickers deposits and of other deposits in this region (Bergendahl, Davis, and Izett, 1961; C. S. Robinson, oral communication, 1958; Robinson and Gott, 1958, p. 243) indicate that regardless of the ultimate source of the uranium there is little doubt that the deposits are the result of precipitation of uranium from ground-water solutions, which moved through a system of saturated or partly saturated aquifers. The deposits studied are now, however, all above the permanent regional ground-water table; some are related to local perched water bodies and the minerals within them have remained largely in their low-valent state, whereas others are now in the zone of oxidation and hexavalent uranium minerals predominate.

The Busfield and Vickers deposits are so situated that it can be assumed that the minerals in both deposits probably were precipitated from the same solutions and under approximately the same conditions and, therefore, that the original character of the deposits should have been similar. Certain differences are now observable in the deposits and these differences, along with other features, furnish evidence pertaining to the behavior of the deposits during oxidation. From this evidence inferences may be made regarding the emplacement of these deposits and, perhaps, of other deposits as well. In the following paragraphs the movement and emplacement of the uranium, its environment of deposition, and its behavior during postdepositional changes in environment are discussed.

We believe that uranium derived from a source not known but probably located above the site of deposition, either updip within the Fall River formation, or within the overlying sediments, or perhaps both, was carried into the area by migrating ground-water solutions. Although the uranyl ion can form complexes in alkaline solutions and is stable in acid solutions and, therefore, could readily be carried in ground water under a variety of chemical conditions (Breger and Deul, 1956, p. 506–507; Gruner and others, 1953, p. 50–51), the weight of evidence now seems to favor alkaline ground water as the transportation medium (Garrels and others, 1957; Garrels, 1957). The exact nature of the solutions, which probably also carried iron and a small amount of vanadium and other associated elements, is not known, but the slight local etching of quartz and the occurrence of carbonate cement in the highest siltstone at the Vickers mine indicates carbonate or bicarbonate solutions.

The close and consistent association of coffinite and carbonaceous debris, with or without pyrite, indicates that carbonaceous material played an important part in precipitating uranium from solution. The ability of organic material to extract uranium from solution in reducing environments has been demonstrated experimentally (Moore, 1954; Breger and others, 1955). The exact mechanism by which this process takes place is not understood, although it has been suggested that uranium may combine with organic matter as an organo-uranium complex, which is very insoluble except under extremely acid conditions (Breger and Deul, 1956).

The present assemblage of carbonaceous material, pyrite, and low-valent uranium minerals in the ore zone, along with the absence of oxidized uranium minerals, indicates that the ore was deposited in a reducing environment which has persisted to the present. The uranium-bearing carbonate or bicarbonate solutions migrated into this reducing environment, and in the presence of H_2S or other reducing agents produced by decaying organic matter, iron was precipitated as pyrite, and uranium was precipitated largely as coffinite. The reactive silica needed for the formation of coffinite either was present in the ore-bearing solutions or was made available by the action of the solutions on quartz grains at the site of deposition.

After the low-valent uranium minerals and probably some low-valent vanadium minerals had been deposited, subsequent lowering of the regional water table brought the upper part of the deposit at the Busfield mine into an oxidizing environment, but the perched body of water allowed the reducing environment to persist in the lower part of this deposit and in the deposit at the Vickers mine. Iron oxides and hexavalent uranium minerals, which occur above the ore zone at the Busfield mine, were formed in the oxidizing environment. There has been little apparent oxidation of the Vickers deposit, which was protected by a relatively impervious cover.

We believe that there is good evidence to show that during oxidation of the upper part of the Busfield deposit secondary enrichment of the low-valent ores occurred. The added uranium was derived largely, though perhaps not entirely, by preferential leaching from the zone of oxidation, and it seems likely that this process is taking place at the present time.

The suggestion of secondary enrichment of uranium arises partly from a study of the vanadium-uranium ratios shown in table 3. In general, the vanadium-uranium ratios in samples from the Busfield deposit are higher than those in samples from the Vickers deposit;

the ratios in samples of oxidized material from the Busfield deposit are highest of all. Several possibilities can be cited to account for what appears to be a deficiency in vanadium in the Vickers deposit. (a) A slight difference in the geochemical environment between the two sites may have caused a greater proportion of vanadium to uranium to precipitate from the original solutions at the Busfield site. (b) If the same solutions were the source of the minerals and if they migrated downdip from the Busfield site to the Vickers site, they may have been deficient in vanadium when they reached the Vickers site. (c) Both deposits may have originally had nearly the same proportion of vanadium to uranium, and the Vickers deposit has since become enriched in uranium owing to lateral migration and reprecipitation of uranium derived either from the oxidized part of the Busfield deposit or from some other updip source.

In support of the third possibility suggested above, three lines of evidence indicate that preferential leaching and migration of uranium has taken place, probably recently, and lend support to the hypothesis that secondary enrichment of the low-valent deposits has occurred.

1. The vanadium-uranium ratios in the oxidized part of the Busfield deposit are generally higher than elsewhere in the deposits, which strongly suggests that during or following oxidation of the low-valent mineral assemblage one of three things might have taken place within this zone: either vanadium combined with clay or in some other way was unavailable as a fixing agent for uranium during oxidation, thereby allowing uranium to be moved out of the zone in the form of uranyl ion, perhaps by intermittent surges of acid sulfate ground-water solutions, as suggested by Garrels and Christ (1959); or following oxidation, solution of hexavalent uranium-vanadium minerals freed the uranium, perhaps as soluble uranyl carbonate complexes, which permitted it to move in solution and leave vanadium behind, possibly combined with clays; or uranium was carried out simply because the original deposit lacked enough vanadium to fix all the uranium available during oxidation of the low-valent minerals.
2. As a general rule oxidized samples are out of equilibrium with an excess of equivalent uranium over chemical uranium, which indicates that uranium has been subtracted from the assemblage leaving radioactive daughter products behind. In unoxidized samples the reverse is true—disequilibrium in favor of chemical uranium over equivalent uranium—suggesting that uranium has been recently added to the assemblage. This disequilibrium in favor of chemical uranium exists in both the low-valent deposits.

3. At least part of the uranium in the Vickers deposit was probably deposited less than 60,000 years ago, according to calculations from radiochemical analyses made by J. N. Rosholt, Jr., of the Geological Survey (written communication, 1958), using the relative abundance of the radioactive isotopes of Pa^{231}, Th^{230}, and Ra^{226} to uranium content. This age indicates that part of the uranium in the low-valent zone was deposited during the Quaternary period and thus might be related to the lowering of the regional ground-water table.

The inference from the available evidence is that the low-valent minerals were deposited when the host rocks were saturated or partly saturated aquifers below the regional ground-water table. The subsequent lowering of the ground-water table allowed only the upper part of the Busfield deposit to come into an oxidizing environment because the perched water body that remained allowed a reducing environment to persist in the lower part of sandstone. During or following oxidation of the low-valent minerals, some of the uranium was leached and migrated downward and laterally within the sandstone beds. Migrant uranium was reprecipitated probably at both the Busfield and Vickers sites and has enriched the low-valent mineral zones. The evidence for recent movement further suggests that these deposits at the present time may be in a cycle of disintegration and accretion and possibly were derived from other, similar deposits which are no longer in existence. This suggested process is in keeping with the multiple migration-accretion hypothesis of Gruner (1956).

The association of selenium with uranium minerals can best be explained by assuming that uranium, iron, selenium, and probably arsenic were carried together by and contemporaneously deposited from the same mineralizing solutions. Although no pyrite was analyzed for selenium content, a comparison of the selenium content of samples listed in table 3 with the selenium content of pyrite from the Busfield mine, reported on by Coleman and Delevaux (1957, p. 520), suggests that a significant part of the selenium probably is contained in the pyrite. Coleman and Delevaux believe that selenium in the Wind River formation has been derived probably from overlying tuff beds, and that following the same depositional pattern as uranium, it is transported by ground-water solutions and is precipitated near the top of the ground-water table in pyrite as a limited substitute for sulfur. In the Busfield deposit selenium apparently was left behind during the oxidation process and the attendant flushing out of the uranium. The relation between selenium and total iron content of 6 selected samples is shown in table 4.

TABLE 4.—*Relations between uranium, selenium, arsenic, and total iron in selected samples from the Elkhorn Creek area*

[Analysts: J. P. Schuch, H. H. Lipp, G. T. Burrow, Claude Huffman, and D. L. Skinner]

Field No.	Serial No.	U (percent)	Se (ppm)	As (ppm)	Total Fe as Fe_2O_3 (percent)
Busfield deposit					
D-56-8	253580	0.003	0.5	<5	0.42
-10	253582	.037	3	<5	.18
-9	253581	.69	4	55	.50
Vickers deposit					
D-56-27	253587	0.006	<0.5	5	2.66
-28	253588	.30	3	220	5.10
-29	253589	.84	20	150	5.76

The arsenic content of the samples listed in table 4 also indicates that a general increase in arsenic accompanies an increase in uranium content. A more systematic association can be observed, however, between arsenic and total iron. Iron analyses are not numerous enough to establish a close correlation, but the analyses indicate that within the unoxidized zone of the Busfield deposit total iron and arsenic are less abundant than in the Vickers deposit (table 4). Table 3 shows also that the arsenic-uranium ratios in samples from the oxidized zone at the Busfield deposit are higher than those in samples from the unoxidized zone. These higher ratios are due probably to the fixing of arsenic and part of the uranium and leaching of excess uranium during oxidation. From the chemical relations it seems likely that the arsenic is associated with the pyrite in the deposits, although the amount of arsenic may also be a function of the amount of carbonaceous material present.

CONTROLS OF DEPOSITION

The factors which controlled the emplacement of these ore deposits can be divided into two general groups, sedimentary and tectonic. Sedimentary features include the lithologic character of the host rock and the sedimentary structures in a potential ore-bearing interval. Tectonic features include joints, faults, and folds on both regional and local scale. The sedimentary features seem to have a rather clearly defined relation to the deposits, and we believe that they are the dominant control in localizing the ore minerals. Although the relation between tectonic features and the deposits is not clearly understood, we believe that tectonic structures exerted a gross control rather than a finite control, in that structural features directed and modified the flow of mineralizing solutions through a system of aquifers within which sedimentary structure and composition of the rock were locally favorable for deposition.

The composition of the host rock, along with the chemical environment it produced locally, was probably the most important factor in localizing the deposits studied. The abundance of carbonaceous material and its intimate association with low-valent uranium minerals, and locally with pyrite, indicate that organic matter, through its decay and attendant formation of H_2S or other reducing agents within a zone of ground-water saturation, produced the reducing environment necessary for reducing the uranyl ion from solution, and also acted as a collecting agent for uranium. No uranium minerals accumulated where carbonaceous debris was not present.

The differences in the proportions of detrital constituents also controlled the differences in texture of the host rock, which in turn influenced the rate of flow of migrating ground-water solutions. The presence of clay in the interstices of the well-sorted even-grained sandstone reduced the permeability and thereby helped to retard the rate of flow of ground water within the geochemically favorable zones. We believe that restricting the rate of flow of mineralizing solutions locally might be an important factor in controlling uranium precipitation.

The textural differences, arising principally from differing grain size, between the ore-bearing sandstone and the underlying units have been responsible for preserving the ore. Without the local water body perched on the impervious unit beneath the ore-bearing sandstone, the ore would have been oxidized and the uranium probably would have been flushed away from the site of the deposit.

Sedimentary structures, which include abnormal changes in thickness of otherwise favorable intervals, and irregularities in the bottom surface of such intervals, probably exerted some influence on ore deposition. The major contribution of such features probably was to help control the direction and rate of local ground-water flow. The long axis of the abnormally thick sandstone lens that contains the Busfield deposit trends nearly at right angles to the regional structure. The lens probably functioned as a natural conduit that diverted large quantities of migrating solutions toward its lower, or west, end. Partial damming at its lower end, caused by thinning and perhaps in part by its irregular bottom surface, retarded the rate of flow and thus added favorable ground-water conditions to an already lithologically favorable site. The abnormal thickening of the sandstone interval in the vicinity of the Vickers deposit also may have been the favorable solution-control factor at that site. The other abnormally thick areas of the lens shown in figure 5 may also have had favorable ground-water conditions, but they probably lacked the favorable geochemical conditions; where these areas are exposed in outcrop, no carbonaceous material was seen in the sandstone.

The degree of influence exerted by minor tectonic features is not known. No evidence has been observed to indicate that the numerous joints had any influence on localizing the ore. The coincidence of small faults, transverse to the probable direction of ground-water flow, and the sites of the ore deposits may have some significance in that a dislocation of beds, perhaps bringing a pervious sandstone bed against an impervious siltstone bed, might have contributed to the partial damming of the ground water. Such a dislocation would have had a greater effect in the thin-bedded sequence at the Vickers mine than in the massive sandstone at the Busfield mine.

The effect of folds on ore localization is not completely understood. Regional folds, expressed in this area by the general northwesterly dip, probably exerted a gross control on the regional rate and direction of ground-water flow, and the broadly terraced area that trends northeastward across the quadrangle probably modified the regional rate of flow. Furthermore, the influence of local folds, such as the slightly domed area in the vicinity of the mines, probably was limited to their effect on the rate of flow of ground water. We have studied the other domes in the quadrangle and some of these have been drilled by prospectors. Although these domes might be considered as structural features favorable for ore deposition, they lack sandstone with lithologic characteristics that we consider suitable, and they lack favorable sedimentary structures. Little or no concentration of uranium minerals has been found associated with these domes.

In summary, we believe that the composition and texture of the host rock, the distribution of zones of reducing environments, and sedimentary structures within lithologically and chemically favorable intervals were the major controlling factors in localizing the ore deposits, and that minor tectonic features, although they contributed to the development of favorable subsurface hydrologic conditions locally, probably were not requisite for localizing the ore.

BENTONITE

Deposits of commercial-grade bentonite occur at various horizons in the marine Cretaceous rocks of the northwestern Black Hills and have been described by Knechtel and Patterson (1956). Only one bed of bentonite that may be of economic importance crops out in the mapped area. This bed occurs about 6 feet above the base of the Newcastle sandstone, which caps a small mesa in sec. 4, T. 56 N., R. 65 W. It is light gray to greenish gray, biotitic near its base, and is 5 feet thick at the northwest point of the mesa. This bentotite bed is probably equivalent to the "A" bentonite of Knechtel and Patterson.

We tested the bentonite to determine if its swelling capacity is great enough to make it suitable for industrial uses. Knechtel and Patterson (1956) state that for bentonite to be suitable for drilling purposes, 2 grams of the crushed material should swell to a minimum of 20 ml in 100 ml of distilled water 1 hour after the last grain has been added to the water. Bentonite must pass other tests before it can be used, but the swelling capacity is of primary importance. We found that the bentonite meets this requirement and, therefore, may be economically important.

Other occurrences of thin discontinuous beds of bentonite and bentonitic claystone, which crop out near the base of the Skull Creek shale, are probably too small to be considered economically important at this time.

ROAD METAL

The fissile siliceous Mowry shale has been used to surface many of the roads in the Black Hills where they cross the black gumbo soils of the marine Cretaceous rocks. Several small scattered slump blocks of Mowry are shown on the geologic map (pl. 1) and one of these, in SE¼ sec. 20, T. 56 N., R. 65 W., has been used by ranchers in the area to surface some of the unimproved roads. The other small patches of Mowry probably could be used in a limited way for the same purpose, but if large quantities of such shale should be needed for road metal, the nearest source is a few miles north of the Little Missouri River.

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