Geology of the Hot Springs Quadrangle Fall River and Custer Counties, South Dakota

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Wolcott—GEOLOGY OF THE HOT SPRINGS QUADRANGLE, FALL RIVER AND CUSTER COUNTIES, SOUTH DAKOTA—Geological Survey Bulletin 1063-

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By DON E. WOLCOTT

GEOLOGY AND URANIUM DEPOSITS OF THE SOUTHERN BLACK HILLS

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GEOLOGY OF THE HOT SPRINGS QUADRANGLE, FALL RIVER AND CUSTER COUNTIES, SOUTH DAKOTA

By Don E. Wolcott

ABSTRACT

The Hot Springs quadrangle covers about 55 square miles on the southeast flank of the Black Hills in parts of Fall River and Custer Counties, S. Dak. Exposed sedimentary rocks, about 3,000 feet thick, are of Permian through Late Cretaceous age. These formations are locally covered by Tertiary and Quaternary deposits. The southeast regional dip off the Black Hills uplift is interrupted by two anticlines in the quadrangle: the north-trending Dudley anticline in the central part and the Cascade Springs anticline in the northwestern part. Subsidence structures attributed to the removal of anhydrite and gypsum by solution from the Minnelusa Formation are present in rocks as young as Early Cretaceous. Sandstone for dimension stone, and limestone, gravel, and sand for aggregate have been exploited and large reserves remain. Gypsum and bentonite have not been exploited but constitute potential resources. No oil and gas test wells are known to have been drilled within the quadrangle, but closed structural highs which may be favorable for the accumulation of petroleum are present.

INTRODUCTION

The Hot Springs quadrangle covers about 55 square miles of the southeast flank of the Black Hills uplift (fig. 85 and pl. 28). Consolidated sedimentary rocks of Permian through Cretaceous age crop out within the area. The "Dakota" hogback, a dissected belt of uplands about 4 miles wide extending northeastward across the quadrangle, is the dominant feature of the landscape. This belt is formed by nonresistant rocks of Jurassic age overlain by resistant rocks of Cretaceous age. Southeast of the hogback, less resistant younger Cretaceous rocks underlie an area of low relief of the Missouri Plateau. Northwest of the hogback is the "Red Valley," underlain by nonresistant red beds of Permian and Triassic age. Older Permian rocks bound the valley on the west. The north-northeast regional strike and eastward dip of the rocks in the quadrangle is interrupted by two major

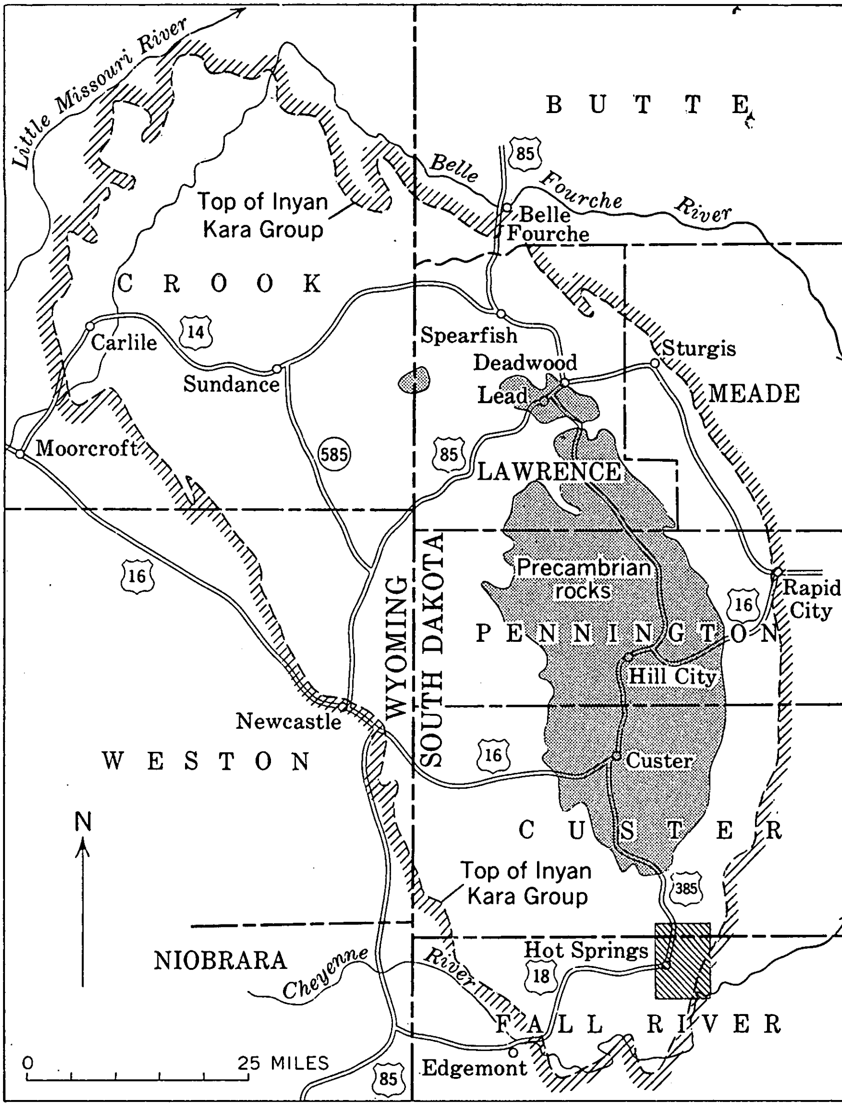

FIGURE 85.—Map of the Black Hills showing the location of the Hot Springs quadrangle, the top of the Inyan Kara Group (fringe pattern), and the Precambrian rocks of the core of the Black Hills (black stipple).

anticlines—the Cascade Springs anticline in the northwestern part of the quadrangle and the Dudley anticline in the central part.

The Cheyenne River and its tributaries drain the quadrangle. The tributaries, with the exception of Cold Brook, head in areas underlain by rocks of Paleozoic and Mesozoic age. Cold Brook heads in an area underlain by Precambrian rocks. The maximum topographic relief in the mapped area is about 1,500 feet, and local relief in the hogback is as much as 600 feet.

Geologic mapping of the quadrangle was part of the detailed geologic investigations by the U.S. Geological Survey in the southern Black Hills on behalf of the Division of Raw Materials of the U.S. Atomic Energy Commission. The author was ably assisted by Charles E. Price during the 1957 field season.

PERMIAN ROCKS

MINNELUSA FORMATION

The upper part of the Minnelusa Formation crops out only in Hot and Cold Brooks in the northwestern part of the quadrangle. The exposed part of the formation consists of brecciated red or yellow sandstone beds and brecciated gray or yellow limestone beds. Brecciation of the rocks was caused by the removal, by solution, of more than 200 feet of gypsum or anhydrite from the upper part of the formation and by the resulting subsidence of the rocks interbedded with and overlying the sulfate beds (Bowles and Braddock, 1963). The contact with the overlying Opeche Formation is placed at the top of the uppermost thick sandstone, which is generally about 25 feet thick. Where seen, the contact is sharp, and the reddish-brown siltstone of the Opeche rests on sandstone of the Minnelusa; however, the uppermost sandstone of the Minnelusa is mostly concealed and the contact is rarely exposed. The exposed Minnelusa is equivalent to the upper part of unit 1 of the Minnelusa in the adjoining Minnekahta NE quadrangle (Wolcott and others, 1962), and this exposed part is considered to be of Permian age. The unexposed part of the formation is of Pennsylvanian and Permian age.

OPECHE FORMATION

Exposures of the Opeche Formation are limited to the valleys of Hot and Cold Brooks in the northwestern part of the quadrangle. The lower part of the formation is dominantly reddish-brown siltstone which grades upward into pale-purple siltstone. The contact with the overlying Minnekahta Limestone is sharp and apparently conformable. Outcrops are commonly poor, for the formation is generally covered with debris from the Minnekahta.

MINNEKAHTA LIMESTONE

The Minnekahta Limestone crops out as cliffs in the western part of the quadrangle, and its upper surface forms extensive dip slopes. It consists of grayish-red laminated very fine grained to lithographic limestone. Intraformational thrust faults of small displacement and minor associated folds are common and conspicuous features in the Minnekahta. These features have been attributed to gravity sliding by Braddock (1963, p. 259–263) and Brobst and Epstein (1963, p. 340–343). Subsidence of the formation, caused by the removal of sulfate beds from the Minnelusa Formation, has resulted in many collapse structures in the Minnekahta and has imparted undulations to the formation. Exposures of the contact with the overlying Spearfish Formation are sparse.

PERMIAN AND TRIASSIC ROCKS

SPEARFISH FORMATION

The Spearfish Formation forms a broad 1- to 2-mile-wide grass-covered lowland in the western part of the quadrangle. Outcrops are sparse except where gullies have cut through the grass cover. The gypsum beds, being more resistant to erosion than the enclosing siltstones, form low cuestas. The Spearfish Formation is estimated to be about 350 feet thick. The determination of an accurate thickness is difficult because outcrops are poor; gypsum beds are draped over siltstone beds in many gullies owing to plastic flow of the gypsum, and it is difficult to determine the downdip extent of solution of sulfate beds from the Minnelusa Formation. This solution factor could introduce an error of as much as 100 feet.

The Spearfish is considered to be Permian and Triassic in age. E. K. Maughan (oral commun., 1959) correlated the top of the uppermost gypsum bed in the gypsiferous unit of this report (see stratigraphic section, pl. 28) with the top of the Ervay Member of the Goose Egg Formation. Maughan (1964, p. B59) considered the Ervay to be the youngest unit of Permian age in southeastern Wyoming and rocks above the Ervay to be of Triassic age. The variegated gypsum bed at the base of the gypsiferous unit probably correlates with the Forelle Limestone Member of the Goose Egg Formation, and the thin variegated gypsum bed in the upper siltstone unit probably correlates with the Little Medicine Member of the Goose Egg Formation.

JURASSIC ROCKS

SUNDANCE FORMATION

The Sundance Formation is exposed along the lower west-facing slopes of the hogback, and the upper member, the Redwater Shale Member, is also exposed in Elm and Spring Creeks. Outcrops are sparse as the formation is largely covered by colluvium and landslide debris derived mostly from the Lakota Formation. Except for the

Redwater Shale Member which seemingly attains a maximum thickness of about 200 feet in the northern part of the quadrangle, the members thin northward. The Sundance Formation overlies the Spearfish Formation unconformably and is mainly of marine origin.

Canyon Springs Sandstone Member.—The Canyon Springs Sandstone Member ranges from orange crossbedded sandstone 50 feet thick, of probable eolian origin, to white or light-gray laminated sandstone and light-brown siltstone only a few feet thick, of marine origin. Locally the marine sandstone contains a few feet of sandy bioclastic limestone. Most outcrops of the member contain sparse chert pebbles and granules near the base and commonly contain medium to coarse well-rounded frosted quartz grains in a fine-grained to very fine grained sandstone matrix. The sandstone is generally poorly cemented with calcite and gypsum. Much of the variation in thickness of the member is probably the result of lateral gradation into the lower part of the Stockade Beaver Shale Member, as the two members seem to have a reciprocal relation in thickness. Undoubtedly the variation in thickness of the Canyon Springs results partly from deposition of sand in irregularities on an eroded surface.

R. W. Imlay (written commun., 1958) identified *Ostrea* sp., *Trigonia* sp., and *Meleagrinella curta* (Hall) from sandy limestone in the marine facies in the SE¼ NW¼ sec. 25, T. 7 S., R. 5 E., and he stated, "The presence of *Meleagrinella* and the oysters indicate shallow waters and a firm sea bottom * * * [they] probably lived just below the littoral zone in much agitated water." Only 2,000 feet southwest of the above locality the Canyon Springs is represented by 50 feet of orange crossbedded sandstone with a few feet of light-gray laminated sandstone at the top.

Stockade Beaver Shale Member.—The Stockade Beaver Shale Member consists of interbedded light-brown calcareous siltstone and greenish-gray claystone and sparse thin fossiliferous bioclastic limestone beds. Except for the uppermost 20 feet, the member is probably laterally equivalent to most of the Canyon Springs Member. The Stockade Beaver was probably deposited in a quiet shallow-water marine environment. The member grades upward into the overlying Hulett Sandstone Member, and the upper contact is arbitrarily placed to include the dominantly silty and clayey beds within the Stockade Beaver.

Hulett Sandstone Member.—The Hulett Sandstone Member is dominantly flaggy ripple-marked fine-grained calcareous glauconitic light-gray sandstone with grayish-green claystone partings. The upper part commonly contains more shale than sandstone. Locally the sandstone is pink. The oscillation ripple marks in the sandstone indicate

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that the member was deposited in a higher energy marine environment than was the Stockade Beaver. The Hulett is better exposed than the underlying or overlying members. The contact with the overlying Lak Member is transitional and is arbitrarily placed to include the light-gray sandstone and shale beds within the Hulett.

Lak Member.—The Lak Member is composed of calcareous, glauconitic siltstone and sandstone red beds; stratification is indistinct. Commonly, the Lak is mottled grayish green in the lower few feet. The presence of glauconite suggests deposition under marine conditions. The contact with the overlying Redwater Shale Member is sharp and seemingly disconformable, with white sandstone or grayish-green shale of the Redwater overlying red beds of the Lak.

Redwater Shale Member.—The Redwater Shale Member consists dominantly of interlaminated light-gray calcareous, glauconitic siltstone and grayish-green clayey shale with a few thin beds of white to light-gray glauconitic sandstone. Locally, as in Spring Creek, the member contains 10–15 feet of reddish-brown mottled grayish-green siltstone at the top. Contact with the overlying Unkpapa Sandstone is sharp and slightly irregular.

UNKPAPA SANDSTONE

The Unkpapa Sandstone is exposed along the west side of the hogback and in a few of the deeper canyons within the hogback. Two units were mapped within the formation, a sandstone unit and a dominantly siltstone unit, each probably a facies of the other. The sandstone unit is composed of very fine grained mostly bright-reddish-brown, violet, pale-purple, or pink sandstone; it commonly has purple and yellow bands near the top which display microfaulting. Locally the whole sandstone unit is white. The lower part of the unit is generally horizontally bedded and probably was deposited in water; the middle part commonly has long wedge-shaped sets of crossbeds and may be of eolian origin; the upper part is typically structureless. The siltstone unit is mostly composed of reddish-brown or white siltstone but includes light-gray and grayish-green claystone near the head of South Knappie Canyon. In Elm Creek (SW¼ NE¼ SW¼ sec. 34, T. 6 S., R. 6 E.) the siltstone unit includes a distinctive thin chert or silicified mudstone bed about 10 feet below the top of the formation. The variation in thickness of the Unkpapa results mainly from erosion prior to the deposition of the Lakota Formation.

The contact with the overlying Chilson Member of the Lakota Formation is generally covered. Where exposed, crossbedded channel sandstone, conglomerate composed of pebbles derived from the Unkpapa, or mudstone of the Chilson Member rest disconformably on the sandstone or siltstone units of the Unkpapa Sandstone. Locally, as in the southwestern part of the quadrangle, mudstone of the Chilson rests on claystone of the Unkpapa and the contact is arbitrary. The formation is well exposed in Spring and Elm Creeks and is locally well exposed along the hogback.

The Unkpapa is restricted to the southeastern part of the Black Hills; elsewhere its stratigraphic position is occupied by the Morrison Formation of Late Jurassic age. The Unkpapa is most probably a facies of the Morrison (Imlay, 1947, p. 246). The claystone at the top of the siltstone unit in the southwestern part of the quadrangle may be a transitional facies between Morrison and Unkpapa. Typical Morrison crops out about 10 miles west of the quadrangle. Where the Unkpapa has not been thinned by pre-Lakota erosion, it is generally from two to three times as thick as the Morrison Formation of nearby areas.

CRETACEOUS ROCKS

INYAN KARA GROUP

The history and development of the nomenclature of the Inyan Kara Group and redefinitions of the included Lakota and Fall River Formations are given by Waagé (1959). Subsequent to Waagé's redefinition of the formations, Post and Bell (1961) introduced the name Chilson Member of the Lakota and designated a reference section for the Fuson Member of the Lakota. Thus, Waagé's redefined Lakota now includes the Chilson, Minnewaste Limestone, and Fuson Members. In this report the use of Lakota and Fall River Formations follows Waagé's (1959) usage as supplemented by Post and Bell (1961). Both Waagé's reference section of the Lakota (1959, section 11) and the type section of the Fall River Formation (section 8) are along the Fall River in the southeastern part of the quadrangle.

LAKOTA FORMATION

The Lakota Formation is composed of, in ascending order, the Chilson, Minnewaste Limestone, and Fuson Members, all of which are present in the quadrangle. The Lakota is overlain disconformably by the Fall River Formation, and the contact is sharp. Most of the variation in thickness of the Lakota is taken up by thickness variations within the Chilson and Fuson Members, but variations in thickness of the two members seem to be unrelated. Deposition of the Chilson Member on an irregular erosion surface gives abrupt variations in thicknesses, which range from less than 200 feet to about 350 feet within a distance of 1 mile. The generally uniform thickness of the lacustrine Minnewaste Limestone Member and the conformable contact between the Minnewaste and Chilson indicate that most of the variation in thickness of the Chilson takes place in its lower part. The absolute variation in thickness of the Fuson is less precisely known owing to poor outcrops, but much of the variation probably resulted from pre-Fall River and post-Fuson erosion. Locally channels containing sandstone of the Fall River Formation cut as deep as 50 feet into the Fuson Member. The Lakota Formation is of fluvial and lacustrine origin.

Chilson Member.—Exposures of the member are generally very good throughout much of the hogback. In the quadrangle the Chilson is made up entirely of a sandstone-mudstone complex which Post and Bell (1961, p. D174) designated unit 2. West of the quadrangle in the southern Black Hills, an older sandstone-mudstone complex has been designated unit 1 of the Chilson Member (Post and Bell, 1961, p. D174). The main distinguishing feature between these units is that unit 1 is characterized by abundant carbonaceous material, whereas unit 2 is almost devoid of carbonaceous material.

The Chilson consists of lenticular crossbedded fluvial sandstone bodies which interfinger with mudstone of lacustrine or flood-plain origin. The sandstone to mudstone ratio ranges from 4:1 to 1:4 although the member commonly contains more mudstone than sandstone. The contact with the overlying Minnewaste Limestone Member is rarely exposed but is probably conformable. Petrified wood is common in the member, especially in the W½ sec. 2, T. 8 S., R. 5 E., and the mudstone units commonly contain ostracodes.

Minnewaste Limestone Member.—The member forms prominent ledges and extensive dip slopes throughout much of the hogback. On the north side of Brady Canyon in the southwestern part of the quadrangle, the Minnewaste seems to be missing and is apparently replaced by a channel sandstone of the Fuson Member. The Minnewaste is a sandy, locally cherty, limestone interbedded with carbonaceous shale; commonly the lower part is limy sandstone. Locally the surface is hummocky and the limestone is brecciated. Anhydrite was reported to be present in the member in a drill hole near Buffalo Gap (Baker, 1948), but none was observed in outcrop. Perhaps the hummocky surface and brecciation of the member resulted from solution and removal of "pockets" of anhydrite. The contact with the Fuson Member is sharp where seen.

Fuson Member.—The Fuson Member generally forms slopes which are grass covered, and so there are few outcrops. The Fuson is composed dominantly of mudstone and claystone and subordinately of sandstone; oolitic and dense limestone lenses commonly occur a few feet above the base. Petrified wood is present near the base in the northeastern part of the quadrangle, and scattered polished siliceous pebbles occur locally in mudstone.

A distinctive sandstone occurs locally at the top of the member; it is conglomeratic, has white clay partings, is as much as 25 feet thick, and occurs in a narrow north-trending belt in the east-central part of the quadrangle.

Mudstone or conglomeratic sandstone at the top of the Fuson is overlain by interbedded carbonaceous siltstone and sandstone, massive sandstone, or interbedded sandstone and mudstone of the Fall River Formation. Siderite pellets are common in the upper few feet of the member (Waagé, 1959, p. 55), but they were observed only as oxidized ferruginous spots.

FALL RIVER FORMATION

The Fall River Formation forms the east side of the hogback. Exposures of sandstone are common, but the siltstone and mudstone units are rarely exposed. The lithologic types within the formation have been grouped informally into lower, middle, and upper units. The lower unit consists of a distinctive sequence of carbonaceous interbedded siltstone and sandstone. The middle and upper units are composed of massive channel-sandstone bodies which interfinger with interbedded sandstone and mudstone. The contact between the middle and upper units was arbitrarily placed at the base of a distinctive variegated mudstone. This mudstone, a useful key bed, has been recognized as far west as the Burdock quadrangle (Schnabel, 1963, p. 206), which is about 20 miles west of the Hot Springs quadrangle. Sandstone in the Fall River Formation is commonly micaceous in contrast to sandstone in the Lakota Formation which is rarely micaceous.

The lower and middle units of this report correspond to Waagé's (1959, p. 61) lower unit, and the upper unit corresponds to his middle and upper units.

The contact with the overlying Skull Creek Shale is exposed in only a few places; where the contact was seen, sandstone of the Fall River grades upward within a few feet into shale of the Skull Creek.

Lower unit.—The lower unit is composed of thin-bedded carbonaceous very fine grained sandstone interbedded with laminated carbonaceous siltstone. It is lithologically distinct from and predates the generally noncarbonaceous middle unit. The upper contact is placed at the base of the channel sandstone or at the base of the interbedded sandstone and mudstone sequence which is a facies of the channel sandstone. The lower unit is generally about 50 feet thick where it has not been thinned by erosion prior to deposition of the middle unit; locally it is completely missing. Apparently this unit was deposited in a coastal swamp (Waagé, 1959, p. 63).

Middle unit.—The middle unit is dominantly light-brown massive sandstone which occurs in channels cut into and locally through the lower unit. Interbedded sandstone and mudstone form the remainder of the unit. At the head of the box canyon in the SW¼ SE¼ sec. 16, T. 7 S., R. 6 E., the stratigraphic relations of the two facies of the middle unit are well exposed. The massive channel sandstone, about 100 feet thick, interfingers southwestward with interbedded sandstone and mudstone within a few hundred feet. The channel sandstone is conglomeratic at the base; the pebbles were derived from conglomeratic sandstone at the top of the Fuson in this area.

Upper unit.—Except for the variegated mudstone at its base, the upper unit is lithologically similar to the middle unit. The unit is mostly interbedded sandstone and mudstone with fewer channel-sandstone bodies than the middle unit. The variegated mudstone is commonly red and gray and locally silty; it contains scattered carbonaceous material.

SKULL CREEK SHALE

The Skull Creek Shale has few exposures; it forms slopes which are grass covered or it is overlain by younger surficial deposits. Most good exposures are in gullies. The formation consists predominantly of dark-gray clayey shale and contains some locally glauconitic siltstone. It contains a few sandstone dikes, and cone-in-cone concretions commonly occur about 150 feet above the base.

MOWRY SHALE

The Mowry Shale forms low hills which generally support a scrub growth of trees. Outcrops are better than those of the Skull Creek. The formation is dominantly medium-gray nonsiliceous shale with conspicuous thin sandstone and siltstone beds. Clastic dikes are abundant. A poorly sorted thin sandstone bed with sparse phosphate pebbles commonly occurs at the base. The contacts with the underlying and overlying formations were placed to include the sandy beds in the Mowry.

BELLE FOURCHE SHALE

The Belle Fourche forms low hills which are grass covered, and outcrops are sparse. It consists of dark-gray clayey shale. The lower part contains distinctive elongate iron-manganese-carbonate concretions as much as 10 feet long and 1 foot thick. Concretions and beds with cone-in-cone structure occur in the upper few feet of the formation. The contact with the overlying Greenhorn Formation is placed at the base of the lowest calcarenite bed in the Greenhorn.

GREENHORN FORMATION

Two units were mapped within the Greenhorn Formation: a lower, dominantly shale unit and an upper, dominantly limestone unit. The lower unit forms low grass-covered hills, and the upper unit forms a prominent cuesta.

Lower unit.—The lower unit consists of grayish-brown to dark-gray calcareous shale with thin beds of medium-brown calcarenite. A 2-foot-thick bed of calcarenite, composed dominantly of prisms from pelecypod shells, occurs at the base and forms a subdued cuesta; it is probably equivalent to the Orman Lake Limestone of Petsch (1949). Bentonite beds as thick as 1 foot are common in the unit, and one bed 2 feet thick occurs about 70 feet above the base. The contact with the upper unit is gradational and is arbitrarily placed between the dominantly limestone unit above and the shale unit below.

Upper unit.—The upper unit is dominantly light-gray thin-bedded ripple-marked calcarenite composed almost wholly of remnants of the pelecypod *Inoceramus labiatus*. Calcareous shale occurs interbedded with the calcarenite. The unit grades upward into the Carlile Shale, and the contact is arbitrarily placed at the top of the dominantly limestone sequence.

CARLILE SHALE

The formation consists of an unnamed shale member, the Turner Sandy Member, and the Sage Breaks Member. It crops out only in the southeastern part of the quadrangle. The unnamed shale member forms a low grass-covered cuesta, and the other members are largely covered by surficial deposits.

Unnamed shale member.—The member consists dominantly of dark-gray shale with fossiliferous dense dark-gray limestone concretions near the middle and a distinctive calcarenite bed in the upper part. The calcarenite bed is shown on plate 28 as a key bed, and its resistance to erosion causes the cuesta formed on the member. The calcarenite is very similar to the one at the base of the Greenhorn Formation. Locally, dark-gray siliceous shale occurs above the calcarenite bed. The contact with the Turner Sandy Member was placed at the base of the lowest sandstone or siltstone bed.

Turner Sandy and Sage Breaks Members.—These members occur mostly beneath terrace deposits, and outcrops are poor. The contact between the members was inferred on the basis of the thickness of the Turner Sandy Member measured by Connor (1963, p. 113).

NIOBRARA FORMATION

The Niobrara is present only in the southeasternmost part of the quadrangle beneath terrace gravels, where it is a light-yellow chalky shale. The contact with the Carlile Formation is concealed by terrace gravels.

TERTIARY(?) ROCKS

WHITE RIVER(?) FORMATION

Rocks assigned tentatively to the Oligocene White River Formation occur in three places in the northern part of the quadrangle. Two of these occurrences are terrace remnants on the Spearfish Formation, and the third is an isolated stream-channel deposit in a wind gap on the Chilson Member of the Lakota Formation. Elsewhere in the quadrangle, no record of these rocks was found. The deposits consist of gravel and sand derived mostly from Precambrian rocks in the central part of the Black Hills. The streams that deposited these rocks carried a much higher percentage of sediments derived from Precambrian rocks than does Cold Brook, which is the only stream in the quadrangle that heads in an area underlain by Precambrian rocks.

In the adjacent Wind Cave quadrangle to the north, similar deposits occur as pediment gravels on top of a thick fill of the White River Formation in the "Red Valley," and the gravel and sand occur in wind gaps in the hogback at altitudes above 4,000 feet. The White River fill is lacustrine in origin and consists of silts, clays, and fresh-water limestones.

It seems likely that a large lake existed in this area during White River time and that the entire "Red Valley" was filled with these lacustrine deposits. Subsequently, through-going streams, heading in the central Black Hills, carried the coarse gravel and sand out onto the pediment cut on the White River fill and through the topographic lows on the hogback. Later drainage changes have resulted in dissection and removal of much of the White River fill in the "Red Valley" by tributaries of Beaver Creek and in isolation of the stream-channel deposits and formation of present-day wind gaps and terrace remnants.

QUATERNARY DEPOSITS

Colluvial terrace gravel.—The colluvial terrace deposits were mapped only on the east side of the hogback. Similar deposits west of the hogback are too greatly dissected to be mapped. The mapped deposits are composed of a very poorly sorted mixture of angular sandstone blocks in a sand and silt matrix, derived mostly from rocks of the Fall River Formation. The contact with the underlying bedrock is fairly smooth and slopes down eastward. The upper surface is also fairly smooth and slopes up westward to where it ends at the dipslope on the Fall River Formation. If the terraces were formerly part of a continuous sheet of colluvium, recent erosion has isolated the deposit as terraces in divide areas. During deposition the climate was perhaps periglacial, and mass-wasting processes were more active than at present.

Fluvial terrace conglomerate.—The conglomerate occurs in extensive terraces and as isolated small patches capping hills in and around Hot Springs. The small patches are higher topographically and probably predate the terraces. The conglomerate consists dominantly of angular to subangular pebbles derived from the Minnekahta Limestone. Long low-dipping foreset-type beds are common in the deposits. The bases of the terraces are very irregular and have local relief of as much as 100 feet. The base of the terrace on the south side of Hot Brook drops eastward more than 100 feet in less than half a mile. The upper slope of this terrace slopes southeastward at a greater rate than the gradient of the Fall River. The irregular bases, the steeper than normal slope of the upper surfaces, and the foreset beds indicate deposition by aggrading streams. Conglomerate was not found below the mouth of Fall River Canyon. Perhaps the two large landslides at the mouth of the canyon dammed up the Fall River, causing it to aggrade upstream and deposit the gravel. Cementation of the gravel probably resulted from deposition of calcium carbonate and calcium sulfate from the highly mineralized water from hot springs near Hot Springs. (See report by Gott and Schnabel (1963, p. 135) for chemical analyses of spring waters in the southern Black Hills.)

Fluvial terrace gravels.—The gravels occur in terraces and terrace remnants along the Cheyenne and Fall Rivers and their tributaries. The terraces range from a few feet to 480 feet above present drainage levels. In the southeastern part of the quadrangle large terraces with flat bases, the upper surfaces of which are about 100 feet above the Cheyenne and Fall Rivers, record a period when the streams were in equilibrium. After this period, these rivers started downcutting to their present-day levels and deposited gravels on gentle slip-off slopes which merge with the alluvium. The course of the Cheyenne River in the quadrangle downstream from the Fall River Formation seems to be in equilibrium again as the base of the alluvium is virtually flat.

Landslide deposits, tufa, colluvium, and alluvium.—Landslide deposits consist largely of sandstone derived from the Inyan Kara Group. The tufa was mapped only at the falls of the Fall River in NE¼ sec. 33, T. 7 S., R. 6 E., where it is on massive sandstone of the Fall River

Formation, and in SE¼ sec. 30, T. 7 S., R. 6 E., where it cements alluvium. The tufa at the falls contains abundant molds of plant stems. The tufa is no longer being deposited, and the river has cut through the deposit and flows on bedrock. The colluvium forms smooth slopes that merge with alluvium.

STRUCTURAL GEOLOGY

The dominant structural features of the Hot Springs quadrangle are the Dudley and Cascade Springs anticlines. The Dudley anticline, trending north in the central part of the quadrangle, is an asymmetrical anticline with a steep west limb. It has an amplitude of as much as 600 feet and probably over 100 feet of closure in the NE¼ sec. 8, T. 7 S., R. 6 E. The nose of the anticline is at the south boundary of the quadrangle, and the anticline extends north of the quadrangle with an amplitude of slightly more than 50 feet.

The northeastern part of the Cascade Springs anticline trends northeastward across the northwestern part of the quadrangle. Although the fold is of low amplitude and is fairly symmetrical within the Hot Springs quadrangle, southwest of the quadrangle it increases in amplitude and becomes asymmetrical with a steep west limb. In the adjacent Minnekahta NE quadrangle, it has an amplitude of as much as 1,300 feet and about 650 feet of closure on the top of the Minnekahta Limestone as determined from the saddle in sec. 2, T. 7 S., R. 5 E., of the Hot Springs quadrangle.

Many minor structural features are also present in the quadrangle, but most of them seem to be due to subsidence rather than to tectonic activity. The removal of more than 200 feet of anhydrite from the upper part of the Minnelusa Formation has affected overlying rocks in varying degrees. The undulatory surface of the Minnekahta Limestone, some of the apparent structural features in gypsum beds within the Spearfish Formation, the isolated downdropped blocks of the Canyon Springs Sandstone Member of the Sundance Formation, and isolated structural features in Cretaceous rocks described below are all probably caused by subsidence following the removal of sulfate beds from the Minnelusa Formation.

Subsidence structural features in the Cretaceous rocks are not so abundant and widespread as in the older rocks. The following features are interpreted as having resulted from the removal of sulfate beds within the Minnelusa Formation. Two recent large sinkholes, locally called the "Lost Wells," occur in the Chilson Member of the Lakota Formation along the line between secs. 35 and 36, T. 7 S., R. 5 E. These nearly circular sandstone-walled depressions are over 100 feet in diameter; the western one is about 60 feet deep, and the eastern about 30 feet deep. In Spring Canyon in the east-central part of the quadrangle, the Minnewaste Limestone Member of the Lakota Formation has been lowered more than 200 feet from its normal position. The graben and associated faulting on Battle Mountain are related structural features.

ECONOMIC GEOLOGY

The major mineral resources of the quadrangle which have been utilized are sandstone, limestone, gravel, and mineralized waters from the hot springs. Potential resources include gypsum and bentonite.

The town of Hot Springs originated as a result of the recognition and utilization of the hot waters. Two spas were built on springs within the city, and Hot Springs became a resort in the early 20th century. In 1959 one spa was still operating.

Many of the buildings within the city were built of sandstone which was quarried within the quadrangle. Most of the building stone was quarried from the Fall River Formation, but some was quarried from the Unkpapa Sandstone. Limestone from the Minnekahta Limestone has been used for riprap in the construction of Cold Brook Dam, and it was also being quarried for aggregate in 1959. Gravel and locally sand have been excavated from the terrace gravels for use as aggregate. Large reserves of gravel are present in the terrace deposits in the southeastern part of the quadrangle.

There is a large supply of gypsum in the gypsiferous unit of the Spearfish Formation, but it is not being utilized now because of the great distance to markets. The 2-foot-thick bentonite bed in the lower part of the Greenhorn Formation may eventually be of economic interest.

Uranium deposits occur in rocks of the Inyan Kara Group in areas west of the Hot Springs quadrangle (Gott and Schnabel, 1963), but none were found during the mapping of the quadrangle. Commercial deposits of uranium may exist in the mapped area, and the most likely locality for prospecting seems to be in the southeastern part of the quadrangle where the Inyan Kara Group is overlain by younger formations.

No oil or gas test wells are known to have been drilled within the quadrangle, but two dry holes resulted from tests in adjacent quadrangles. One of these was drilled about 1 mile west of the town of Hot Springs in the Minnekahta NE quadrangle. The test well was on the Cascade Springs anticline and reached the Minnelusa Formation. The other dry hole was drilled a few miles north of the Hot Springs quadrangle in the Wind Cave quadrangle. The hole was on a small anticline, which may be a continuation of the Dudley anticline, and penetrated the Minnelusa Formation.

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