Geology of the Jewel Cave SW Quadrangle Custer County, South Dakota

---

GEOLOGICAL SURVEY BULLETIN 1063-G

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

Braddock—GEOLOGY OF THE JEWEL CAVE SW QUADRANGLE, CUSTER COUNTY, SOUTH DAKOTA—Geological Survey Bulletin 1063-G

Geology of the Jewel Cave SW Quadrangle Custer County, South Dakota

By WILLIAM A. BRADDOCK

GEOLOGY AND URANIUM DEPOSITS OF THE SOUTHERN BLACK HILLS

GEOLOGICAL SURVEY BULLETIN 1063-G

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

UNITED STATES GOVERNMENT PRINTING OFFICE WASHINGTON : 1963

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

CONTENTS

ILLUSTRATIONS

[Plates are in pocket]

GEOLOGY OF THE JEWEL CAVE SW QUADRANGLE CUSTER COUNTY, SOUTH DAKOTA

By WILLIAM A. BRADDOCK

ABSTRACT

The Jewel Cave SW quadrangle is in the southwestern part of the Black Hills in Custer County, S. Dak., about midway between Edgemont, S. Dak., and Newcastle, Wyo. All the rocks that crop out within the quadrangle are of sedimentary origin and range in age from Pennsylvanian to Early Cretaceous.

The Minnesota Formation of Pennsylvania and Permian age, which is about 1,000 feet thick, was studied in outcrop and from two diamond-drill cores. In the subsurface the upper part of the formation consists of gray sandstone, very fine grained dolomite, and anhydrite. The anhydrite has been leached from the formation near the outcrop, perhaps in the early part of the Cenozoic Era, and the resulting subsidence has produced collapse breccias in the Minnelusa and milder deformation in the overlying units. In the collapse breccias the rocks have been oxidized and are red, whereas in the subsurface they are gray. The anhydrite cement of the subsurface sandstone has been replaced by calcite, and the dolomite beds have been partially converted to limestone.

The Opeche Formation of Permian age consists of 75 to 115 feet of red siltstone and shale and two thin gypsum beds. The Minnekahta Limestone of Permian age is about 40 feet thick.

The Spearfish Formation of Permian and Triassic age is about 550 feet thick and consists of red siltstone, red sandstone, dolomite, and gypsum. The dolomite and gypsum beds are restricted to the lower half of the formation. In the northeast corner of the quadrangle the gypsum beds have been dissolved by ground water. The Sundance Formation of Late Jurassic age is divided into five members that have a total thickness of about 360 feet. The Morrison Formation of Late Jurassic age ranges in thickness from 60 to 120 feet. It consists of blocky-weathering noncarbonaceous mudstone and subordinate beds of limestone and sandstone.

The Inyan Kara Group of Early Cretaceous age has been subdivided into the Lakota Formation and the Fall River Formation. The Lakota Formation consists of 200 to 300 feet of carbonaceous siltstone, blocky-weathering claystone, and fine-grained to conglomeratic sandstone. These rocks were deposited in stream channels, flood plains, and ponds. The Fall River Formation is about 110 to 130 feet thick. Along the northeast side of the outcrop the formation consists of fine- to medium-grained sandstone, which forms an elongate body at least 1½ miles wide and more than 25 miles long. To the southwest the

formation consists of thinly stratified interbedded sandstone, carbonaceous siltstone, and varicolored mudstone. The Skull Creek and Mowry Shales of Early Cretaceous age consist of black fissile shale. The Mowry contains abundant fish scales and weathers to a silver gray.

Alluvium fills the bottom of many intermittent streams, and small gravel-covered terraces mark the former high levels of these streams. Gravel, which caps hills at altitudes of 4,460 to 4,620 feet, is believed to have been deposited by a Pleistocene stream that drained southeastward toward the town of Minnekahta. Many landslides are present along the northward- and eastward-facing scarp of the Inyan Kara hogback.

The Dewey fault, trending N. 75° E., crosses the quadrangle. It is probably a vertical dip-slip fault, and has an apparent displacement of 250 to 440 feet. Two northwest-trending anticlines are in the quadrangle—one extends from the Edgemont NE quadrangle to near the center of the Jewel Cave SW quadrangle, and the other is limited to the center of the Jewel Cave SW quadrangle.

Collapse structures, which were produced by the solution of anhydrite, are (a) breccias in the Minnelusa Formation, (b) limestone-dolomite breccias in the Spearfish Formation, (c) undulations and normal faults in the formations overlying the Minnelusa, and (d) breccia pipes that extend upward from the Minnelusa to at least as high as the Lakota Formation. The leaching probably occurred in early Cenozoic time.

Minor deformational structures in the Minnekahta Limestone and the Spearfish Formation occur in areas where there has been little subsidence; these structures are probably due to sliding of the strata away from the center of the Black Hills.

Several small uranium deposits and several radioactivity anomalies are known in the quadrangle, but no large economic deposits have been found. The known occurrences of uranium minerals are all within the Inyan Kara Group.

INTRODUCTION

The Black Hills of South Dakota are a range of mountains carved from a domal uplift (fig. 43). They are oval in plan and are 60 miles wide and 125 miles long in the direction of the main north-northwest axis. Precambrian rocks crop out in the central Black Hills, and Paleozoic and younger rocks dip outward from this Precambrian terrane. The Jewel Cave SW quadrangle is in the southwestern part of the Black Hills in Custer County, S. Dak. The quadrangle extends from the southwest side of the outer hogback, which is held up by sandstone of Early Cretaceous age, northeast to the outcrop of the Carboniferous rocks (pl. 20). All the rocks that crop out in the quadrangle are of sedimentary origin.

This study was part of the U.S. Geological Survey's continuing study of the geology and ore deposits of the southern Black Hills, which was stimulated by the discovery of uranium deposits in sandstone in the area in 1951 (Page and Redden, 1952; Bell and Bales, 1955). Since that time, twelve 7½-minute quadrangles that blanket the outer hogback from the vicinity of Hot Springs, S. Dak., to Newcastle, Wyo., have been mapped (Mapel and Gott, 1959). The

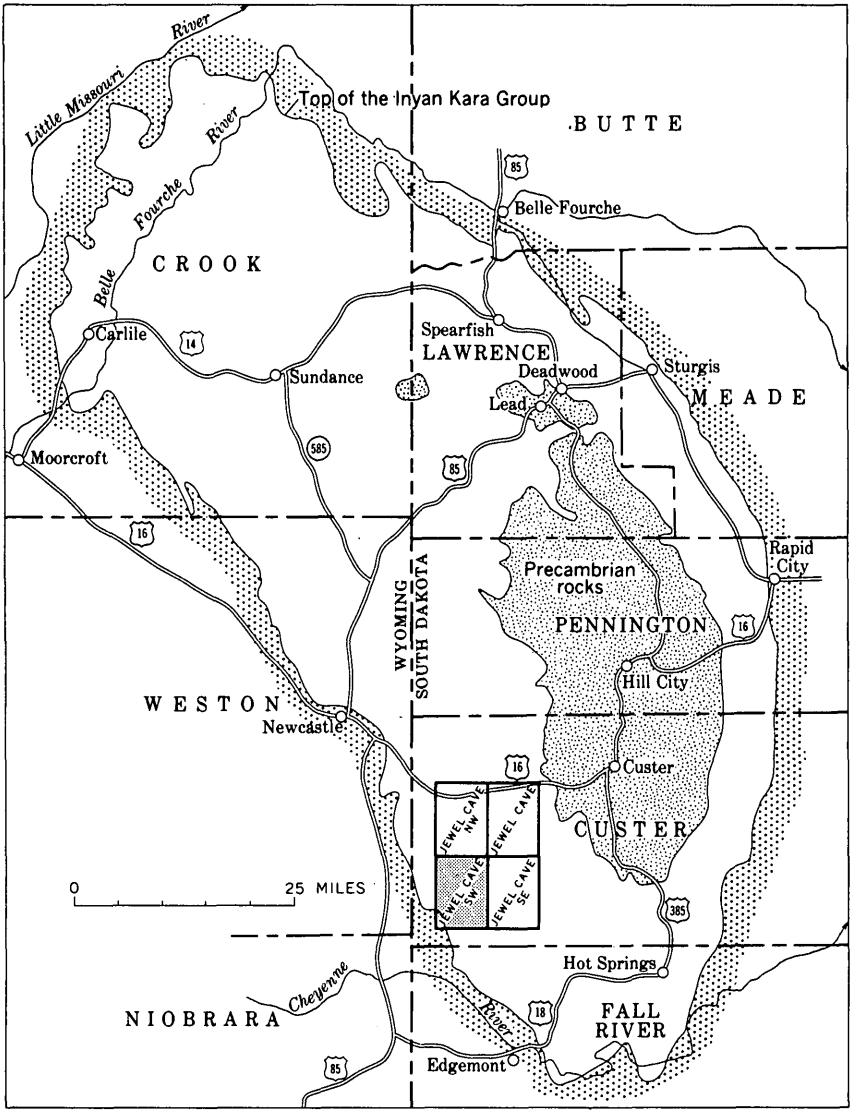

FIGURE 43.—Index map of the Black Hills showing the location of the Jewel Cave SW quadrangle, and some of the adjoining quadrangles.

main purpose of most of this work was to determine the geologic relationships that caused the occurrence of the many uranium deposits in sandstones of Early Cretaceous age in this area.

The Jewel Cave SW quadrangle is on the northwest fringe of the Edgemont mining district, and no important uranium deposits have yet been found in the quadrangle. The Inyan Kara Group, which contains most of the known uranium-vanadium deposits in the mining district, crops out only in the southern and eastern parts of the quadrangle. A large part of the present report deals with the petrography and structure of rocks of Pennsylvanian and Permian age from which substantial amounts of evaporite sediments have been leached. It is suspected that the solution of these rocks, and the associated collapse and brecciation of overlying rocks, may have played a role in the genesis of uranium deposits throughout the southern Black Hills.

ACKNOWLEDGMENTS

The author began work in the southern Black Hills in 1952. Since that time he has worked with 12 other geologists of the Survey who have been doing similar work in this area. The writer has benefited greatly from exchange of ideas with these men, and it is impossible to acknowledge specifically the influence that each of them has had on the ideas presented in this report.

George Carter and Thomas Bridge assisted with the mapping during the summers of 1955 and 1956, respectively.

STRATIGRAPHY

PERMIAN ROCKS

MINNELUSA FORMATION

The name Minnelusa Sandstone was given by Winchell (1875, p. 38 and 65) to rocks on the west side of the Black Hills in the valley of Cold Spring Creek. The limits of the formation were redefined by Darton (1901, p. 510) as the top of the Pahasapa Limestone of Mississippian age and the base of the red mudstone of the Opeche Formation. Darton and Paige (1925, p. 8) designated Rapid Creek on the east side of the Black Hills near Rapid City as the type locality; a detailed description of the formation at this locality is given by Boardman.[1]

The Minnelusa Formation in the southern Black Hills has been divided into six units (C. G. Bowles, oral communication, 1961), but only unit 1 crops out within the Jewel Cave SW quadrangle.

The Minnelusa Formation was first thought to be of Pennsylvanian age, but lithologic correlations with rocks of eastern Wyoming (Agatston, 1954; Bates, 1955; McCauley, 1956; Foster, 1958; and Maughan, written communication, 1960) indicate that the top of the Pennsylvanian System should be placed at the base of a persistent bed of red mudstone informally called "the red marker" (pl. 21). The red marker is the base of unit 1 of the Minnelusa.

[1] Boardman, D. C., 1942, Minnelusa formation in Rapid Canyon area, Black Hills, South Dakota: Iowa Univ. M.S. thesis.

Foraminifers collected from the USGS 2, Pass Creek core test (pl. 21) confirm the Early Permian age of unit 1 of the Minnelusa Formation in the Black Hills. The following fossils collected from about 150 feet below the top of the formation were identified by L. G. Henbest:

Osagia? sp. or girvanellid accretions
Textulariidae
Globivalvulina sp.
Tetrataxis sp.
Primitive Lagenidae?
Spandelinoides? sp.
Geinitzina postcarbonaria Spandel, 1901
Spandelina? sp. and other supposed Lagenidae
Echinoid spines having complex cribriform structure

He states that the *G. postcarbonaria* and related primitive Lagenidae? indicate Wolfcamp or Leonard age. The seemingly Permian forms of *Globivalvulina*, *Tetrataxis*, and echinoid spines support that determination.

The lower part of the Minnelusa (units 2–6), which is composed predominantly of limestone, dolomite, shale, and sandstone, does not crop out within the Jewel Cave SW quadrangle. The lithologic data for this part of the formation (pl. 21) were obtained from surface exposures along Hell Canyon in the adjoining Jewel Cave and Jewel Cave NW quadrangles, and from subsurface cores (USGS 1, Hell Canyon core test in the NW¼ sec. 1, T. 6 S., R. 1 E.).

In the subsurface, unit 1 of the Minnelusa Formation (pl. 21) is characterized by thick beds of anhydrite that alternate with beds of sandstone and dolomite; but in most surface exposures the anhydrite has been dissolved, and the sandstone and dolomite are brecciated and altered.

The upper 120 feet of unit 1, which consists of unbrecciated sandstone, dolomite, and gypsum, is exposed in lower Hell Canyon (sec. 31, T. 5 S., R. 2 E.) (see pl. 21). Farther up Hell Canyon, in the northeast corner of the quadrangle, the same part of the formation is exposed, but the upper two gypsum beds have been dissolved, and the sandstone and carbonate rocks are brecciated and contorted.

The Minnelusa Formation in the Jewel Cave SW quadrangle is about 1,000 feet thick where anhydrite or gypsum is present, but only about 870 feet thick where the anhydrite has been removed by leaching.

PETROGRAPHY OF THE UPPER PART OF THE MINNELUSA FORMATION

The USGS 2, Pass Creek core test, in the NW¼ sec. 1, T. 6 S., R. 1 E., penetrated the upper 430 feet of the Minnelusa Formation (pl. 21).

689-415 O—63——2

In this drill hole, 237 feet of anhydrite are interbedded with dolomite, anhydrite- or gypsum-cemented sandstone, and minor mudstone.

SANDSTONE

The sandstone in this well is uniformly fine grained to very fine grained, well sorted, and has subangular to subrounded grains. Most of the units seem to be thinly and horizontally laminated, but the thickest unit, which is at the top of the formation (pl. 21), is strongly crossbedded in the outcrop. The crossbeds are planar and about 6 feet in length.

The color of the sandstone varies—the upper two beds, which total 70 feet in thickness, are red to yellow, the lower beds are dominantly light gray to dark gray. In several beds the top of the sandstone is mottled purplish red, and the base is gray. Some beds are irregularly spotted and mottled with red, yellow, or purple in streaks paralleling the stratification. Gray sandstone changes to red near fractures.

The detrital constituents of the sandstone are more than 95 percent quartz, less than 2 percent feldspars (plagioclase, microcline, and untwinned potassium feldspar), and chert. The accessory minerals are dominantly well rounded grains of zircon, tourmaline, and leucoxene.

The cement of the two red sandstone beds near the top of the formation is fibrous to coarsely crystalline gypsum. Some patches of coarsely crystalline gypsum surrounding several sand grains contain small rounded to rectangular crystals of anhydrite.

The cement of the gray to mottled sandstone is predominantly coarsely crystalline anhydrite that poikilitically includes sand grains.

Many crystals of carbonate are distributed through the anhydrite and gypsum cement. The carbonate is dolomite in most places, but in the upper red sandstone some of the carbonate is calcite. Where the carbonate is dolomite, it occurs as either very small isolated rhombs or as aggregates of rhombs floating in the sulfate. Where the carbonate is calcite, it occurs as rather large crystals that include several sand grains or partially replaced quartz grains.

Pyrite occurs with anhydrite as interstitial filling in several of the gray sandstone beds. The relationship between pyrite, iron oxide, gypsum, and anhydrite is of particular interest in the sandstone bed that occurs between 578 and 594 feet below the top of the drill hole: The lower part of this bed is light gray to dark gray and contains interstitial pyrite and anhydrite; the upper part is mottled pink to dark purple, contains no pyrite, and is cemented largely by gypsum. This relation indicates that oxidation has altered pyrite to iron oxide, inducing the pink to purple color, and that anhydrite has been converted to gypsum.

Authigenic iron oxide occurs in the upper two red sandstone beds but was not observed in lower beds. The oxide occurs as crystals in the interstices of the sandstone. These crystals commonly are euhedral and, although very small, they appear to be flat rhombohedrons having striated faces.

DOLOMITE

All the beds of dolomite consist entirely or predominantly of the mineral dolomite, which is extremely fine grained. The color varies from dark gray to grayish red. Some specimens are noticeably mottled and have concentrations of red or yellow iron oxide around small shell fragments or around small vugs. Stratification is apparent only at the contact with other units where there is frequently a gradational boundary showing fine planar or contorted laminations.

ANHYDRITE

The anhydrite is light gray to dark gray and consists of many small rectangular crystals that have a tendency to be elongate parallel to the stratification. This fine-grained euhedral texture is useful in distinguishing primary anhydrite from the replacement anhydrite discussed below. Detrital impurities are very rare. Rather large lath-shaped crystals of quartz were observed in several slides. These crystals are too large to be detrital, and many contain small inclusions of anhydrite. They frequently form aggregates in which the individual laths radiate from a common center.

Anhydrite has been partially converted to gypsum throughout the entire depth of the core. Hydration is patchy, however, and is most common adjacent to sandstone or dolomite beds and along fractures. Some of the anhydrite has a fetid odor when freshly broken.

REPLACEMENT OF DOLOMITE BY ANHYDRITE

Replacement of dolomite by anhydrite is rare. However, in several slides there are conspicuous patches of coarsely crystalline anhydrite that differ markedly in texture from the typical fine-grained primary sulfate. Because many of these patches contain relict outlines of fossils, they are believed to have been caused by replacement of the dolomite by anhydrite.

FLUORITE

Small crystals of fluorite were found in two specimens in the Minnelusa and also in a similar rock type in the Minnekahta Limestone. In the Minnelusa the two fluorite occurrences are similar.

In the core of USGS 2, Pass Creek, the contact between dolomite and anhydrite at the depth of 484 feet is very irregular. Nodular to lenticular masses of anhydrite, which have the typical fine-grained rectangular texture of primary anhydrite, occur with masses of fine-grained dolomite. The dolomite masses contain small clots of coarsely crystalline anhydrite, which appear to be filling small vugs. The vugs are rimmed with red iron oxide, and within many are small cubes of fluorite. The fluorite is colorless, except for irregular purple patches.

The highest dolomite in the core of USGS 2, Pass Creek contains abundant patches of anhydrite replacing fossils and the dolomite groundmass. In the adjacent surface outcrops in Hell Canyon, this bed contains fluorite within patches of gypsum that have the same textural appearance as the replacement anhydrite in the core.

LEACHING OF ANHYDRITE AND ALTERATION OF ASSOCIATED ROCKS

Throughout the Black Hills the anhydrite beds in the upper part of the Minnelusa Formation have been leached in a zone near the outcrop. Only two places are known to the writer where gypsum is preserved at the surface. One locality northeast of Sundance, Wyo., has been described by Brady.[2] The other locality is in the Jewel Cave SW quadrangle in sec. 31, T. 5 S., R. 2 E. Leaching of anhydrite from correlative beds in the Hartville uplift of eastern Wyoming has been described by Bates (1955).

The removal of several hundred feet of rock from the lithologic column has resulted in the formation of many subsidence structures, which are described in the section on "Structure." In the zone from which anhydrite beds have been removed, the remaining rocks have been altered to an important degree. The alterations recognized are extensive oxidation, the replacement of anhydrite and dolomite cement by calcite, and the alteration of dolomite to dolomitic limestone.

OXIDATION

Most of the sandstone units penetrated in the USGS 2, Pass Creek core test are gray. However, the upper two beds in the core, and most of the brecciated beds in the outcrop, are shades of yellow and red. Pyrite, though not abundant, is a common constituent of sandstone in the core, but has not been observed in surface exposures. Authigenic crystalline iron oxide was observed in all surface sandstone examined and in the two top sandstone beds in the core.

[2] Brady, F. H., 1930, Some problems of the Minnelusa Formation near Beulah, Wyoming: Iowa Univ. M.S. thesis.

The dolomites in the USGS 2, Pass Creek core are dominantly gray to grayish red, but in the surface outcrops many of the carbonate rocks are markedly red and contain abundant spots and dendrites of manganese oxide. Surface carbonate units that are largely gray are oxidized to reds and yellows in vuggy zones and along fractures.

It is probable that rock that has undergone the initial stages of oxidation is present in the core from USGS 2, Pass Creek. The sandstone between 578 and 594 feet from the top of the core is oxidized in the upper part, and the anhydrite cement has been altered to gypsum. Many of the other units in this core, both dolomite and sandstone, have patchy to mottled iron oxide near small vugs and along fractures. The dominant gypsum cement in the upper two red sandstone beds contains both anhydrite remnants and authigenic iron oxide crystals. It seems likely that these sandstone beds were altered from the typical gray of underlying sandstone at the same time the anhydrite cement was altered to gypsum.

REPLACEMENT OF ANHYDRITE AND DOLOMITE CEMENT BY CALCITE AND IRON OXIDE

In the USGS 2, Pass Creek core the sandstone is completely cemented by anhydrite or gypsum containing rhombs of dolomite. In the outcrop all the sandstone is friable, and the dominant cements are calcite and iron oxide. The calcite cement is present as coarse crystals that include several sand grains.

ALTERATION OF DOLOMITE TO DOLOMITIC LIMESTONE

The carbonate rocks in the core of the USGS 2, Pass Creek are dominantly very fine grained dolomite. In the outcrop the carbonate rocks are calcitic dolomite breccia, calcitic dolomite, and coarse-grained limestone that contains less than 1 percent dolomite (pl. 21). These mixed carbonate rocks are the product of replacement of dolomite by calcite.

OPECHE FORMATION

The Opeche Formation was named and defined by Darton (1901, p. 513). The type locality of the formation is on Battle Creek on the east side of the Black Hills.

The formation crops out in Tepee, Schenk, and Hell Canyons in the northeastern part of the quadrangle, where the thickness ranges from 75 to 115 feet. Part of the variation in thickness is believed to be due to minor flexures in the overlying Minnekahta Limestone that are not reflected concentrically in the base of the Opeche. At two locations the thickness of the formation was measured beneath the trough of a syncline in the Minnekahta and compared with the thickness beneath the crest of the adjacent anticline as follows:

Location	*Thickness beneath trough (feet)*	*Thickness beneath crest (feet)*
SE¼ sec. 24, T. 5 S., R. 1 E	90	105
Center of sec. 31, T. 5 S., R. 2 E	75	90

The Opeche Formation consists predominantly of red mudstone. The upper 15 to 20 feet are a distinctively purplish red in contrast to the reddish brown of the rest of the formation. Two gypsum beds 5 to 7 feet thick occur—one near the middle, the other very near the base of the formation. The lower bed was reached at a depth of 150 feet in the USGS 2, Pass Creek core test; at this depth it consists of more than 50 percent anhydrite.

Northeast of sec. 29 in Hell Canyon the gypsum beds are present only as isolated patches. The gypsum in the intervening areas has probably been leached away.

In the extreme northeast corner of the quadrangle, a wedge of sandstone is at the base of the formation. This wedge consists of beds of pink to yellow fine-grained sandstone that range from 2 to 20 feet in thickness and are separated by thin beds of red siltstone. At the north boundary of the quadrangle the thickness of this wedge is about 40 feet.

No fossils have been found in the Opeche Formation, but it is underlain and overlain by rocks of Permian age.

MINNEKAHTA LIMESTONE

The Minnekahta Limestone was named and defined by Darton (1901, p. 513); it is a medium-gray to light-red, thinly bedded limestone that ranges from 35 to 50 feet in thickness. The type locality of the formation is the area around Minnekahta, S. Dak.

The Minnekahta Limestone in the Jewel Cave SW quadrangle can be divided into four recognizable units. For convenience of description, these units are numbered from bottom to top.

Unit 1, which is about 4 feet thick, consists of alternating thin beds of pure limestone and thin beds of silty or argillaceous limestone. Individual strata are thinly lenticular and do not extend laterally more than a few feet. Small pelecypod shells and casts of gastropods are very common. This unit is less resistant than the overlying unit, and seldom is exposed.

Unit 2, which is about 15 feet thick, consists of layers of light-gray limestone alternating with thin layers of reddish-brown limestone; the color variation parallels the bedding. Etched polished surfaces indicate that the thin red layers contain a higher proportion of insoluble material, and in thin sections this insoluble material is seen to be predominantly clay size.

Unit 2 consists of a mosaic of anhedral crystals of calcite whose sizes range from 0.02 to 0.15 mm; the smaller sizes are the more abundant. Quartz grains are not abundant, but in some specimens they make up about 5 percent of certain laminae.

Anhydrite is a common accessory mineral in this unit, but does not exceed 5 percent by volume. The former existence of anhydrite is indicated in the outcrop by many small vugs. In fresh samples, the anhydrite is in flattened ellipsoidal masses, as much as 0.5 inch in diameter, around which the stratification in the carbonate is deflected.

Zones of ellipsoidal calcite concretions occur at several localities in unit 2. These concretions range from about 6 inches to 1 foot in diameter. Stratification passes through the concretions, and some beds contain abundant small pelecypod fossils both outside and within the concretions. Somewhat similar structures in the Minnekahta Limestone in the northern Black Hills have been described by Knaack [3], and were considered by him to be algal structures (*Rhodophyceae*). Polished slabs from the concretions in the Jewel Cave SW quadrangle show no structures that could be interpreted by the writer as algal. Many strata within some of the concretions are crenulated on a very fine scale, but crenulations of this type occur outside the concretions as well. Examination under the binocular microscope shows that the crenulation has resulted from compaction around many small pelecypod shells. The origin of these concretions is not known.

Unit 3 is 3 to 5 feet thick and consists of thinly laminated, dark-reddish-gray limestone containing many red-siltstone laminae. Pelecypod shell fragments are abundant.

Unit 4 is about 15 feet thick and is a thinly stratified dominantly reddish gray limestone, which is frequently mottled with irregular splotches of medium gray color. The mottled parts of the rock commonly have a fetid odor when broken. The mottling is probably due to the small amount of organic matter that maintains the iron in the reduced valence. Irregular patches of anhydrite were observed in several specimens, and may make up as much as 10 percent of the rock.

Throughout the center of the quadrangle the Minnekahta is overlain by basal gypsum beds of the Spearfish Formation. Here, the upper 2 feet of the formation is a thinly laminated pink to red anhydritic limestone. On the outcrop, most of the anhydrite has been leached out; the leaching produced a honeycomb texture. In

[3] Knaack, E. L., 1936, Origin of certain structures of the Minnekahta formation in the Whitewood region, northern Black Hills, South Dakota: Iowa Univ. M.S. thesis.

fresh rock the anhydrite occurs as large crystals that commonly have a rectangular or rhombic cross section. In several places the lamination in the limestone is deflected around these crystals. Associated with the anhydrite are large irregular to subhedral crystals of calcite that contain inclusions of anhydrite. Subhedral grains of fluorite, which are 0.1 to 0.25 mm in diameter, occur sparingly along certain laminae. Some of the fluorite grains are surrounded by fine-grained calcite, some are entirely within anhydrite crystals, and some are partly within anhydrite and partly within coarse calcite. No age relation of the fluorite to the other constituents of the rock could be seen.

The only dolomite observed in the Minnekahta is a 1-foot-thick bed of white to light-gray rock that occurs near the top of the formation in sec. 29, T. 5 S., R. 2 E.

Very near the top of the formation in the NW¼NW¼ sec. 1, T. 6 S., R. 1 E., are structures that may be algal heads. These structures resemble flat, inverted saucers and range from 2 to 4 feet in diameter. Although good cross sections of the structures were not visible, the doming of the limestone laminae apparently is limited to a thickness of about 4 inches.

Fossil remains of pelecypods and gastropods are very common throughout the formation. Most fossil remains are small internal casts that are hard to identify. Published data concerning the identification of these fossils are summarized below:

Forms	*Source (Darton, 1925, p. 10)*
Pteria (*Avicula*)	Identified by Girty.
Sedgwickia	Do.
Schizodus or *Myophoria*	Do.
Yoldia? cf. *Y. subscitula*	Identified by Schuchert.
Edmondia? sp	Do.
Fragmentary fish remains:	
palaeoniscids	Identified by Hussakof.

Dr. John Chronic of the University of Colorado (written communications, 1958) examined material collected by the writer from the lower part of the formation and reported the following forms to be present:

Gastropods:
- *Bullimorpha* cf. *B. meeki* Sayre
- *Sphaerodoma* cf. *F. fusiformis* (Hall)

Pelecypods:
- *Nuculana* cf. *N. obesa* White
- *Pleurophorus* cf. *P. albequus* Beede
- *Schizodus* cf. *S. wheeleri* Swallow

He stated: "In my opinion the Minnekahta samples are definitely Permian. In comparison with known Triassic faunas of the Rocky Mountain states, these are quite different, environmentally as well as faunally. The earliest Triassic faunas of Wyoming are quite specialized, but are not at all like that of the Minnekahta."

Fragments of a fish found in the lower part of the formation were examined by Dr. D. H. Dunkle, U.S. National Museum. He reported (written communication, 1957): "The only known group to which it might possibly belong is the amphicentrids, or Amphicentridae, a group of chondrostean fishes which parallel the platysomids in body habit and stratigraphic distribution (Mississippian to Upper Permian)."

PERMIAN AND TRIASSIC ROCKS

SPEARFISH FORMATION

The Spearfish Formation was defined by Darton (1901, p. 516) as the red shale and gypsum beds underlain by the Minnekahta Limestone and overlain by the gray sandstone and shale of the Sundance Formation of Jurassic age. The type locality is near Spearfish, S. Dak.

In the Jewel Cave SW quadrangle, as in the rest of the Black Hills, the nonresistant nature of the Spearfish has resulted in the development of a broad grass-covered valley at the position of the outcrop. Thus the formation generally lacks good exposure, and its stratigraphic thickness is difficult to measure.

The Spearfish Formation consists predominantly of siltstone, sandstone, and gypsum, and contains a minor amount of carbonate rocks. The variations of lithology within the formation are shown on figure 44.

In the Jewel Cave SW quadrangle it was possible to map the distribution of three layers of the Spearfish Formation, consisting principally of gypsum. In adjacent areas, however, it was possible only to subdivide the formation into lower, middle, and upper units. For the sake of continuity, the Spearfish in this report has been divided into lower, middle, and upper units, and the lower and middle units have been further subdivided into separate subunits consisting principally of gypsum or siltstone (pl. 20; fig. 44).

The red siltstone and minor, very fine grained red sandstone in the lower, middle, and basal upper units are almost structureless. Thin laminations are common in the sandstone in the top of the upper unit, and some beds are ripple laminated. The siltstone and sandstone consist of about 65 percent quartz, 2 percent feldspar, 3 percent chert grains, 2 percent white mica, 9 percent detrital dolomite grains, 15

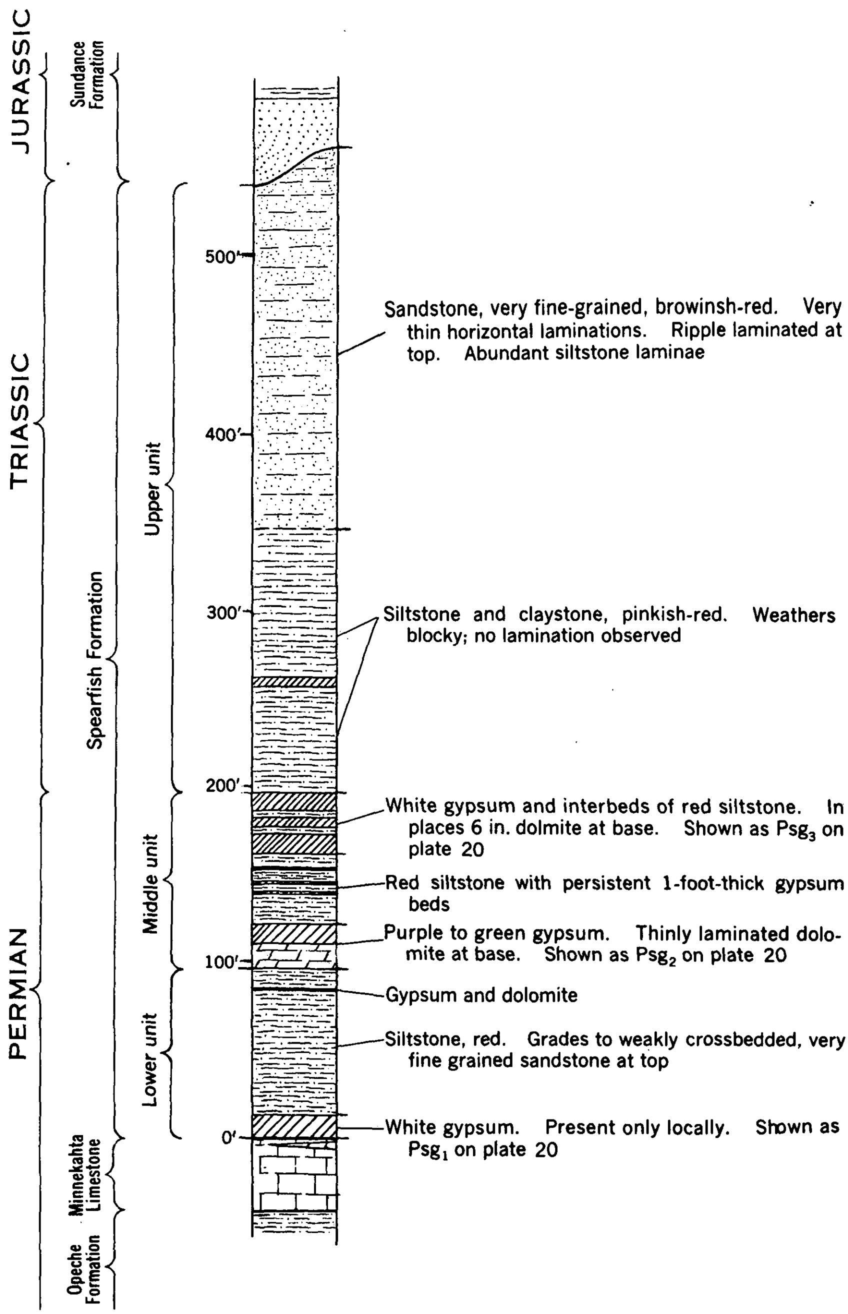

FIGURE 44.—Lithology of the Spearfish Formation.

percent matrix, and 4 percent calcite cement. Rounded grains of ilmenite are common, and in some specimens they make up almost 2 percent of the volume. The matrix consists of iron oxide, carbonate, mica, and clay. Authigenic overgrowths are scarce, except on the detrital dolomite grains, which frequently have euhedral rhombic overgrowths. The calcite cement occurs in scattered patches of coarse crystals that enclose many detrital grains. The red pigment of the rock is concentrated in the matrix and occurs as thin coatings on the detrital grains. The detrital dolomite grains are irregularly coated with pigment on the original rounded margins, but the secondary rhombic overgrowths are free of pigment.

The G_1 gypsum bed in the lower unit (fig. 44) rests directly on the Minnekahta Limestone, but the bed occurs only in the center of the quadrangle (pl. 20). The G_2 and G_3 gypsum beds in the middle unit are continuous along the outcrop between the Jewel Cave SW quadrangle and Hot Springs, S. Dak., a distance of about 28 miles, but in the northeast corner of the quadrangle these two gypsum beds have been leached out, and their stratigraphic positions are marked by thin beds of dolomite-siltstone breccia. All the gypsum beds are virtually free of detrital material. Most thin sections of gypsum contain small, rounded to rectangular remnants of anhydrite, and a small percentage of small dolomite rhombs.

Carbonate rocks were found in the lower and middle units. A thin bed of carbonate and gypsum occurs in the lower unit about 65 to 85 feet above the Minnekahta. At most places where this bed was observed, the carbonate was dolomite; in the SW¼ sec. 33, T. 5 S., R. 2 E., it consists of rather coarse-grained limestone containing abundant unidentifiable fossil fragments. A 5- to 15-foot-thick bed of thinly laminated dolomite occurs at the base of the middle unit about 100 feet above the Minnekahta. Locally, a thin dolomite bed about 6 inches thick occurs at the base of the G_3 gypsum bed.

No identifiable fossils have been found in the Spearfish in the Black Hills. The age of the formation must be inferred from regional correlation with the red-bed sequence in Wyoming and with the fossiliferous marine units in Idaho and adjacent areas. The latest published correlations are by Thomas (1940) and Condra and others (1940). These authors believe that the Minnekahta Limestone is well below the Permian-Triassic boundary. Condra has placed the top of the Permian at the top of the part of the Spearfish that contains thin limestone and gypsum beds (near the base of the upper unit). Thus the age of the Spearfish Formation is probably Late Permian and Triassic.

JURASSIC ROCKS

SUNDANCE FORMATION

The Sundance Formation was named and defined by Darton (1899). He (*in* Darton and O'Harra, 1909, p. 3) referred to the area north of Sundance, Wyo., as the type locality. Darton recognized several persistent lithologic units within the formation but did not name them. Imlay (1947) studied the formation throughout the Black Hills, subdivided it into five members, and suggested that a well-exposed area 1 mile north-northwest of Spearfish, S. Dak., be used as a standard reference.

The total thickness of the Sundance Formation in the Jewel Cave SW quadrangle is about 360 feet.

CANYON SPRINGS SANDSTONE MEMBER

The Canyon Springs Sandstone Member at the base of the Sundance is 35 feet thick in the southeast corner of the quadrangle, but it thins to the northwest. North of the Dewey fault, along the east side of the Elk Mountains, the member is from 0 to 7 feet thick. The contact with the underlying Spearfish Formation is sharp and generally conformable. Just north of the Dewey fault in sec. 10, however, the contact is a rolling surface having perhaps 20 feet of relief. Black or brown pitted and polished chert pebbles as much as 2 inches in diameter occur just above the basal contact. Where the Canyon Springs is fairly thick it generally consists of two parts. The lower part consists of about 15 feet of massive pink to brown crossbedded sandstone. The crossbeds are troughlike and form a festoon pattern suggestive of eolian deposition. The sandstone is predominantly fine grained, but many of the cross laminae contain about 15 percent of well-rounded medium to coarse grains floating in the finer grained sand matrix. The upper part of the Canyon Springs ranges from 5 to 15 feet thick and is slabby and horizontally stratified in contrast to the massive crossbedded lower part. Individual strata may have either ripple lamination or thin, low-angle cross lamination.

Both the upper and lower parts of the member are similar mineralogically and texturally. The finer grained parts consist of subrounded grains of quartz and minor amounts of chert, feldspar, limestone fragments, and shell material. The coarser grained part is well rounded and consists of quartz, quartzite fragments, chert, fine-grained limestone fragments, and carbonate shell fragments. Calcite cement is abundant. Fragments of limestone and shell fragments are more abundant in the upper, horizontally stratified part. It is likely that the horizontally stratified upper part represents the moderate reworking of the crossbedded lower part at the time of the transgression of the Sundance sea.

STOCKADE BEAVER SHALE MEMBER

The thickness of the Stockade Beaver Shale Member ranges from 45 to 60 feet. It is a dark-gray thinly bedded shale that contains a few very thin beds of calcareous sandstone and limonitic nodules. At one locality, geodes containing calcite and barite were observed. The contact with the underlying Canyon Springs is sharp, and the contact with the overlying Hulett Sandstone Member is gradational through a few feet.

HULETT SANDSTONE MEMBER

The Hulett Sandstone Member consists of about 55 feet of thin-bedded sandstone. The contact with the underlying and overlying members is gradational, but can be placed within a few feet. The sandstone is fine grained and well sorted, and consists predominantly of quartz and minor amounts of feldspar, chert, glauconite, and detrital calcite grains. Coarse fossil fragments, calcite cement, and oscillation ripple marks are common. Many thin strata of gray shale occur between the sandstone layers.

LAK MEMBER

The Lak Member consists of 70 feet of fine-grained red sandstone and a persistent 3-foot bed of light-gray sandstone about 15 feet below the top of the member. Stratification is very poor; it is represented in the lower part by irregular contorted laminae of siltstone and in the upper part by very thin horizontal laminae marked by concentrations of opaque minerals.

Two point-counts of about 350 grains each show that the Lak Member consists of 60 to 80 percent quartz, 2 percent feldspar, 1 percent chert grains, 7 to 13 percent detrital dolomite grains, 0 to 25 percent matrix, and 1 to 3 percent calcite cement. The matrix is probably largely very fine grained dolomite and quartz. The calcite cement occurs as scattered patches of coarse crystals enclosing the detrital grains. Red pigment forms thin rims on the detrital grains and is disseminated through the matrix. The detrital dolomite grains have rounded iron oxide-coated cores and clear rhombic overgrowths. In texture and mineralogy the 3-foot-thick light-gray bed is similar to the rest of the unit, except that there is very little matrix.

REDWATER SHALE MEMBER

The Redwater Shale Member is about 150 feet thick and consists of greenish-gray soft fissile shale and minor amounts of sandstone near the base and at the top. Stratification is very pronounced; most strata are thin, ranging from a fraction of an inch to several feet in thickness. Glauconite is an abundant constituent of the sandstone.

The contact of the Redwater with the red beds of the Lak is fairly sharp, but it is locally gradational through a few feet. The contact with the overlying Morrison Formation is sharp and is marked by the abrupt change from thinly laminated interbedded shale and sandstone to blocky calcareous mudstone.

REGIONAL CORRELATION

About 10 miles north of the Jewel Cave SW quadrangle, the Gypsum Spring Formation of Middle Jurassic age rests disconformably upon the Spearfish Formation. Southward the Gypsum Spring has been so beveled that in the area discussed the Sundance Formation of Late Jurassic age rests upon the Spearfish. Thus the regional disconformity at the base of the Sundance in the southern Black Hills represents part of the Triassic and all of Early and Middle Jurassic.

Imlay (1947) and Peterson (1954) have correlated the Sundance Formation with the Rierdon and Swift Formations in Montana on the basis of similar lithology and fossils. Peterson (1954) has suggested the following modifications: that the formation be raised to the status of a group (Sundance Group); that the names Rierdon and Swift be extended into Wyoming; that the Canyon Springs, Stockade Beaver, Hulett, and Lak Members be included in the Rierdon Formation; and that the Redwater Shale Member be called the Swift Formation. This nomenclature has not been used by geologists in this area.

ENVIRONMENT OF DEPOSITION

The Sundance Formation apparently was deposited in marine water in a shelf area, which extended northwestward between the Williston basin in North Dakota and the Twin Creek trough in southwestern Wyoming. There is evidence that the Sundance sea became shallow during the close of the time of deposition of sediments equivalent to the Rierdon Formation (Peterson, 1954). The deposition of red beds equivalent to the Lak Member occurred over much of southern Wyoming and western South Dakota during this period of regression. Peterson stated (1954, p. 502):

> The relatively uniform nature and the well bedded character of the "Sundance red" or Lak red beds suggest that they were probably deposited under marine conditions, and their association locally with gypsum suggests restricted (possibly lagoonal) conditions.

He thought that the source of the red sediment was probably the late Paleozoic and early Mesozoic red-beds of the region, and that the red color was preserved because the depositional environment was nonreducing. Peterson also stated (1954, p. 503):

> * * * Most of the Swift and Rierdon shales may have been originally laid down as red sediments which were subsequently changed to their characteristic grey and green colors through the reducing action of decaying organic matter. * * *

Glauconite is common in the units that overlie and underlie the Lak Member. It is believed that glauconite forms under slightly reducing conditions in water of normal marine salinity and probably in the presence of organic matter (Pettijohn, 1957, p. 503). Peterson's concepts of the depositional environments are consistent with those implied by the presence of glauconite. When the marine environment was abnormally saline (that is, abundant dolomite precipitated) and organic matter did not accumulate, red strata were deposited. When the salinity was normal and the environment slightly reducing (as indicated by the presence of glauconite), the red color of the sediment was destroyed.

MORRISON FORMATION

The sequence of light-colored claystones of Late Jurassic age that overlie the Sundance Formation and underlie the Lower Cretaceous sandy rocks were formerly called the Beulah Clays by Jenney (1899), who studied these rocks in the Hay Creek coal field north of Beulah, Wyo. He recognized that these beds included the Atlantosaurus beds on the east side of the Black Hills, and that the Atlantosaurus beds were in turn similar in lithology and fauna to rocks along the Front Range in Colorado. The name Atlantosaurus beds was abandoned and the name Morrison Formation was extended by Darton (1904) into the Black Hills region from its type locality at Morrison, Colo. This name has replaced the original term Beulah Clays in the Black Hills. The formation crops out in the southwestern, northern, and eastern parts of the Black Hills, but it is absent in the southeastern part where the Unkpapa Sandstone of Late Jurassic age overlies the Sundance Formation.

The Morrison Formation in the Jewel Cave SW quadrangle consists predominantly of gray to grayish-green blocky-weathering noncarbonaceous mudstone, thin beds of lithographic clayey limestone, and, less commonly, thin beds of sandstone. Stratification within individual beds is indiscernible, except in the sandstone that is ripple laminated or cross stratified. It is impossible to determine accurately the lateral extent of the sandstone or limestone beds because the formation is generally poorly exposed. However, these beds probably do not persist laterally for more than a few thousand feet. Clayey limestone and lithographic limestone are most common in the lower half of the formation. In the NW¼ sec. 14, T. 6 S., R. 1 E., a local channel filled with 10 feet of crossbedded clayey sandstone occurs about 10 feet above the base of the formation. All other sandstone beds are less than 2 feet thick and have lateral extents of at least 1,000 feet.

The thickness of the Morrison Formation in the quadrangle ranges from about 60 to 120 feet. The poor exposure of the formation does not permit the construction of a detailed isopach map, but it is possible to determine the general trend of thickness variation. Along the north-facing scarp in secs. 16 and 17, T. 6 S., R. 2 E., the formation is 60 feet thick. In the NE¼NW¼ sec. 28, T. 6 S., R. 2 E., where the formation was penetrated by a diamond-drill hole, the thickness is 80 feet. About one-half mile southwest of this drill hole the formation is 110 feet thick. In the NE¼ sec. 19, T. 6 S., R. 2 E., the base is not exposed, but the total thickness must be greater than 90 feet. Just south of the Dewey fault the total thickness is 120 feet. It seems very likely that lines of equal thickness trend about N. 50° W., and that the formation thins to the northeast.

At many places in the Black Hills the upper part of the Morrison Formation and the lower part of the Lakota Formation are gradational, and the selection of a formation boundary is difficult. In the Jewel Cave SW quadrangle there is a sharp and persistent change in lithology that has been used as the contact. Below the contact the Morrison rocks are principally blocky noncarbonaceous claystone; above the contact the rocks of the Lakota are either laminated, highly carbonaceous siltstone or thick channel sandstone.

Several types of invertebrate fossils, which were collected in the extreme southeast corner of the quadrangle, were identified by personnel of the U.S. Geological Survey, and are listed below.

Identified by John B. Reeside, Jr.:

- *Amplovalvata scabrida* (Meek and Hayden)
- *Lioplacodes*? sp.
- *Unio* cf. *U. nucalis* (Meek and Hayden)
- *Cyzicus* ("Estheria") sp. undet.
- *Gyraulus veternus* (Meek and Hayden)

Identified by Raymond E. Peck:

Class, Charophyta:
- Order, Charales:
  - Family, Characeae:
    - *Aclistochara latisulcata* (Peck)
    - *Latochara latitruncata* (Peck)
    - *Praechara voluta* (Peck)
    - *Stellatochara obovata* (Peck)
    - *Aclistochara complanata* (Peck)
    - *Sphaerichara verticillate* (Peck)

Identified by I. G. Sohn:

Ostracodes:

Theriosynoscum sp.
"*Metacypris*" sp.
Darwinula sp.

Both Peck and Reeside state that these forms are fresh-water types and generally imply ponded water.

The Morrison Formation throughout the western interior of the United States is a nonmarine formation consisting of channel deposits, flood-plain deposits, and pond or lake deposits. In the vicinity of the Jewel Cave SW quadrangle, the absence of appreciable sandstone filling ancient channels and the preponderance of clay, clayey limestone, and limestone suggest that no major streams crossed this area, but rather that the area was one of poor drainage and abundant ponds.

CRETACEOUS ROCKS

INYAN KARA GROUP

Sandstone units now included in the Inyan Kara Group of the Black Hills region have been subjected to a long sequence of nomenclatural changes since they were first described by Hayden in 1858. The classification used in this paper is the one that was defined by Karl M. Waagé (1959), and by E. V. Post and Henry Bell, 3d (1961).

The Inyan Kara Group consists of sandstone and mudstone that overlie the Morrison Formation and underlie the black marine Skull Creek Shale. The group is subdivided into two formations—the Lakota Formation at the base, and the Fall River Formation at the top. In some areas of the southern Black Hills, the Lakota Formation can be separated into three members—a basal unit called the Chilson Member, a medial limestone called the Minnewaste Limestone Member, and a top unit called the Fuson Member. The Minnewaste Limestone Member does not occur in the Jewel Cave SW quadrangle.

The local correlation and extent of the various lithologic units within the Inyan Kara are a matter of some importance because of their implications to the regional stratigraphy and because of the occurrence of uranium deposits in the group at several localities in the Black Hills. For these reasons, each of the major lithologic units has been mapped (see pl. 20). Their relationships in the Jewel Cave SW quadrangle are shown schematically in plate 22.

LAKOTA FORMATION

The Lakota Formation is about 300 feet thick in the southeastern part of the Jewel Cave SW quadrangle, and it thins gradually to the

689-415 O—63——4

west, where it is about 200 feet thick along Pass Creek. The major rock types are thinly laminated, highly carbonaceous siltstone; very fine to coarse grained and occasionally conglomeratic sandstone; and blocky-weathering gray, green, yellow, or red sandy mudstone.

CHILSON MEMBER

Basal carbonaceous siltstone.—Throughout most of the quadrangle the basal part of the Lakota consists mainly of thinly laminated, highly carbonaceous siltstone. The carbonaceous matter is present both as disseminations of microscopic particles producing black mudstone and as fairly large plant fragments. In many places the siltstone, which has weathered to large silver-gray sheets, is termed "paper shale." Very fine grained cross-stratified or ripple-laminated sandstone is present as beds ranging from a fraction of an inch to 5 feet in thickness. Flat ellipsoidal limestone concretions as much as 18 inches in diameter occur in the siltstone. These concretions consist of light-gray lithographic limestone and contain many small fossil shell fragments. The thickness of the carbonaceous siltstone unit ranges from 0 to about 30 feet. Part of this variation of thickness is due to erosion prior to the deposition of the overlying channel sandstone.

At most places the contact between the basal carbonaceous siltstone and the overlying S_1 sandstone is a disconformity caused by fluvial erosion. The best field example of this relation is in the NE¼ sec. 28, T. 6 S., R. 2 E.; it is shown on figure 45. The contact relations between these two units are not everywhere as simple as the example in figure 45 would indicate. Along the common boundary between secs. 18 and 19, T. 6 S., R. 2 E., a well-exposed outcrop provides evidence that, at least locally, the S_1 sandstone is interbedded with the carbonaceous siltstone. The relations at this outcrop are shown diagrammatically in figure 46.

S_1 sandstone.—The S_1 sandstone is principally a complex of anastomosing channel sandstone that is interbedded with and that grades laterally into gray mudstone. Good exposures of the marginal features of the individual channels occur at several localities. At such places the channel sandstone either thins abruptly as a result of having been deposited in erosional channels in the underlying sediments or interfingers with the adjacent mudstone. The anastomosing nature of the S_1 sandstone is best exhibited in the southeast corner of the quadrangle. In this area of good exposure, individual channels can be traced for only a few hundred feet before their identity is lost because they merge with adjacent or overlying channels. Individual channels were not seen along the southwest and west sides of the quad-

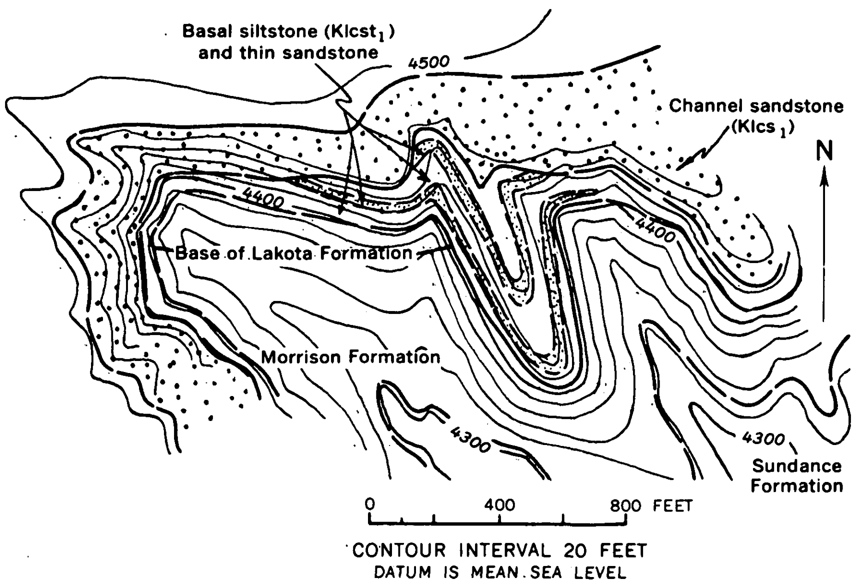

FIGURE 45.—Geologic map of part of secs. 28 and 29, T. 6 S., R. 2 E., showing the truncation of basal siltstone of the Lakota Formation by the overlying S_1 channel sandstone.

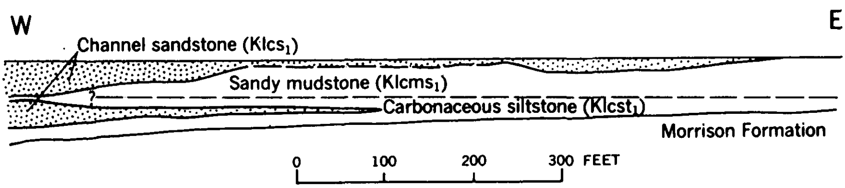

FIGURE 46.—Diagrammatic cross section along the boundary of secs. 18 and 19, T. 6 S., R. 2 E., showing interfingering of the S_1 channel sandstone and carbonaceous siltstone.

rangle. Here the unit consists of a sheet of sandstone of relatively uniform thickness, which in a few areas interfingers with laminated, carbonaceous mudstone.

Mudstone.—The mudstone, which is interbedded with the S_1 sandstone, is predominantly light gray to medium gray, is thinly laminated, and contains thin layers of sandstone. Carbonaceous material is common, but it is not as abundant as in the basal siltstone.

Sandstone and mudstone.—At a few places, such as the NW¼ sec. 17, T. 6 S., R. 2 E., thinly stratified sandstone and abundant interbedded mudstone occupies the entire interval of the S_1 sandstone. These places represent interstream areas that received predominantly very fine-grained material during this stage of deposition. In such areas the contact of the thin sandstone and mudstone is gradational with the underlying and overlying units.

FUSON MEMBER

In some parts of the southern Black Hills the Minnewaste Limestone Member marks the boundary between the Chilson Member and the Fuson Member of the Lakota Formation. In this quadrangle the Minnewaste is missing. R. W. Schnabel (1963) believes that isolated bodies of limestone above the S_1 sandstone in the adjoining Burdock quadrangle are correlative with the Minnewaste Limestone Member. For this reason the top of the S_1 channel complex has been shown as the top of the Chilson Member in the Jewel Cave SW quadrangle, but this contact is gradational in many places.

Mudstone.—Between the top of the S_1 sandstone complex and the base of the Fall River Formation are several beds of mudstone that are separated by sandstone beds (the individual sandstone beds are described in the following paragraphs). The mudstone beds have several common features that set them apart from the underlying gray mudstone: (a) the almost complete absence of carbonaceous matter, (b) the lack of lamination (most are blocky weathering), and (c) the occurrence of green, yellow, red, and variegated colors. In addition, the mudstone that occurs between the S_1 sandstone and the S_3 sandstone is commonly slightly calcareous and contains abundant calcareous concretions as much as 5 feet in diameter. Beds of limestone have also been observed in this unit. Both the concretions and the limestone beds consist of aggregates of small spheres of calcite that are about 0.5 to 1.0 mm in diameter and that have a radial-fibrous structure. The concretions probably formed at the time the enclosing mudstone was being deposited rather than by later replacement, because the interstices between the calcite spheres are either empty or filled with chalcedony.

At many places the mudstone contains abundant sand-size quartz grains and may grade laterally into clayey sandstone. Where sand-size material is abundant, the mudstone is unstratified and very poorly sorted. Within a thin section the areas that consist of predominantly clay-size material are irregularly interspersed with patches containing as much as 50 percent sand.

Within the mudstone interval between the top of the S_1 complex and the base of the S_3 sandstone, there are a few small sharply defined sandstone bodies that clearly fill small channels.

S_3 sandstone.—The S_3 sandstone, which is generally between 20 and 30 feet thick, is a sheetlike body of thin- to thick-bedded cross-stratified gray sandstone that is dominantly fine grained but that is locally coarse grained or conglomeratic. At its upper and lower boundaries the S_3 sandstone is irregularly interbedded with sandy mudstone, and in places it contains thin interbeds of mudstone. Very

commonly the upper 1 to 2 feet of sandstone is cemented with calcite.

In the southern part of the Jewel Cave SW quadrangle the S_3 sandstone occurs about 200 feet above the base of the Lakota Formation, but the base of sandstone S_3 truncates the underlying mudstone and the S_1 sandstone northward from the center of sec. 4, T. 6 S., R. 1 E. To the north in the Dewey, Clifton, and Fanny Peak quadrangles, the S_3 sandstone seems to fill a generally northeast- to north-trending channel in the lower part of the Lakota Formation (Brobst, 1961, p. 34).

White massive sandstone.—A distinctive massive noncarbonaceous white sandstone lies immediately above the S_3 sandstone in the southern part of the quadrangle; it ranges in thickness from 0 to about 30 feet, is well sorted and fine to very fine grained, and grades both laterally and vertically into sandy mudstone. On the east side of Pass Creek, in secs. 14 and 23, T. 6 S., R. 1 E., the sandstone contains large well-rounded, highly polished pebbles as much as 2 inches in diameter. On the west side of Pass Creek, similar pebbles were observed in the upper part of the S_3 sandstone.

Dolomite.—Approximately 5 feet of gray to pinkish-gray massive dolomite caps an isolated hill in the NW¼ sec. 17, T. 6 S., R. 2 E. The dolomite rests on about 10 feet of coarse-grained cross-stratified sandstone, which is mapped as S_3 sandstone. The dolomite consists of a mosaic of anhedral dolomite grains less than 0.03 mm in diameter, and 30 to 60 percent by volume of very fine grained quartz.

S_4 sandstone.— The S_4 sandstone fills a large channel that was cut from very near the top of the Lakota down into the upper part of the S_3 sandstone. The channel enters the quadrangle from the south in the NE¼ sec. 29, T. 6 S., R. 2 E., and trends about N. 30° E. The channel is about 1 mile wide and approximately 70 feet deep at its center. Although only about 1½ miles of the channel remain in the Jewel Cave quadrangle, the S_4 sandstone extends for about 20 miles to the southeast.

A thin bed of sandstone at the top of the Lakota Formation, which is believed to be correlative with the S_4 sandstone, crops out along the west side of Pass Creek south of the Dewey fault.

COMPOSITION OF SANDSTONE OF THE LAKOTA FORMATION

Twenty-two thin sections selected to represent the various sandstone units were examined. Most of these sections were stained with sodium cobalt nitrite to determine the presence of potassium feldspar. The volumes of the various types of detrital constituents were estimated visually.

The composition of sandstone from all units is very similar. In the fine-grained rocks the dominant detrital constituent is quartz, which makes up about 85 to 95 percent. Chert grains are the next most abundant material, and make up from 1 to 7 percent. The total feldspar content is about 1 to 10 percent and probably averages about 3 percent; plagioclase is a very minor constituent. The chert and quartz content varies considerably with change in grain size. Medium- to coarse-grained sandstone may contain as much as 60 percent of well-rounded chert grains. Many of these grains are clearly fragments of silicified limestone, because they contain minor remnants of calcite and silicified shell fragments. Much of the chert is white, and on weathered surfaces some of the grains are rather soft and may be mistaken for fragments of claystone.

Among the accessory minerals, zircon, ilmenite, and leucoxene are most abundant. Yellow-brown tourmaline is very common; garnet and rutile are consistently present in minor amounts; and traces of amphibole, apatite, muscovite, and monazite were observed.

The sandstone is only moderately well cemented. The dominant cementing material is quartz, which is present as oriented overgrowths. Calcite is a cement only in localized concretionlike masses or in irregular patches a few feet across. Iron oxide is locally an important cement and is probably a late addition resulting from the near-surface oxidation of other iron-bearing constituents.

ENVIRONMENT OF DEPOSITION OF THE LAKOTA FORMATION

Clearly recognizable stream channels are present at all horizons within the formation. That the general direction of streamflow was to the north or northwest is indicated by the dominant trends of channel axes and by the directions of the dip of cross strata (fig. 47). Sandstone strata that have been described as sheetlike bodies have an observable lateral extent of less than 3 miles normal to the dominant direction of streamflow, and they probably represent broad, braided, or meandering stream courses.

Laminated sandy carbonaceous mudstone that underlies or interfingers with the channel sandstone is interpreted as flood-plain and swamp deposits of the interstream areas.

Nonlaminated, noncarbonaceous, blocky-weathering mudstone that contains abundant, large syngenetic calcite concretions makes up much of the upper part of the formation. Associated rock types are carbonate rock and massive unstratified sandstone; the former is dolomite in the Jewel Cave quadrangle and limestone (Minnewaste Limestone Member) in adjacent areas to the southeast. These sediments were probably deposited in interstream areas, possibly largely in ponds and lakes.

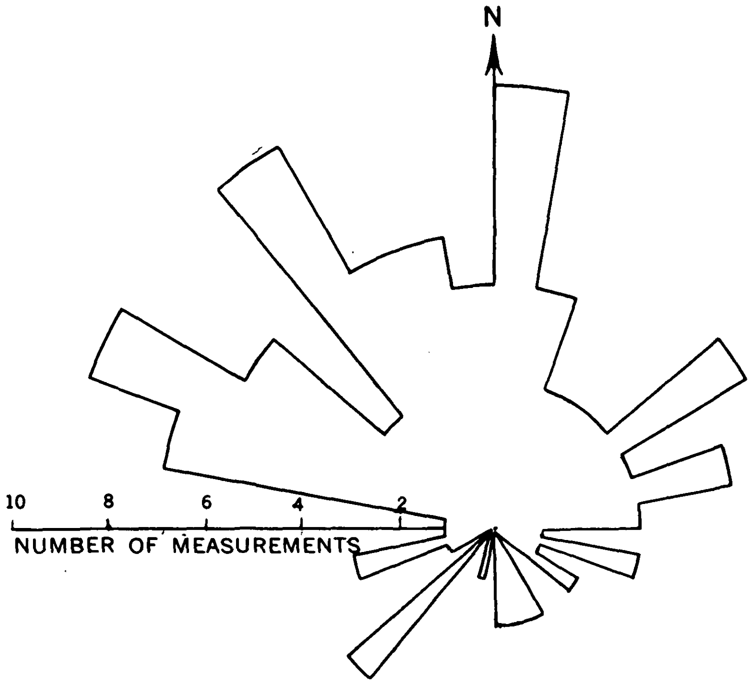

FIGURE 47.—Plot showing the direction of dip of 115 cross strata in the S_1 sandstone.

Chert grains containing silicified fossil fragments are very common, particularly in the coarse-grained sandstone, and indicate that an appreciable amount of the Lakota sediment was derived from preexisting sedimentary formations. The streams that deposited much of the Lakota sediment entered the area from the east and southeast, and in these directions the basal sandstone of the Cretaceous gradually transgresses lower and lower in the section until, in eastern South Dakota, it rests on Precambrian rocks. The Pahasapa Limestone of Early Mississippian age and the Minnelusa Formation of Pennsylvanian and Permian ages, which the Lakota streams must have crossed, contain abundant limestone units from which the chert was probably derived.

FALL RIVER FORMATION

The Fall River Formation, which crops out only along the south side of the quadrangle (see pl. 20), is about 110 to 130 feet thick; it consists of a lower unit of laminated siltstone, a middle unit composed of thick medium-grained brown-weathering sandstone, interbeds of claystone, and very fine grained sandstone, and an upper unit of varicolored mudstone and thinly bedded sandstone.

LOWER UNIT

Carbonaceous siltstone.—In the southwest corner of the quadrangle the lower unit of the Fall River is composed of thinly bedded carbonaceous siltstone that contains many thin lenticular strata of sandstone. The siltstone ranges in thickness from 0 to about 25 feet. This unit contrasts markedly with the blocky-weathering, noncarbonaceous mudstone of the upper part of the Lakota.

MIDDLE UNIT

S_5 sandstone.—The S_5 sandstone is a fine- to medium-grained well-sorted sandstone forming an elongate body trending northwestward. The sandstone ranges in thickness from about 15 to 90 feet; it is about 1½ to 2 miles wide in a northeast-southwest direction and has been traced for 25 miles along the southwest rim of the Black Hills (G. B. Gott, oral communication, 1958).

Only the southwest side of the body is present in the Jewel Cave SW quadrangle, the northwest side having been removed by erosion. The southwest margin of the S_5 sandstone is exposed along Pass Creek in secs. 22, 23, and 26, T. 6 S., R. 1 E. Here, the base of the sandstone seems to be an erosion surface that cuts across the underlying siltstone at a gentle angle. One 15-foot-thick sandstone, which overlies the carbonaceous siltstone in sec. 26, T. 6 S., R. 1 E., has been shown on the geologic map as continuous with S_5. This thin sandstone seems to have been truncated by the S_5 sandstone and is probably older.

The S_5 sandstone body is not flat on top; on the contrary, the interval between the base of the Fall River and the top of the S_5 sandstone increases from about 40 feet at the southwest margin to about 100 feet near the center of the body (pl. 22). The contact of this upper surface with the fine-grained marginal sediments is not well exposed, but it seems to be transitional. A zone of thin-bedded sandstone and interbedded mudstone representing this transition zone was mapped in secs. 22, 23, 25, and 26, T. 6 S., R. 1 E. (pl. 20).

The southwest margin of the body trends about N. 45° W. in the Jewel Cave SW quadrangle, but the dominant dip direction of crossbeds is to the west (fig. 48). Generally, the crossbedding consists of planar sets ranging from 1 to 2 feet thick separated by thin horizontally stratified sandstone beds. Very long cross strata, which extend across the full thickness of the S_5 sandstone (about 30 feet), occur near the margin of the body and are separated by thin partings of mudstone. The elongate form, the scoured lower surface of the sandstone body, and the short planar crossbeds suggest that the S_5

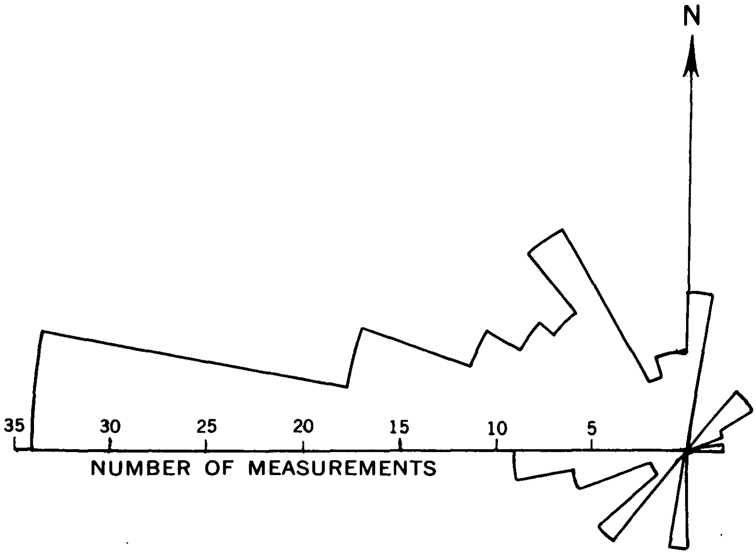

FIGURE 48.—Plot showing the direction of dip of 160 cross strata in the S_5 sandstone.

sandstone was deposited in a river channel; however, the anomalous features of crossbedding and the convex shape of the upper surface suggest the possibility that the S_5 may have been deposited in a distributary channel.

Mudstone and sandstone at the southwest margin of the S_5 sandstone.—Thin beds of sandstone and mudstone make up the middle unit of the Fall River Formation in secs. 22 and 23, T. 6 S., R. 1 E. These thin beds in part are truncated by the S_5 sandstone and in part grade laterally into the S_5 sandstone.

UPPER UNIT

A thin bed of yellow to gray mudstone overlain by thinly laminated siltstone and shale forms the upper unit of the Fall River Formation. These beds crop out only in the southwestern part of the quadrangle. They overlie the S_5 sandstone, where that sandstone is present, and where the S_5 sandstone is absent, they overlie the thin beds of sandstone and mudstone that make up the middle unit of the Fall River.

A composite section of the entire Fall River Formation, measured along the sides of Pass Creek in secs. 22 and 26 is given below.

Composite section of the Fall River Formation in the NW¼ sec. 26, T. 6 S., R. 1 E.

[Subunits 4–8 shown on pl. 20 as Kfmm]

	Thickness (feet)
Skull Creek Shale:	
12. Shale, black, silty	Not measured
Fall River Formation:	
Upper unit:	
11. Siltstone and silty shale and minor fine-grained sandstone; thinly and irregularly interbedded	12.0
10. Sandstone, very fine grained	2.0
9. Claystone to siltstone, yellow to gray	19.0
Middle unit:	
8. Sandstone, very fine grained	2.0
7. Claystone, yellow to gray; some thin and irregular lenses of sandstone	18.0
6. Mudstone, black, highly carbonaceous; well-developed shaly parting	15.0
5. Sandstone, very fine grained	1.5
4. Mudstone, black, laminated; many very thin strata of sandstone	2.0
3. S_5 sandstone, light-gray, fine-grained, crossbedded; abundant clay galls. Contains uranium deposits. (Throughout most of its extent sandstone S_5 occupies the equivalent positions of subunits 4–8, and in some areas also occupies the position of subunit 2)	15.0
Lower unit:	
2. Siltstone and moderately fine to very fine grained sandstone; thinly and irregularly interbedded; abundant carbonaceous material	24.0
Total thickness of Fall River Formation	110.5
Lakota Formation:	
1. Claystone, white to red, sandy	Not measured

COMPOSITION OF SANDSTONE OF THE FALL RIVER FORMATION

Ten thin sections representing the various sandstone units of the Fall River were selected for study. Several of these sections were stained with sodium cobalt nitrite to determine the presence of potassium feldspar, and the volumes of the various types of detrital constituents were estimated visually.

The fine-grained sandstone marginal to sandstone S_5 is uniform in composition. Quartz grains make up about 95 percent of all samples, chert grains make up only about 1 to 3 percent, and feldspar (primarily potassium) is less than 1 percent. White mica is common and may make up as much as 3 percent of the rock. The fine- to medium-grained samples from sandstone S_5 are similar to each other in composition. Quartz is dominant, feldspar (primarily potassium) occurs from trace amounts to about 3 percent, chert is less than 2 percent of the rock, and mica occurs only in traces.

Ilmenite, leucoxene, tourmaline, garnet, and zircon are abundant accessory minerals; rutile is common; amphibole and apatite were observed.

The sandstone of the Fall River Formation is moderately well cemented in most places. The dominant cementing material is quartz, which is present as oriented overgrowths on quartz. Calcite was observed in only a few very thin brown beds immediately below the Skull Creek Shale. Iron oxide is locally an important cement and probably results from the near-surface oxidation of other iron-bearing constituents. Limonite pseudomorphs after pyrite, which are very common near the margins of the S_5 sandstone in Pass Creek, suggest that the brown color of the unit is due to the oxidation of disseminated pyrite.

In the N½ sec. 29, T. 6 S., R. 2 E., near the top of Pilger Mountain, parts of the S_5 sandstone are very extensively silicified. The secondary silica is present as clear oriented quartz overgrowths on the well-rounded detrital quartz grains. The S_5 sandstone in this area also contains abundant iron oxide, which imparts to the rock a purplish-brown to dark-brown color. Examination in thin section shows that the iron oxide was deposited before the secondary quartz, because the oxide is present only as coatings around the original rounded quartz grains, and the quartz overgrowths cover the oxide rims. The original extent of silicified sandstone is unknown for the S_5 sandstone has been eroded from most of the adjacent area. However, a small hill in the south-central part of sec. 18, T. 6 S., R. 2 E., which is about 2 miles northwest of Pilger Mountain, is covered with float blocks of silicified S_5 sandstone. These two areas are only a few hundred feet from the crest of a prominent northwest-trending anticline. A third area of intensely silicified S_5 sandstone has been mapped in the southern Black Hills (V. R. Wilmarth and Henry Bell, 3d, oral communication, 1958) along the crest of the Chilson anticline south and west of Parker Peak. These areas of silicification, localized on structurally high areas, may have been places of major ingress of ground water into the Fall River at a time when a less dissected erosion surface truncated the Lakota and Fall River hogback. Little is known about the Cenozoic history of the southern Black Hills, but it seems to the writer that the areas of silicified sandstone may represent remnants of a pre-White River (Oligocene) pediment.

ENVIRONMENT OF DEPOSITION OF THE FALL RIVER FORMATION

Waagé (1959, p. 63), as a result of a study of the features of the Inyan Kara and related rocks throughout the Black Hills, characterized the environment of the Fall River as follows:

> The type of bedding prominent in the Fall River and the abundance of soft-bodied animals, indicated by the numerous burrows and castings, are indicative of marginal marine, probably tidal-flat, environment. Associated carbonaceous beds, dominantly shaly local phases, and massive sandstone, probably were formed in coastal swamp, estuarine and deltaic environments respectively. Ordinarily marine fossils might be expected at least in the tidal flat and estuarine phases. Washings of a few Fall River shale samples revealed worn mollusk shell fragments and some fragments of what may have been arenaceous Foraminifera, but no undoubted marine fossils.

From a study of the limited outcrops of the formation in the Jewel Cave SW quadrangle this writer cannot make any additions to this general picture.

SKULL CREEK SHALE AND MOWRY SHALE

The Skull Creek Shale was defined as a member of the Graneros Shale by Collier (1922, p. 79). The type locality is Skull Creek, southeast of Osage, Wyo. The Mowry Shale was defined as a part of the Benton Formation by Darton (1904). The type locality is in the east flank of the Bighorn Mountains on Mowrie Creek northeast of Buffalo, Wyo. Both of these members were raised to formation rank in this area by Reeside (1944).

The Skull Creek Shale and Mowry Shale crop out only in the extreme southwest corner of the quadrangle, and exposures are poor. The contact of the Skull Creek with the Fall River seems to be transitional with several feet of silty black fissile shale alternating with thin sandstone. The top of the Skull Creek is exposed only on the north side of a small gravel-capped hill in the NW¼ sec. 27, T. 6 S., R. 1 E. The lower 15 feet of this exposure consists of black fissile shale in which no fish scales were found and which contained several beds ¼ to 4 inches thick of light-gray bentonite. The upper part of the exposure consists of black fissile shale that weathers to silvery gray and that contains abundant fish scales. The part bearing fish scales was mapped as Mowry Shale.

Northwest of the Jewel Cave SW quadrangle a unit of sandstone and carbonaceous shale called the Newcastle Sandstone lies between the Skull Creek and the Mowry Shales. In the Jewel Cave SW quadrangle, the interval that would be occupied by the Newcastle is very poorly exposed. The only rock that might be placed in this interval is a mass of rubbly calcite-cemented sandstone, which forms the top of a very gentle hill in the NW¼ sec. 27, T. 6 S., R. 1 E., about 500 feet from the west section line.

QUATERNARY DEPOSITS

Small remnants of gravel-covered terraces that occur along Pass Creek, Hell Canyon, and Schenk Canyon mark the former levels of these streams. Remnants of gravel terraces also cap hills at altitudes of 4,460 to 4,620 feet in the northern part of the quadrangle between Hell Canyon and Schenk Canyon. Darton (*in* Darton and Paige, 1925, p. 15) believed that this high-level gravel was deposited by a stream of probable Pleistocene age that drained southeastward along the Spearfish Valley toward Minnekahta, S. Dak. This stream would antedate the present drainage, which extends from the Precambrian southwestward through the Paleozoic and Mesozoic rocks. In the Jewel Cave SW quadrangle the high-level gravel consists of boulders and pebbles of the Minnekahta Limestone, chert, coarse-grained hematitic and silicified sandstone and conglomerate, and gray to yellow limestone. No Precambrian rocks were found.

Patches of landslide debris are particularly abundant on the steep hogback slopes that face into Spearfish Valley. Much of the debris is from the Inyan Kara rocks. In many of the slide areas, large masses of rocks have remained intact while sliding downhill and have been rotated so that they dip steeply toward the source of the slide. The landslide areas in the quadrangle are timbered, and no fresh slide scars were observed.

Alluvium fills the bottom of most of the major streams, except where the streams pass over resistant rock and are narrow. Some of the small valleys in the hogback composed of Inyan Kara also contain alluvial fill. In most places the alluvium has been partly eroded so that the present intermittent streams flow in narrow steep-walled gullies.

STRUCTURE

The Jewel Cave SW quadrangle is on the southwest side of the broad domal Black Hills uplift. The sedimentary rocks in the area generally dip from 2° to 4° SW. Structural features superimposed upon this regional dip are: the east-northeast-trending Dewey fault, two northwest-trending anticlines, contortion of bedding and other minor structures resulting from subsidence, and minor structures in the Permian and Triassic rocks that have probably resulted from sliding of the rocks parallel to the dip.

DEWEY FAULT

The most conspicuous structural feature in the quadrangle is the rather sinuous Dewey fault that extends across the center of the quadrangle; it has a trend of about N. 75° E. The fault is known to extend at least 6 miles to the southwest (Brobst, 1961, p. 51), but its northern extension is unknown. The fault is exposed at only one place, the gully in the SW¼NE¼ sec. 10, T. 6 S., R. 1 E., and here it seems to be vertical. Elsewhere the fault can be recognized by the steep dips in the beds along it and by the omission of strata on the south side. The rocks on the south side of the fault have apparently been displaced downward. The amount of displacement varies, but the maximum displacement is near the west side of the quadrangle. The movement has been accomplished by separation along the fault and by bending of strata adjacent to the fault. The cross sections of figure 49 illustrate the apparent displacement. Along section B–B′ the total stratigraphic displacement, including that caused by bending, is about 440 feet; and along section D–D′ the total stratigraphic displacement is about 250 feet. Because of the rather sinuous trend of the fault, it seems most likely that the major component of movement was parallel to the dip of the fault.

NORTHWEST-TRENDING ANTICLINES

Two broad, gentle anticlines are present in the quadrangle. The southernmost anticline extends from sec. 2, T. 7 S., R. 2 E. in the Edgemont NE quadrangle southeast of the Jewel Cave SW quadrangle to sec. 34, T. 5 S., R. 1 E. in the Jewel Cave SW quadrangle—a total distance of about 10 miles. Throughout this distance the trend of the axis of the fold, which changes from about N. 50° W. at the south to about N. 40° W. at the north, is very nearly parallel to the regional strike of the formations. The northernmost of the two anticlines extends for only 3 miles between Hell Canyon and Tepee Canyon. The trend of the axis is about N. 45° W., roughly parallel to the regional strike. The dips on the limbs of these folds are small; they range from about 6° to 13°. At several places the northeast-dipping limbs are somewhat steeper than the southwest limbs.

There are several areas of closure on the folds. On the northern fold the closure is about 110 feet. The axis of the southern fold, although nearly horizontal, undulates gently and produces long areas of closure. Southeast of the Jewel Cave SW quadrangle, in the Edgemont NE quadrangle, oil has been produced from the lower part of the Minnelusa Formation on the closure that marks the south limit of the fold. The center of sec. 7, T. 6 S., R. 2 E. is the crest of an area of inferred closure of about 30 feet on the base of the Sundance Formation. In this area rocks of the upper part of the Spearfish Formation crop out, but are very poorly exposed; thus the delineation of the shape of this part of the structure is uncertain. Just north of the Dewey fault there is a closure of at least 120 feet on the top of the Minnekahta Limestone; the closure is due largely to drag along the fault. The casing of an abandoned well (listed by the Conserva-

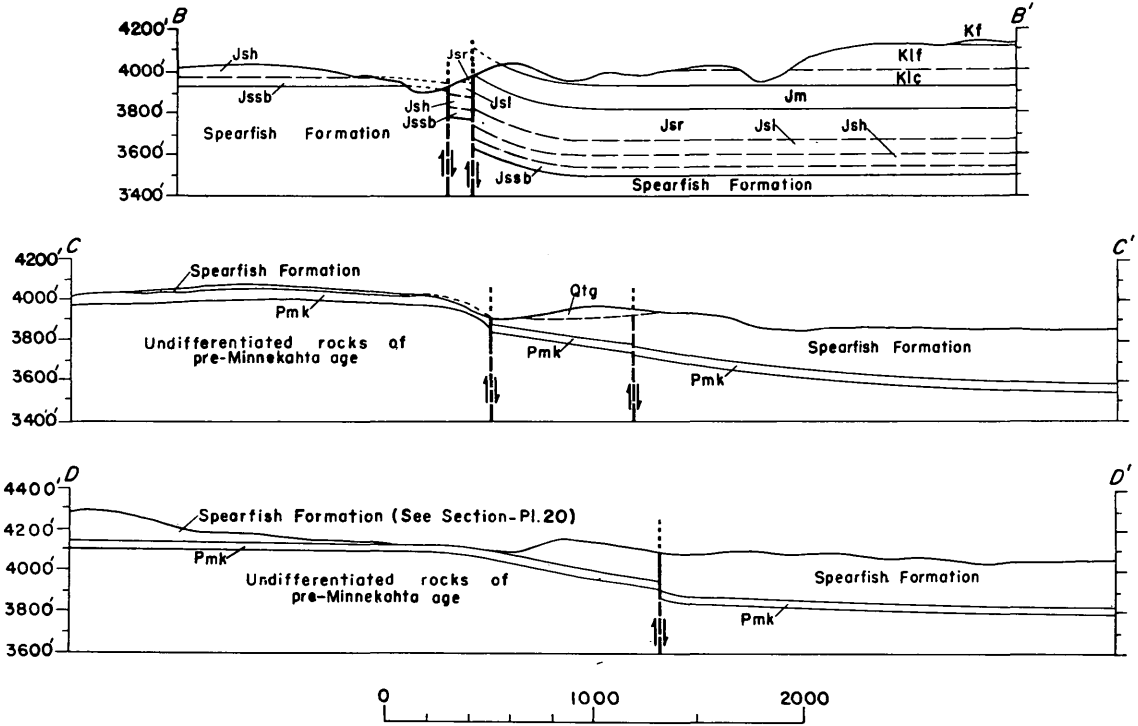

FIGURE 49.—Sections of the Dewey fault. Locations of sections shown on plate 20. Qtg, terrace gravel of Quaternary age; Kf, Fall River Formation; Klf, Fuson Member of Fall River Formation; Klc, Chilson Member of Lakota Formation; Jm, Morrison Formation; Jsr, Redwater Shale Member, Jsl, Lak Member, Jsh, Hulett Sandstone Member, Jssb, Stockade Beaver Shale Member, all of the Sundance Formation; Pmk, Minnekahta Limestone.

tion Division, U.S. Geol. Survey, as "L. Gokel, Pass Creek well, drilled 1935, abandoned Jan. 1936, T.D. 1035") is visible on the crest of this part of the structure.

SUBSIDENCE STRUCTURAL FEATURES

In the Jewel Cave SW quadrangle many minor structural features were caused by the subsidence of overlying units when large volumes of soluble sediments were dissolved, principally from the Minnelusa Formation. N. H. Darton mentioned the presence of breccias in the Minnelusa at several localities in the Black Hills, but he did not give any interpretation of them. In 1930 F. H. Brady [4] described the transition from an area containing about 150 feet of gypsum to an area of brecciation in the northern part of the Black Hills, but he did not explain the origin of the breccias, and he interpreted the termination of the gypsum beds as a primary depositional feature. Breccias in the Minnelusa in the southern part of the Black Hills were ascribed to tectonic forces by P. M. Work.[5] The breccias, which are present in the type section of the Minnelusa along Rapid Creek, were interpreted by D. C. Boardman [6] as having originated by leaching of anhydrite from the formation. J. P. Gries (1952, p. 71) expressed the view that:

> Although it has been suggested that up to 200 feet of anhydrite and carbonate is missing in the outcrop sections, recent studies show very small discrepancies between outcrop measurements and nearby subsurface thicknesses. Lack of extensive "collapse" or brecciated sections, and an increase in the quantity of clastics in the outcrops suggest that deposition of clastics over the site of the Black Hills occurred simultaneously with the precipitation of evaporites in the adjacent areas.

In a recent publication, R. L. Bates (1955) describes breccias both in the Black Hills and in the Hartville uplift in Wyoming. He interprets these breccias as being the result of solution of anhydrite "penecontemporaneous" with their deposition in Permian time.

The subsidence structures in the Jewel Cave SW quadrangle include: collapse breccias in the Minnelusa, residual limestone-dolomite breccias in the Spearfish, undulations and normal faults in the formations overlying the Minnelusa, and breccia pipes that extend upward from the Minnelusa at least as high in the stratigraphic section as the Lakota Formation.

COLLAPSE BRECCIAS IN THE MINNELUSA FORMATION

The strata of the upper part of the Minnelusa Formation in the northeast corner of the quadrangle are extensively fractured, brec-

---

[4] F. H. Brady, 1930, Some problems of the Minnelusa formation near Beulah, Wyoming: Iowa Univ. M.S. thesis.

[5] P. M. Work, 1931, Stratigraphy and paleontology of the Minnesula formation of the southern Black Hills of South Dakota: Iowa Univ. M.S. thesis.

[6] D. C. Boardman, 1942, Minnelusa formation in Rapid Canyon area, Black Hills, South Dakota: Iowa Univ. M.S. thesis.

ciated, and contorted. The highest bed in the Minnelusa is only moderately deformed, as are the overlying formations. The thick sandstone at the top of the Minnelusa (pl. 21) changes downward from almost undeformed rock to highly fractured rock and finally to breccia in which the fragments have been rotated and mixed to a minor extent with fragments of the underlying unit. Below this sandstone is about 300 feet of highly deformed rocks. Individual strata of limestone, sandstone, or siltstone are moderately to intensely brecciated and markedly contorted. The former positions of anhydrite beds can be identified in most places because weakly brecciated beds are overlain by beds that are intensely brecciated at the base and that grade upward into less intensely brecciated rock.

The contortion of strata is made apparent by the alternation of thin resistant carbonate rock units and nonresistant sandstone units. The carbonate beds maintain a relatively uniform thickness, but the intervening sandstone varies appreciably in thickness. Beds of sandstone may range in thickness from 2 to 16 feet in a horizontal distance of about 30 feet. This variation in thickness must be the result of the poorly cemented sandstone's having been squeezed into areas from which anhydrite was being removed.

In several places, intrusive masses of rock resembling conglomerate occur along the contact between beds. This conglomeratic-looking rock probably resulted from the partial milling of breccia fragments of sandstone as it was squeezed into its present position. In addition to being brecciated and undulatory, thick beds of sandstone are broken by many small vertical or steep gravity faults.

Many of the above-described features are shown in figure 50, which was photographed in Hell Canyon northeast of the mapped area. As shown in this picture, the rocks at the base of the cliff are brecciated and fractured only to a minor degree. These rocks occupy a position below that part of the Minnelusa that in the subsurface contains abundant anhydrite. It can be inferred that below this horizon only thin beds of anhydrite were present, because only a few thin units are brecciated.

All the anhydrite has probably been leached from the Minnelusa Formation in the northeast corner of the Jewel Cave SW quadrangle. The downdip limit of complete leaching as located on plate 20 is based on several facts: The exposures of the Minnelusa in Hell Canyon, in the NE¼ sec. 31, T. 5 S., R. 2 E., contain gypsum beds and are not brecciated. The boundary of extensive solution must lie updip from these exposures. There is a noticeable concentration of breccia pipes in the northeast corner of the quadrangle, and the bounding line was placed downdip from this concentration.

A gentle structural depression extending more than 3,000 feet along the east side of sec. 9, T. 6 S., R. 2 E. (pl. 20) contains a large

FIGURE 50.—Lower part of the collapse breccia in the Minnelusa Formation in sec. 3, T. 5 S., R. 2 E., Jewel Cave quadrangle. The numbered units correspond to those shown in the upper Hell Canyon columnar section of plate 21

collapse pipe. In this depression the base of the Hulett Sandstone Member of the Sundance may be downwarped as much as 100 feet (fig. 52). It seems probable that the depression overlies an isolated area from which anhydrite was dissolved from the Minnelusa Formation.

BRECCIAS IN THE SPEARFISH FORMATION

The G_2 and G_3 gypsum beds in the lower half of the Spearfish Formation are absent in the northeast corner of the Jewel Cave SW quadrangle. North of the boundary line shown on plate 20 the equivalent positions of the gypsum beds are occupied by 3- to 10-foot-thick beds that consist of fragments of dolomite and limestone in a matrix of red siltstone. The transition from gypsum to dolomite, as observed in two places, occurs within a horizontal distance of about 300 feet.

UNDULATIONS AND NORMAL FAULTS IN THE MINNEKAHTA LIMESTONE

Subsidence structures are particularly noticeable in the Minnekahta Limestone, which is the first resistant unit above the Minnelusa. Throughout much of the northeast corner of the quadrangle the Minnekahta Limestone crops out on dip slopes. The area of extensive outcrop overlies the breccia zone of the Minnelusa in the northeast and the unbrecciated Minnelusa in the central part of the quadrangle. A difference in the character of the outcrop is progressively evident toward the areas of extensive subsidence. The Minnekahta Limestone is distinctly undulatory where it overlies breccia in the Minnelusa. Irregular domes alternating with bowl-shaped depressions are common. The size of the individual basins or domes is variable; the largest are about 500 to 1,000 feet in diameter and have amplitudes of a few tens of feet. Commonly, small domes or basins are superimposed on larger ones. The structure contours in the northeast corner of the map (pl. 20) are based largely on elevations on top of the Minnekahta. No attempt was made to smooth or generalize the contours when they were converted to the base of the Hulett, because it was desired to illustrate the subsidence deformation. The shape of the contours in secs. 17, 18, and 20, T. 5 S., R. 2 E., are considered to be typical of the areas underlain by extensive collapse. The contours in secs. 25, T. 5 S., R. 1 E., and 30, and 31, T. 5 S., R. 2 E., along the anticline, are based on the top of the Minnekahta Limestone also, and are considerably smoother. This area is believed to be underlain by unbrecciated Minnelusa.

On the walls of Hell Canyon in secs. 16, 17, 20, 21, and 29, T. 5 S., R. 2 E., the undulations can be seen in cross section. On these cliffs many small faults are exposed, but none of the faults can be traced away from the canyon walls.

BRECCIA PIPES

Breccia pipes are vertical, nearly cylindrical bodies within which the rock has subsided more than the surrounding rock. They are most abundant in the northeast corner of the quadrangle, but a few pipes have been found as much as 4 miles downdip from the area of complete leaching. The locations of all known pipes are shown on plate 20.

The appearance of the breccia pipes varies. Those that penetrate the upper part of the Minnelusa Formation are generally small; they range from about 10 to 100 feet in diameter and are filled with a breccia consisting of limestone or calcareous sandstone fragments set in a matrix of calcareous sandstone.

Breccia pipes that penetrate the Minnekahta Limestone range in size from a diameter of about 40 feet (fig. 51) to a maximum observed diameter of about 300 feet. The Minnekahta Limestone within the pipes is characteristically intensely brecciated. The amount of downward movement of the Minnekahta could be estimated in two pipes; in one the displacement exceeds 80 feet, and in the other the displacement is about 100 feet. In several places coalescing groups of pipes suggest that joint sets, striking about N. 80° E. and N. 50° W., have localized the solution of underlying rock.

Several breccia pipes having diameters of about 50 feet penetrate the Spearfish Formation. These pipes are filled with fragments of

FIGURE 51.—Small breccia pipe that penetrates the Minnekahta Limestone in the SE¼ sec. 25, T. 5 S., R. 1 E. Small normal faults cut Opeche-Minnekahta contact at left side of pipe.

dolomite from the overlying gypsum beds of the Spearfish set in a matrix of calcareous red siltstone. Because of the calcite cement, some of these pipes are more resistant than the surrounding siltstone and stand 15 to 20 feet above the ground level.

The largest pipe within the quadrangle penetrates the base of the Sundance Formation in the northeast corner of sec. 9, T. 6 S., R. 2 E. Where the pipe penetrates the Canyon Springs Sandstone Member, it is aproximately 450 feet in diameter. The vertical displacement at this level is about 70 feet (fig. 52). The Hulett Sandstone Member in the center of the pipe is not brecciated, but dips gently inward toward the center of the pipe.

Several breccia pipes are known to penetrate as high as the lower part of the Lakota Formation. One of these pipes is in the Edgemont NE quadrangle, and has a vertical displacement of about 60 feet (G. B. Gott, oral comunication, 1958). Another is in the NE¼ sec. 24, T. 6 S., R. 1 E., in the Jewel Cave SW quadrangle. This pipe is marked only by a conical downwarp of the strata in the base of the Lakota. Subsidence in this pipe probably did not extend much higher into the Lakota.

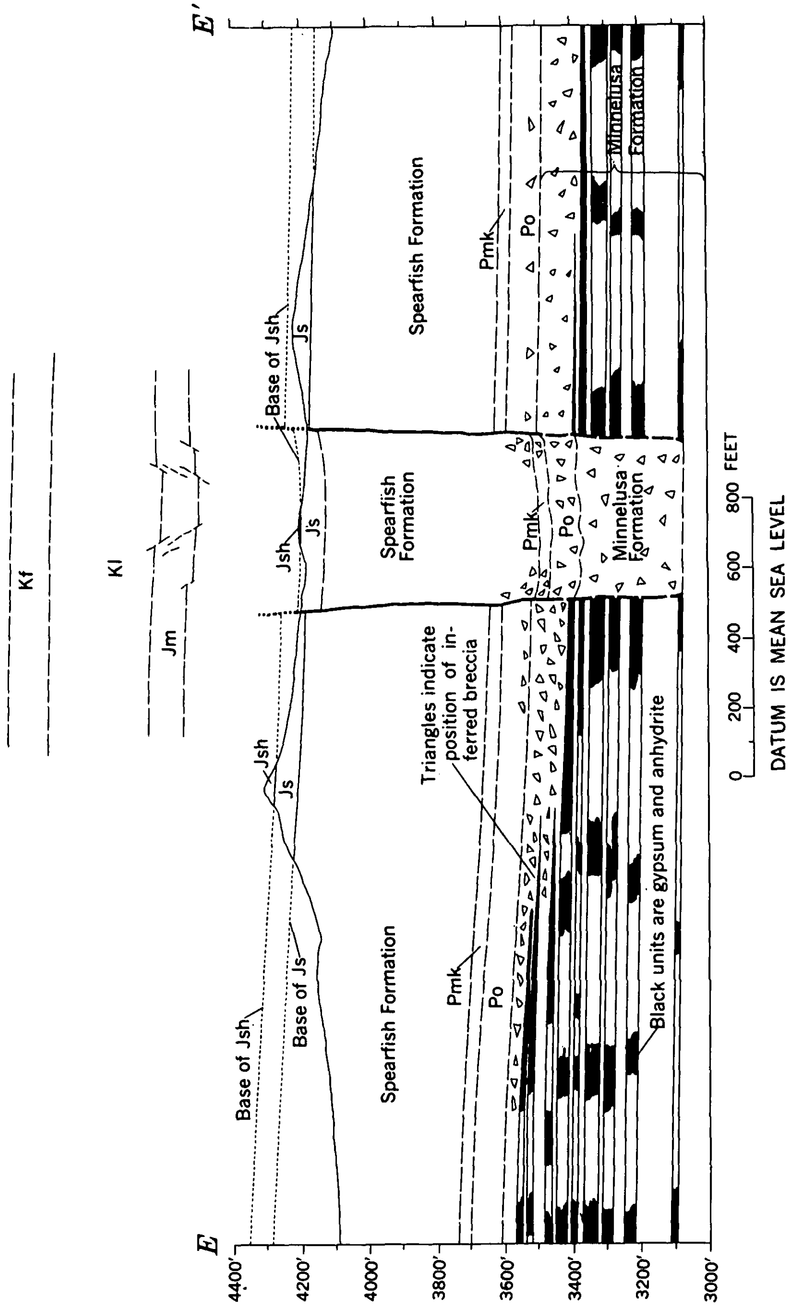

FIGURE 52.—Cross section *E–E′* of plate 20 showing inferred vertical extent of breccia pipe. Jsh, Hulett Sandstone Member of Sundance Formation; Js, Sundance Formation; Pmk, Minnekahta Formation; Po, Opeche Formation.

ORIGIN OF SUBSIDENCE STRUCTURES

All the structures described are clearly related to the removal of soluble rocks from underlying formations. The logs of many wells that penetrate the Minnelusa Formation around the periphery of the Black Hills have been published by the Geological Survey of South Dakota (Baker, 1947, 1948, 1951). All but two wells contained anhydrite. The anhydrite, which is present in many thin beds, is concentrated in the upper half of the Minnelusa Formation. A few beds less than 5 feet thick are in the lower half of the formation. The total thickness of anhydrite in the upper half of the formation ranges from about 100 feet north of the Black Hills to about 300 feet at the southern end of the Black Hills.

Most of the described collapse features are due to the solution of anhydrite from the upper part of the Minnelusa. The brecciated parts of the Minnelusa in the outcrop are at the same stratigraphic position as the major anhydrite beds in the subsurface. Only minor breccias or subsidence structures occur below the middle of the Minnelusa, and these are due to solution of a few thin beds of anhydrite that occur in the lower part of the Minnelusa.

Subsidence structures above the middle part of the Spearfish Formation may be due to, or augmented by, leaching of about 60 feet of anhydrite from the lower part of the Spearfish Formation.

TIME OF LEACHING

The leaching of anhydrite from the Minnelusa Formation must have occurred at some time after the Early Cretaceous, because breccia pipes penetrate strata as young as Early Cretaceous. From Early Cretaceous time until uplift of the region in Late Cretaceous and early Cenozoic time, anhydrite-bearing sediments were buried beneath more than 3,000 feet of nearly horizontal sediments. The sedimentary cover of the center of the Black Hills had been tilted and eroded down to the Precambrian rocks by the Oligocene Epoch, and probably earlier, and thus artesian circulation may have been established in the anhydrite-bearing units early in the Cenozoic Era. The climate of this region during the early Cenozoic is believed to have been more humid than it was during the later part of the period (Brown, 1952, p. 91), and solution as extensive as that described would be facilitated by a humid climate. Solution features produced under the semiarid climate, which exists today, are very minor in the gypsum beds of the Spearfish Formation. Thus it seems probable that the major part of the leaching was accomplished in the early part of the Cenozoic, although solution on a limited scale may have continued to the present time.

MINOR DEFORMATIONAL STRUCTURAL FEATURES IN THE MINNEKAHTA LIMESTONE AND SPEARFISH FORMATION

In addition to the subsidence features previously described, a group of structural features occurs in the Minnekahta Limestone and Spearfish Formation that are believed to have been produced by slippage of the formations downdip. This group includes small thrust faults and related minor folds, dolomite breccias, pull-apart structures, small tight folds in thin gypsum beds, and cross folds.

Description of structural features.—Thrust faults of small displacement and associated minor folds occur throughout the outcrop area of the Minnekahta Limestone. The observed displacements on the faults range from several inches to about 3 feet (fig. 53). The faults may be either smooth planes having slickensides parallel to the dip of the faults, or they may be narrow brecciated zones. Where the fault displacement has taken place through a zone instead of along a single surface, the thin strata of the Minnekahta have been rotated around an axis parallel to the strike of the fault. Intense rotation has produced a brecciated zone; less intense rotation has produced asymmetric minor folds. In the latter, the steeply dipping limb of the fold is parallel to the thrust fault zone. Some of the faults cut

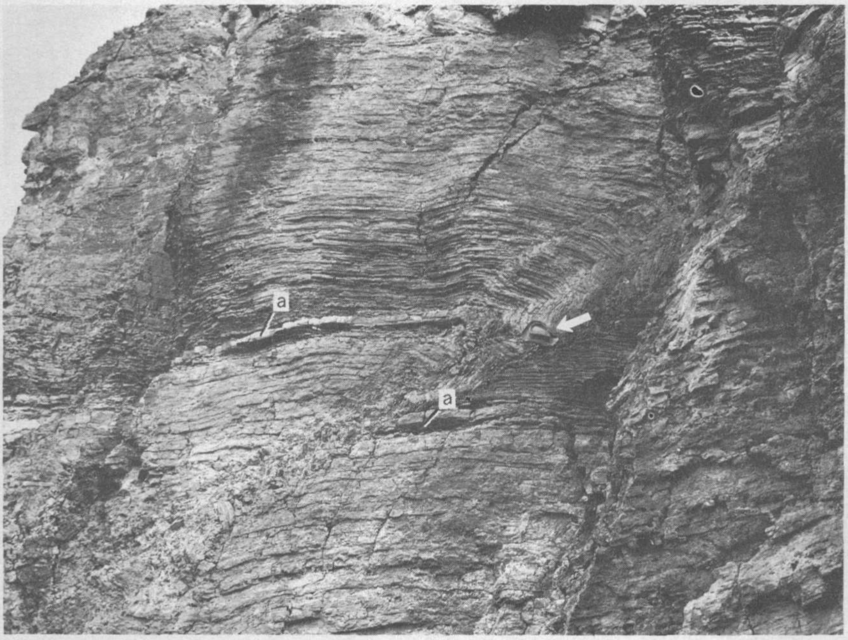

FIGURE 53.—Thrust fault that passes upward into small fold. Minnekahta Limestone, SW¼ sec. 9, T. 5 S., R. 2 E. The displacement is shown by offset of the conspicuous bed (a). View looking northwest. Arrow points to hat for scale.

entirely across the Minnekahta; others are restricted to the Minnekahta and die out both upward and downward within the formation.

The strike of the thrust faults and the axes of the associated minor folds have a preferred orientation of about N. 45° W., which is almost parallel to the direction of strike of the formations in the vicinity (fig. 54). The thrust faults dip about 45° either to the northeast or to the southwest.

A varying thickness of thinly laminated dolomite commonly occurs in the Spearfish Formation at the base of gypsum bed G_2 (fig. 44). In many exposures the dolomite is extensively brecciated. At some places small northwest-striking thrust faults extend from the brecciated dolomite upward into the overlying gypsum.

The structure shown on the right side of figure 55 is termed a "pull-apart" structure by the writer. The basal bed of the G_3 gypsum in the Spearfish Formation has been pulled apart a distance of about 40 feet, and the underlying siltstone and thin gypsum beds have been forced upward into its former position. The third dimension of this structure could not be observed. Smaller examples of pull-apart structures in thin gypsum beds are shown in figure 56.

At many localities in the Spearfish Formation the thin beds of gypsum between beds G_2 and G_3 are tightly folded. The folds range from small symmetrical folds, having amplitudes of about 1 foot, to overturned and recumbent folds like those shown in figure 56.

Several sharp anticlines and synclines that trend at nearly right angles to the regional strike occur in the Minnekahta Limestone in the northeast quarter of the quadrangle. An anticline that trends

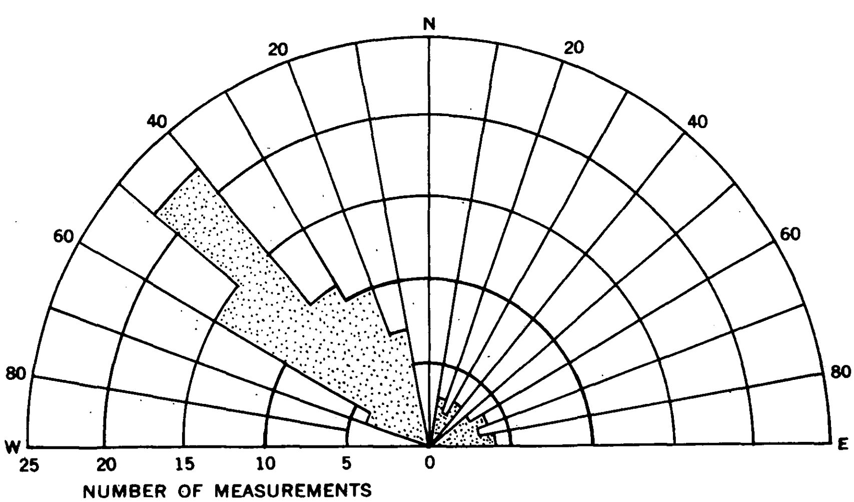

FIGURE 54.—Bearing of the axes of 92 minor folds in the Minnekahta Limestone, Jewel Cave SW quadrangle.

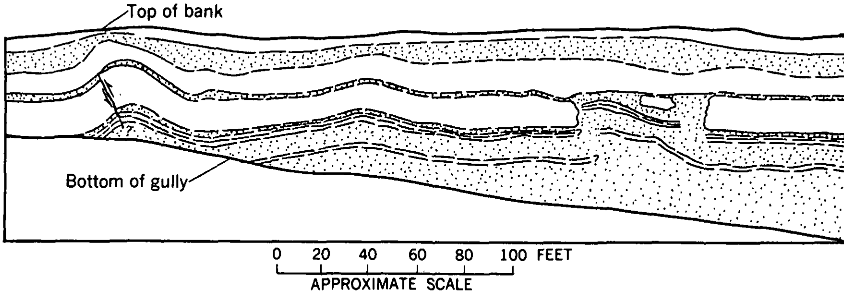

FIGURE 55.—Deformed gypsum beds in the Spearfish Formation. Stippled areas are siltstone. SW¼ sec. 26, T. 5 S., R. 1 E. Looking northeast.

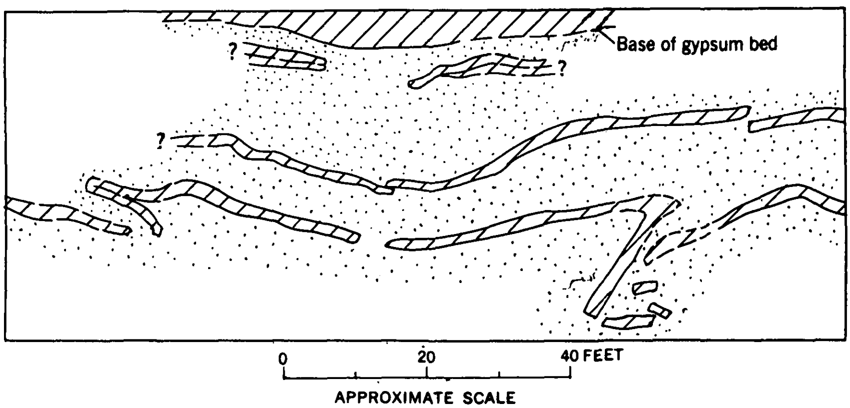

FIGURE 56.—Cross section of thin contorted gypsum beds underlying G_3 gypsum bed of the Spearfish. Stippled area is siltstone. NE¼ sec. 35, T. 5 S., R. 1 E. Looking northeast.

about N. 30° E. begins in the SE¼ sec. 28, T. 5 S., R. 2 E., and extends for at least 1 mile to the northeast (pl. 20). The Spearfish Formation is flexed at the southern end of this fold. A sharp V-shaped syncline extends from the middle of sec. 31, T. 5 S., R. 2 E., to the SE¼ sec. 36, T. 5 S., R. 1 E. It is paralleled on the north side of Hell Canyon by several smaller synclines that have similar shapes.

The G_3 gypsum bed in the Spearfish has been folded to form an arcuate syncline-anticline pair in sec. 26, T. 5 S., R. 1 E. (pl. 20). Near the center, and at the southern boundary of sec. 26, several reverse faults too small to be mapped occur just east of the synclinal trough (left side of fig. 55). The syncline exposed in the eastern part of sec. 34, T. 5 S., R. 1 E., may be a continuation of the folds in sec. 26.

Origin of the minor deformational structures.—Possible mechanisms of formation of the minor structural features are irregular subsidence due to leaching of anhydrite, deformation due to expansion when anhydrite was converted to gypsum, plastic flowage of beds of gypsum, and deformation as a result of sliding of large masses of rock.

In the northeast corner of the quadrangle all the anhydrite originally present in the Minnelusa, Opeche, and Spearfish Formations has been leached out, and the approximate southwest limit of complete leaching is believed to extend across Hell Canyon near the SW corner, sec. 29, T. 5 S., R. 2 E. All the minor structures are southwest of the area of complete leaching. The thrust faults and minor folds in the Minnekahta Limestone also occur where the Minnekahta overlies the leached area, and they probably formed before the leaching of anhydrite took place. The writer believes that the only minor structures described that could be related to solution of underlying rock are the long southwest-plunging synclines in the Minnekahta Limestone and the arcuate syncline in the Spearfish Formation. The long synclines could be the reflection of subsidence directly over elongate solution chambers. This possibility is rejected, however, because breccia pipes were not observed along the trends of the synclines and because the parallelism between the trend of the synclines and the sharp anticline in the Minnekahta Limestone (which could not be due to subsidence) suggests a common origin.

The conversion of anhydrite to gypsum could result in expansion of the rocks and produce the minor deformational features. In USGS 2, Pass Creek core test (pl. 21), the sulfate beds of the Opeche Formation, which were penetrated at a depth of about 150 feet, are gypsum. However, underlying beds of sulfate in the Minnelusa Formation, are anhydrite. Where the Minnekahta Limestone is exposed on the surface and where stream valleys do not cut into the Minnelusa Formation, sulfate beds in the Minnelusa are probably still anhydrite; consequently the sulfate beds must be dismissed from the present considerations. The writer does not believe that the expansion of the two 5-foot beds of sulfate in the Opeche Formation, which are 60 feet below the Minnekahta or that expansion of sulfate beds in the Spearfish, which are 100 feet above the Minnekahta, could have had any appreciable deforming effect upon this limestone unit. Those structures in which the gypsum beds themselves have been deformed are the ones most likely to have been produced by recrystallization, if this mechanism is effective. It does not seem possible that the intense folding and segmentation of thin gypsum beds, such as that shown in figure 56, could be the result of expansion of anhydrite. The large pull-apart structure shown in figure 55 implies the extension of the gypsum bed rather than the compression of it; the relation of this extension to volume increase during recrystallization is extremely difficult to visualize.

Many examples of plastic flowage of salt and gypsum have been described in the literature, and De Sitter (1956, p. 79) lists gypsum as one of the most incompetent rock types. Thus the structures in the gypsum beds may be due to plastic flowage caused by differential compaction or incipient folding. It is probable that these beds were converted to gypsum only after erosion had removed all but a few hundred feet of the overlying strata, and it is also probable that the structures shown by these beds were developed during uplift of the Black Hills in Late Cretaceous. The writer's impression is that when the beds were deformed, the sulfate units were more competent than the enclosing siltstone units. The sulfate beds fractured, and they were segmented and separated in much the same fashion as thin competent units caught up in a mass of plastically deforming shale.

The uniform preferred orientation of the small thrust faults and minor folds in the Minnekahta Limestone indicates that this unit was deformed by compressive stress directed parallel to the bedding in a northeast-southwest direction. The compressive stress was probably the small component of the weight of the overlying column of rocks that, following the tilting of the rocks away from the center of the Black Hills, acted parallel to the dip. As the angle of tilt increased, the component of gravity probably became great enough to cause shortening of the rocks parallel to the direction of the dip.

This line of reasoning indicates that the siltstone in the Opeche and lower part of the Spearfish were particularly incompetent parts of the stratigraphic section at the time of uplift of the Black Hills, and that the overlying rocks may have slid relatively more downdip than the underlying units. Within the incompetent units, minor structures were produced as a result of the sliding. The southwest-trending anticlines and synclines in the Minnekahta Limestone are nearly parallel to the postulated direction of sliding. These folds may have been produced as a result of adjacent masses of rock sliding in slightly different directions. The pull-apart structure in the G_3 gypsum bed could also have been produced by adjacent rock sliding that tended to stretch the bed. The many small folds in the thin gypsum beds and the dolomite breccias would have formed as a result of the plastic deformation of the incompetent zone during sliding. The angle of dip (sliding gradient) in the Jewel Cave SW quadrangle is about 2°; it becomes somewhat steeper to the southwest.

URANIUM DEPOSITS

The Jewel Cave SW quadrangle is on the northwest fringe of the Edgemont mining district. Several small uranium deposits and a few radioactivity anomalies are known in the quadrangle, but no large economic deposits have been found. The known occurrences of uranium minerals are all within the Inyan Kara Group.

In the Chilson Member, the S_1 sandstone contains secondary yellow uranium minerals at two places: in the NE¼ sec. 19, T. 6 S., R. 2 E., and in the NE¼ sec. 9, T. 6 S., R. 1 E. At the first of these localities the S_1 sandstone is about 20 feet thick and consists of thin beds of sandstone separated by carbonaceous mudstone. No ore has been produced from this occurrence. At the second locality the S_1 sandstone is 80 feet thick and consists of massive, intricately channeled sandstone having irregular pods and lenses of carbonaceous siltstone and clay galls. Yellow uranium minerals occur as disseminations in the sandstone, and the sandstone contains irregular areas that are stained purplish red by hematite, which forms a thin coating on the sand grains. This second occurrence has been prospected by rim cuts and drilling, but concentrations of uranium minerals were so small and scattered that no mining has been attempted.

Most of the occurrences of uranium minerals are in the Fall River Formation in the vicinity of Pass Creek. Many of these occurrences are at the top of the S_5 sandstone along its southwest margin in rock that has been mapped as interbedded sandstone and mudstone. The rock consists of 1- to 2-foot-thick beds of sandstone and thin interbeds of shale, and it is believed to represent the lateral transition of the thick S_5 sandstone to dominantly mudstone units. These uranium occurrences have been extensively explored by drilling in the S½ sec. 23 and the N½ sec. 25, T. 6 S., R. 1 E., but no commercial ore has been found. The underlying massive S_5 sandstone is not mineralized. Several uranium deposits are in a thin sandstone that overlies the carbonaceous siltstone of the lower unit of the Fall River. (See page 244.) The Wicker-Baldwin mine, in the NW¼ sec. 26, T. 6 S., R. 1 E., and the Dark mine in the NE¼ sec. 15, T. 6 S., R. 1 E., are the only mines in the quadrangle from which uranium ore has been produced, but the total production is very small. At the Wicker-Baldwin mine the ore-bearing sandstone is 15 feet thick, fine grained, and carbonaceous. Parts of the sandstone are stained purplish red, presumably by hematite. At the Dark mine the ore occurs in the basal part of the 10-foot-thick sandstone and in the upper part of the underlying carbonaceous siltstone.

The writer does not believe that there is much likelihood of finding large uranium deposits in the Inyan Kara rocks east of Pass Creek. Throughout most of this area the Inyan Kara Group has been deeply dissected, but only rare radioactivity anomalies or uranium occurrences are known.

Uranium deposits may exist in the Fall River Formation west of Pass Creek and south of the Dewey fault. In the main part of the Edgemont mining district many commercial uranium deposits occur in the sandstone interbedded with siltstone of the lower unit of the Fall River Formation, along the southwest margin of the S_5 sandstone. The margin of the S_5 sandstone trends diagonally across the southwest corner of the Jewel Cave SW quadrangle (pl. 22), and by analogy with the known stratigraphic occurrences in the main part of the mining district, this region may contain commercial deposits.

Exploration for uranium deposits here will have to be by rather deep drilling (as deep as 300 feet), because the margin of the S_5 sandstone is overlain by appreciable thicknesses of the Fall River Formation and the Skull Creek Shale.

REFERENCES CITED

Agatston, R. S., 1954, Pennsylvanian and Lower Permian of northern and eastern Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 38, p. 508–583.

Baker, C. L., 1947, Deep borings in western South Dakota: South Dakota Geol. Survey Rept. Inv. 57, 112 p.

——— 1948, Additional well borings in South Dakota: South Dakota Geol. Survey Rept. Inv. 61, 40 p.

——— 1951, Well borings in South Dakota: South Dakota Geol. Survey Rept. Inv. 67, 67 p.

Bates, R. L., 1955, Permo-Pennsylvanian formations between Laramie Mountains, Wyoming, and Black Hills, South Dakota: Am. Assoc. Petroleum Geologists Bull., v. 39, p. 1979–2002.

Bell, Henry, 3d, and Bales, W. E., 1955, Uranium deposits in Fall River County, South Dakota: U.S. Geol. Survey Bull. 1009–G, p. 211–233.

Brobst, D. A., 1961, Geology of the Dewey quadrangle, Wyoming–South Dakota: U.S. Geol. Survey Bull. 1063–B, p. 13–60 [1962].

Brown, R. W., 1952, Tertiary strata in eastern Montana and western North and South Dakota, *in* Billings Geol. Soc. Guidebook 3d Ann. Field Conf., 1952: p. 89–92.

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

Condra, G. E., and Reed, E. C., 1935, The Permo-Pennsylvanian section of the Hartville area of Wyoming: Nebraska Geol. Survey Paper 9, 46 p.

——— 1940, Correlation of the Carboniferous and Permian horizons in the Black Hills and the Hartville uplifts, *in* Kansas Geol. Soc. Guidebook 14th Ann. Field Conf.: 127–128.

Condra, G. E., Reed, E. C., and Scherer, O. J., 1940, Correlation of the formations of the Laramie Range, Hartville uplift, Black Hills, and western Nebraska: Nebraska Geol. Survey Bull. 13.

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

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

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

Darton, N. H., and O'Harra, C. C., 1909, Description of the Belle Fourche quadrangle [South Dakota]: U.S. Geol. Survey Geol. Atlas, Folio 164.

Darton, N. H., and Paige, Sidney, 1925, Description of the Central Black Hills quadrangle [South Dakota]: U.S. Geol. Survey Geol. Atlas, Folio 219.

De Sitter, L. U., 1956, Structural geology: 1st ed., New York, McGraw-Hill, 522 p.

Foster, D. I., 1958, Summary of the stratigraphy of the Minnelusa formation, Powder River Basin, Wyoming, *in* Wyoming Geol. Assoc. Guidebook 13th Ann. Field Conf.: p. 39–44.

Gries, J. P., 1952, Paleozoic stratigraphy of western South Dakota, *in* Billings Geol. Soc. Guidebook 3d Ann. Field Conf., 1952: p. 70–72.

Imlay, R. W., 1947, Marine Jurassic of the Black Hills area, South Dakota and Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 31, p. 227–273.

Jenney, W. P., 1899, Field observations in the Hay Creek coal field, Wyoming: U.S. Geol. Survey, 19th Ann. Rept., pt. 2, p. 568–593.

Love, J. D., Henbest, L. G., and Denson, N. M., 1953, Stratigraphy and paleontology of Paleozoic rocks, Hartville area, eastern Wyoming: U.S. Geol. Survey Oil and Gas Inv. Chart OC–44.

McCauley, V. T., 1956, Pennsylvanian and lower Permian of the Williston Basin, *in* North Dakota Geol. Soc., Williston Basin Symposium, 1st Internat., Bismarck, Oct. 1956: p. 150–164.

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

Page, L. R., and Redden, J. A., 1952, The carnotite prospects of the Craven Canyon area, Fall River County, South Dakota: U.S. Geol. Survey Circ. 175.

Peterson, J. A., 1954, Marine Upper Jurassic, eastern Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 38, no. 4, p. 463–507.

Pettijohn, F. J., 1957, Sedimentary rocks: 2d ed., New York, Harper & Bros., 718 p.

Post, E.V., and Bell, Henry, 3d, 1961, Chilson member of the Lakota formation in the Black Hills, *in* Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424–D, p. D173–D178.

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

Schnabel, R. W., 1963, Geology of the Burdock quadrangle, South Dakota: U.S. Geol. Survey Bull. 1063–F, p. 191–215.

Thomas, H. D., 1940, Pennsylvanian and Permian stratigraphy of central and southeastern Wyoming, *in* Kansas Geol. Soc. Guidebook 14th Ann. Field Conf., 1940: p. 121–126.

Waagé, K. M., 1959, Stratigraphy of the Inyan Kara group in the Black Hills: U.S. Geol. Survey Bull. 1081–B, p. 11–90.

Winchell, N. H., 1875, Geological report, *in* Ludlow, William, Report of a reconnaissance of the Black Hills of Dakota: Washington, 1875, p. 21–66.

INDEX

U.S. GOVERNMENT PRINTING OFFICE: 1963 O—689-415