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THE BLACK HILLS

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THE BLACK HILLS

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CONTENTS

ILLUSTRATIONS

THE BLACK HILLS

GENERAL GEOLOGY

By Cleophas C. O'Harra

About 100 miles (161 kilometers) east of the Rocky Mountain front ranges, the Black Hills of western South Dakota and eastern Wyoming rise, islandlike, several thousand feet above the surrounding Great Plains. (See fig. 1.) This mountainous unit about 120 miles (193 kilometers) long and 60 miles (97 kilometers) wide, trends slightly west of north and is an elongate dome-shaped uplift with an eroded pre-Cambrian core comprising a great thickness and variety of highly folded schists, sedimentary in the main but in part igneous, intricately invaded in the southern hills by large and small masses of granite. Flanking this Algonkian mass are the upturned truncated edges of sedimentary formations ranging in age from Upper Cambrian to Tertiary, which dip, in general, away from the central core and toward the plains. Two branches of the Cheyenne River nearly encircle the Black Hills and receive from them many tributaries.

GEOMORPHIC UNITS

Four convenient geomorphic units are recognized as the result of differential erosion in the region (pl. 1)—(1) the central pre-Cambrian nucleus of rugged mountains; (2) a prominent Carboniferous limestone plateau surrounding the inner mountains and in many places rising considerably above the crystalline rocks, its outward dip slope descending to the third unit; (3) the Red Valley, sometimes called the "racetrack," carved chiefly from Triassic red shales; (4) the hogback ridge of Cretaceous sandstone, which presents a bold inward escarpment to the Red Valley and declines down its own dip slope into the surrounding plains. Many streams radiating from the Black Hills cut through this cuesta and divide it into long ridges.

The Algonkian mass (see fig. 2) exposed in the center of the Black Hills consists of igneous and sedimentary metamorphic rocks, invaded by granite (locally gneissoid) and pegmatite. Most of this complex core is composed of the metamorphosed

equivalents of conglomerate, grit, sandstone, shale, and limestone. Metamorphosed igneous rocks (amphibolites) derived from intrusive diorite and gabbro are locally present.

During or after the deposition of the Algonkian sediments diorite and gabbro were intruded. Subsequent crustal move-

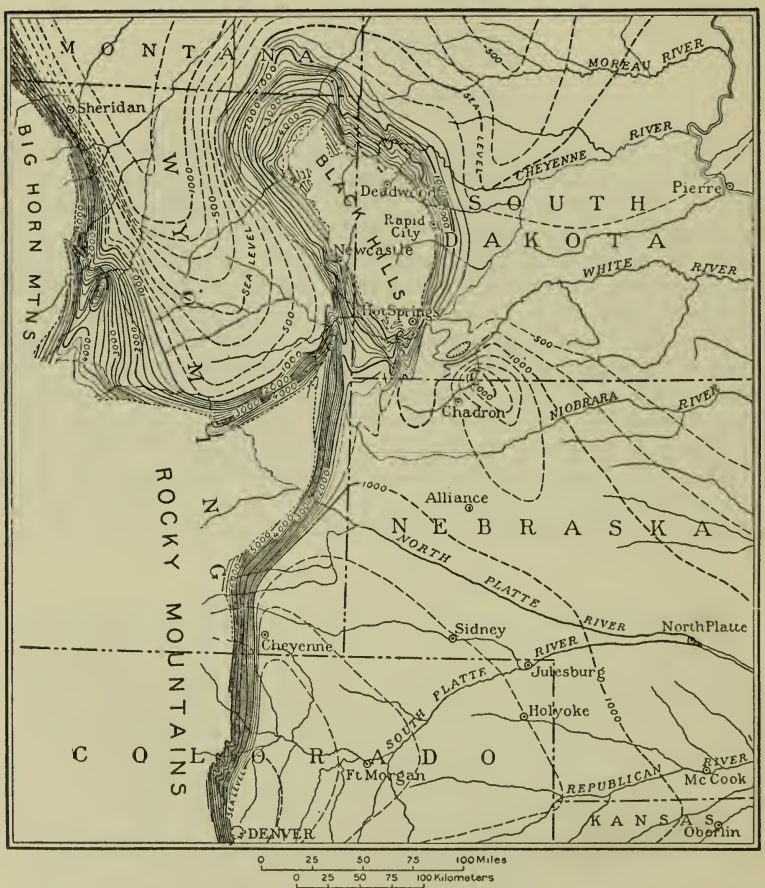

FIGURE 1.—Map showing structure of the Rocky Mountain front and the Black Hills uplift. By N. H. Darton. Contours are drawn on the Dakota sandstone and are not shown where that formation has eroded. Broken lines are hypothetical. Contour interval 250 feet

ments deformed the rocks into many great complex north-northwest folds. The shales and sandstones were changed to schists, slates, and quartzites, and the diorites and gabbros to

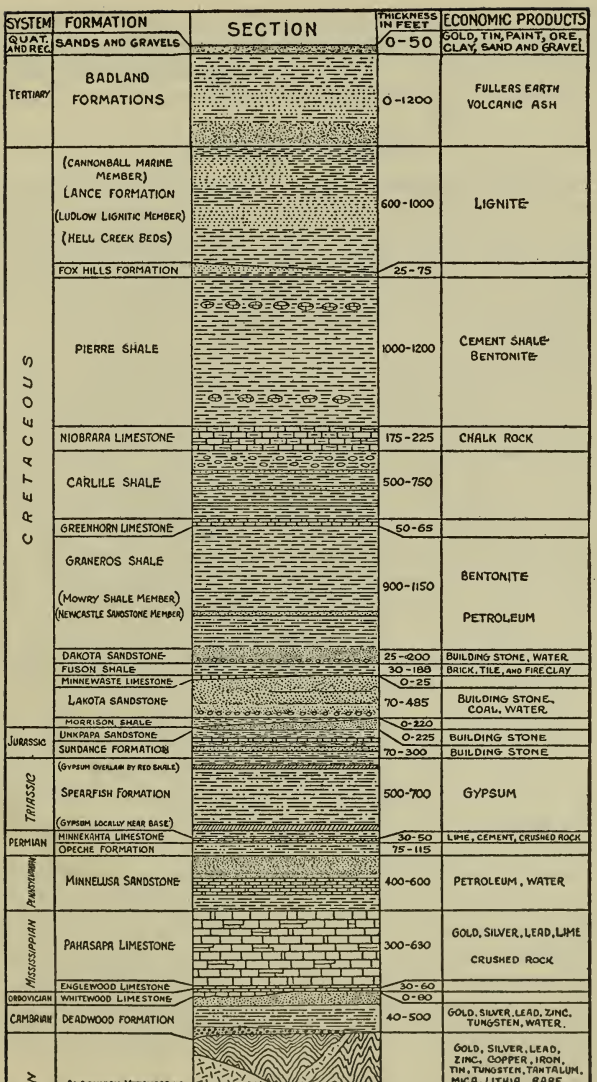

FIGURE 2.—Generalized columnar section of the Black Hills

amphibolites. Contemporary with the general folding, or slightly later, granite was intruded in the Harney Peak region. A series of concentric folds occurs around the periphery of the granite, with axial planes nearly parallel to the intrusive contact.

GEOLOGIC HISTORY

Upper Cambrian submergence.—The region was planed down during early Cambrian time and then gradually submerged under the Upper Cambrian sea. The Deadwood formation, from 40 to 500 feet (12 to 152 meters) thick, was deposited upon the relatively smooth surface cut on the schists and granites, although there were a few local shallow channels and low projecting ridges.

Ordovician to Devonian.—The time between the upper Cambrian and the beginning of Carboniferous deposition is represented only by the Whitewood limestone, of late Ordovician (Richmond) age. This formation is confined to the northern part of the area, where it attains a thickness of 80 feet (24 meters). If additional sediments were deposited during this interval they were eroded before Carboniferous time, leaving no evidence either of their former presence or of their removal.

Carboniferous.—Early Carboniferous submergence is recorded by several hundred feet of Mississippian (Englewood and Pahasapa) limestones (fig. 2), which now form the high limestone plateau. There is a hiatus at the top of these beds, but later Carboniferous (Pennsylvanian) deposits include thick regular beds of marine sandstone, shale, and limestone (Minnelusa). The next stage was marked by uplift and the accumulation of a thin red shale (Opeche formation), probably of Permian (latest Carboniferous) age, and a thin limestone (Minnekahta) whose fossils do not show with certainty whether it is Permian or Triassic.

Triassic.—A resumption of "red bed" deposition resulted in the accumulation of 700 feet (213 meters) of red sandy clay, the Spearfish formation, supposedly of Triassic age. This formation is eroded into the great concentric Red Valley and contains many beds of almost pure gypsum ranging in thickness from a few inches to 30 feet (9 meters), probably the product of evaporation in basins during a period of little rainfall and hence of suspended erosion.

Uplift with consequent planation and channeling followed, representing a portion of Triassic and Jurassic time of unknown duration.

Jurassic.—Alternately shallow and moderately deep marine water covered the region in late Jurassic time, as recorded by sandstone, shale, and fossiliferous limestone (Sundance). An

overlying sandstone (the Unkpapa), irregular and discontinuous in distribution, may have been deposited in fresh water, thereby indicating widespread uplift.

Jurassic or Cretaceous (?).—Unconformably resting upon the Unkpapa and, in its absence, upon the Sundance is the Morrison formation, which contains dinosaur remains and invertebrates. It is uncertain whether this formation is of late Jurassic or early Cretaceous age.

Cretaceous.—During the Cretaceous period thick and extensive deposits were laid down in a great series, beginning with sediments that are characteristic of shallow seas and estuaries along a coastal plain. The indurated Lakota sandstone is of this type and is a controlling factor in the formation of the prominent hogback ridge inclosing the Black Hills. Limestone (Minnewasta) and shale (Fuson) next appear in the stratigraphic column, indicating deeper, quiet marine waters. These sediments are overlain by a coarse sandstone (Fall River), indicative of strong currents. The sandstone contains the earliest American dicotyledonous flora of Upper Cretaceous age. In the succeeding great Upper Cretaceous submergence, which prevailed throughout the Colorado and Pierre epochs, several thousand feet of clay was laid down, with minor intercalations of limestone, bentonite, and sandstone. The withdrawal of the Cretaceous sea during the Fox Hills epoch caused the development of large bodies of brackish and fresh water, which received the sand, clay, and marsh deposits of Lance and later formations, some of which may have extended into early Tertiary time. These Upper Cretaceous formations crop out around the outside of the hogback ridge, and are eroded into gently rolling country which is part of the Great Plains.

Eocene.—The late Cretaceous uplift of the Black Hills continued into early Tertiary time, and the region was the scene of active erosion, which outlined the present topography before the beginning of the Oligocene epoch. Contemporary intrusive bodies of rhyolite, rhyolite porphyry, monzonite, quartz monzonite, phonolite, and grorudite in the form of dikes, sills, plugs, and laccoliths in the northern hills produced marked deformation and consequent topographic features.

Oligocene and post-Oligocene.—Clay and volcanic ash of the White River group (Oligocene) were laid down in sluggish streams and temporary lakes, forming a mantle around the flanks of the hills and in many of the valleys. Erosion has removed the White River sediments from the higher parts of the region, but the extensive and picturesque badlands to the southeast are composed of the same materials and yield numerous vertebrate fossils. Deposits of gravel, sand, and loam

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occupy terraces (chiefly of Pleistocene age) in many valleys in the hills and cover large areas along the divides radiating out from the foothills.

ECONOMIC GEOLOGY

The Black Hills are noted for their mineral wealth. Gold has always been of paramount importance. More than one-eighth of the gold mined annually in the United States is produced in the Black Hills, chiefly in the northern part. The total gold production of the region, beginning with the first mining in 1875, is approximately $300,000,000. Other mineral products raise the value of the total mineral production to more than $350,000,000. In addition to gold, minerals of known or prospective economic importance are silver, lead, copper, iron, tin, and tungsten ores; columbite, tantalite, mica, arsenic, lithia, and cesium minerals; fuller's earth, bentonite, volcanic ash, coal, petroleum, and structural materials.

The central hills are particularly rich in minerals. Some of these have long been of commercial value, and with the rapidly developing need for new minerals in industry others have become increasingly important. Clay, gypsum, cement ingredients, and building stone are abundant in the foothills. To the west there are several productive petroleum fields, and prospective drilling has been active on the south, east, and north. Farther away there are coal beds of great extent. Much of the coal is lignite, but its great areal distribution and the thickness attained by some of the beds suggest an important future source of supply.

CLIMATE

The Black Hills have a modified continental climate, comparatively free from extremes of weather. The annual precipitation within the foothills ranges generally from 18 to 24 inches (46 to 61 centimeters) and the average in the northern hills approximates 28 inches (71 centimeters). Much of the rain falls during the crop-growing season. A forest of western yellow pine, scattered spruces, and scanty underbrush clothes the higher country in evergreen. Parklike groves with a variety and profusion of flowering plants connect with the wooded fringes along the distant foothills.

WESTERN AND NORTHERN BLACK HILLS

By Cleophas C. O'Harra and Joseph P. Connolly

The excursion to the western and northern hills presents a general introduction to Black Hills structure, topography, and

stratigraphy and includes a visit to the Homestake mine, the largest gold producer in the United States. The route follows United States Highway 85 from Newcastle, Wyoming, through Lead (leed), South Dakota, to Deadwood; State Road 24 to Sturgis; and United States Highway 16 to Rapid City. Mileages are given for a speedometer set at zero at Newcastle. (See fig. 3.)

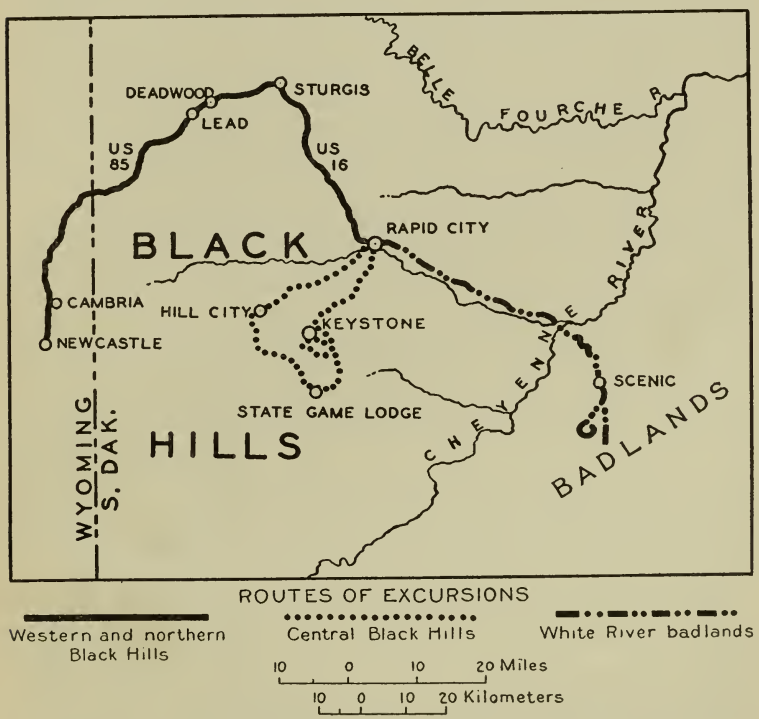


FIGURE 3.—Map showing routes of excursions in the Black Hills

This trip begins near the center of the concave western edge of the bean-shaped Black Hills uplift, at Newcastle, and proceeds in a northeasterly direction. As the strata dip to the west, the observer obliquely traverses successively older formations from the Cretaceous to the pre-Cambrian.

The Pierre shale (Upper Cretaceous, see fig. 2) can be observed south and west of Newcastle. The beds dip gently southwestward and are eroded to an undulating plain that supports only a few drought-resisting shrubs and grasses. Below the Pierre

shale are the Niobrara limestone, the Carlile shale, and the Greenhorn limestone (fig. 2), more steeply inclined toward the southwest and concealed by alluvium south and west of Newcastle. The town of Newcastle is built upon the dark-gray Graneros shale, close to the hogback of Cretaceous sandstone, which encircles the hills and can be seen, clothed in evergreens, north and west of Newcastle. The lower portion of the Graneros shale includes a prominent 40-foot (12-meter) bed of petroleum-bearing sandstone, commonly called the Newcastle sandstone. As the road ascends the hill east of the town the 500-foot (152-meter) ridge made by the Newcastle sandstone can be clearly seen, but before actually crossing this member of the Graneros formation another interesting member may be examined, at 0.5 mile (0.8 kilometer), in the excavation at the left of the road. This is the Mowry shale member (stratigraphically a few feet above the Newcastle), which contains many fish scales.

The basal shales of the Graneros separate the Newcastle sandstone from the main Cretaceous hogback by a line of narrow valleys. The entire thickness of the Graneros is 900 to 1,100 feet (274 to 335 meters).

The Fall River sandstone (so-called Dakota), the outer slope of which comes down to the upper suburbs of Newcastle, crops out over a large, high area north and northwest of the town. Its character may be observed in good exposures at 1.4 miles (2.3 kilometers) on the right of the road. To the southeast this formation is less prominent but is characterized by reddish-brown massive sandstones in the lower part and thin-bedded sandstones in the upper part. In places, as in the high tablelands east of Salt Creek, the formation, 50 to 100 feet (15 to 30 meters) thick, is nearly horizontal and forms vertical cliffs.

The Fuson formation, made up of gray and buff or red and maroon shales, underlies the Fall River sandstone and overlies the Lakota. Its greatest thickness near Newcastle is scarcely 40 feet (12 meters), and its outcrop is generally concealed. Elsewhere in the Black Hills it is much thicker.

From Newcastle toward Lead the highway rises rapidly over the Fall River sandstone and the Fuson formation exposures at the crest of the hogback and comes out upon a considerable area covered by Lakota sandstone. The Fall River and Lakota sandstones resemble each other, and in the early literature they, with accompanying shale beds, were collectively designated Dakota. The early Cretaceous sandstones are excellent aquifers and supply water for many wells in the eastern part of South Dakota.

The Lakota formation is the most prominent sandstone of the Black Hills. Together with the overlying Fall River sandstone,

it forms the great Cretaceous hogback that encircles the uplift. Along and to the east of the automobile highway Salt Creek and its tributaries have cut deeply through the formation and into the underlying beds, leaving detached remnants and promontories of a former high Lakota-capped plateau. Mount Pisgah, on the northern boundary of the Newcastle quadrangle, and Sweetwater Mountain, a little to the northwest in the Sundance quadrangle, are examples of such remnants. West of Salt Creek the plateau, with eastward-facing escarpment, is deeply trenched by several streams. The entire thickness of the formation, 150 to 200 feet (46 to 61 meters) in this locality, is exposed in many places. A massive sandstone constitutes the upper half or more of the formation. Below are dark shales and a 50-foot (15-meter) massive sandstone, underlain by thin-bedded sandstones and carbonaceous shales that contain valuable coal beds. Coal crops out in many places from a point a little north of Newcastle, through Cambria, above Skull Creek, to the vicinity of Aladdin, more than 50 miles (80 kilometers) from Newcastle. Coal mining was carried on in a small way for a number of years at Aladdin, but the main production has been obtained in the immediate vicinity of Cambria, beyond the ridge west from Cambria Park. Mining operations carried on here from 1889 to 1928 on a bed averaging about 5 feet (1.5 meters) in thickness produced approximately 12,500,000 tons (11,339,750 metric tons) of high-grade steaming coal.

As the road descends northward to Salt Creek the narrow horizontal outcrop of the Morrison shale, which underlies the Lakota escarpment, is crossed. The thickness is a little more than 150 feet (46 meters). Across the valley to the east, where the middle and lower portions of remnant table-lands are somewhat gently sloping, the formation covers a considerable area. Elsewhere in the Black Hills the formation has yielded bones of large saurians.

The Sundance formation occupies the floor of the Salt Creek Valley. Its thickness averages approximately 350 feet (107 meters). It has at the top 150 feet (46 meters) or more of dark greenish-gray shales—well exposed on the left of the road at 6.65 miles (10.7 kilometers)—interbedded with thin layers of highly fossiliferous limestones. Below this are reddish sandy shales; a heavy buff sandstone, seen at 7.3 miles (11.7 kilometers); and at the base approximately 60 feet (18 meters) of dark shales. Fossils are abundant. The upper shales carry *Ostrea*, *Avicula*, *Lingula*, *Camptonectes*, *Astarte*, *Trapezium*, *Pleuromya*, *Tancredia*, *Dosinia*, *Saxicava*, *Ammonites cordiformis*, and *Belemnites densus*. The lower shales yield *Pentacrinoides*, *Ostrea*, *Camptonectes*, *Pseudomonotis*, *Psammobia*, and *Belem-*

nites densus. *Belemnites densus*, which is very characteristic of the formation, is most plentiful in the upper shale member, particularly in the sandy layers, and the cigar-shaped pens may be found on weathered outcrops. The outcrop, beginning on lower Salt Creek nearly due east of Newcastle, extends northward in a rather wide, irregular, considerably dissected area and continues to the northwest far beyond the area to be observed.

Salt Creek takes its name from a small group of saline springs in or near the bed of the creek alongside the highway a short distance north of Cambria Park. In the early days of Black Hills settlement the water from the springs was evaporated, and the salt was sold for household consumption within the hills and for chloridizing the gold and silver ores of the Galena district, near Deadwood. The springs vary with the rainy season in salinity and in amount of flow. An analysis of the water made in 1928 at the South Dakota State School of Mines gave slightly less than 3 per cent of sodium chloride. The water is now piped to Cambria Park and is used in connection with the recreational activities there. The springs evidently originate in the Spearfish ("Red Beds") formation (below the Sundance) near its southernmost outcrop in this locality.

The outcrop of the Spearfish gradually widens from the salt springs northward, connects around Mount Pisgah (at 11 miles (17.7 kilometers) on the right) with a broad belt that occupies much of the valley of Stockade Beaver Creek and continues as a wide, irregular, treeless, pronouncedly red area far to the northwest and entirely around the higher Black Hills. The formation consists chiefly of red sandy shales with intercalated beds of gypsum in the lower part and has a thickness of 500 to 600 feet (152 to 183 meters). It shows many erosional prominences, some of which can be seen from the highway, in which the bright-red sandy clays are in striking contrast to the thick accompanying beds of snow-white gypsum. Red Butte (pl. 2, *A*), just east of the highway, near the head of Salt Creek, is a convenient and striking example. It can be seen directly ahead at 11.5 miles (18.5 kilometers) and is passed at 13 miles (20.9 kilometers). This butte of red thin-bedded shales reaches high above its surroundings and is capped by a 30-foot (9-meter) bed of gypsum.

The Minnekahta limestone rises gently to the east along the eastern margin of the Red Valley. Its thickness is only about 40 feet (12 meters), but its dip corresponds closely to the general westerly slope of this part of the hills; hence it shows in places a wide outcrop. Its width along a northeast-southwest line across Canyon Springs Prairie, a little north of the Newcastle-Lead highway, approximates 4 miles (6.4 kilometers). There are good

exposures along the road at 16 miles (25.7 kilometers). This limestone is remarkable for its uniformity of thickness and character throughout its hundreds of miles of outcrop around the Black Hills. It is, moreover, one of the most clearly exposed of all Black Hills formations, and its outcrops are characterized by gentle outward slopes, infacing escarpments, and sharp notches wherever intersected by canyons. The outward slope in many places is rocky and bare and supports only scattering shrubbery or a scant forest growth. Canyon Springs Prairie, with more gentle incline and many undulations, has a deeper soil and in places carries a considerable Pleistocene terrace deposit. Fossils are rarely found in the Minnekahta, and such as have been obtained are not very distinctive. A few fishes of the family Palaeoniscidae have been found near Rapid City. The formation is probably of Permian age.

The Opeche red and purplish-red shales (not to be confused with the Spearfish red shales already described) lie immediately below the Minnekahta. The formation averages less than 80 feet (24 meters) in thickness and generally forms a short slope beneath the Minnekahta escarpment. Exposures may be seen along and near the highway just west of the Wyoming-South Dakota State line, not far from the point where Weston County touches the corners of Lawrence and Pennington Counties. The age of the formation is not definitely known and with the Minnekahta it is regarded as probably Permian.

The outcrop of the Minnelusa (underlying the Minnekahta) where crossed by the Newcastle-Lead highway on the State line at 29.9 miles (48.1 kilometers) is several miles wide. Here the thickness of the formation is about 500 feet (152 meters). It is made up of a heavy, coarse, more or less concretionary sandstone at the top, shale and sandstone and some limestone near the middle, and buff and gray sandstones near the bottom.

The sandstones are very porous. They are the source of many copious springs and supply artesian water for a considerable number of wells. They show petroleum in some localities, especially to the north and south of the area to be visited; and farther west, in favorable structural regions, they yield oil in commercial quantities.

The highway passes onto the great Pahasapa limestone a short distance after entering the State of South Dakota. For many miles down main Spearfish Creek and along its tributaries the formation can be seen in bold vertical or nearly vertical precipices. A quarry may be studied on the left of the road at 33.7 miles (54.2 kilometers). The formation is a massive-bedded light-gray limestone and in Spearfish Canyon is more than 600 feet (183 meters) thick. It contains innumerable cavities,

lined generally with crystals of calcium carbonate. These cavities show a wide range in size and include very large underground caverns, some of which—for example, Wind Cave, north of Hot Springs; Crystal Cave and Wonderland Cave, near Piedmont; and Jewel Cave, west of Custer—have several miles of tortuous crystal-decked galleries. The Pahasapa contains many fossils, chiefly brachiopods and corals. The most abundant among these are *Syringopora*, *Leptaena*, *Schuchertella*, *Chonetes*, *Productus*, *Spirifer*, and *Syringothyris*. They indicate that the formation is of lower Mississippian age.

Immediately below the Pahasapa is the Englewood limestone, which, in Spearfish Canyon, is little more than 40 feet (12 meters) thick. The limestone is pinkish to purplish gray, locally yellow, is thin bedded, and in places partakes of the nature of shale. It contains many brachiopods and some corals, of lower Mississippian age. The outcrop is commonly pretty well covered by talus but can be located near the mouth of Hellgate Canyon, at 44.6 miles (71.8 kilometers).

The Whitewood limestone, of Ordovician age, one of the less widely distributed formations of the Black Hills but of considerable extent in the northern part of the uplift, lies below the Englewood. It reaches a thickness of 60 to 80 feet (18 to 24 meters) in places but thins southward and practically disappears along the highway at Spearfish crossing. It has afforded many fossils, including *Receptaculites*, *Maclurina*, *Endoceras*, *Halysites*, *Dalmanella*, *Buthotrephis*, and *Hormotoma*.

The Deadwood formation, the lowest of the sedimentary units, forms the floor of Spearfish and East Spearfish Canyons for many miles and, rising over the pre-Cambrian metamorphic rocks, crops out in a long, narrow, irregular belt that passes entirely around the structural dome. On the east side it joins the outcrop on the north in irregular manner across the much disturbed intruded area near the center of which are Deadwood and Lead.

Three main divisions are easily seen in the Deadwood formation—a lower brownish or buff coarse quartzitic sandstone or quartzite, conglomeratic at the base; a middle, less indurated portion made up chiefly of thin-bedded sandy glauconitic shales (seen at 48.9 miles (78.7 kilometers) on the left of the road), or limy beds that are in places more or less filled with flat calcareous pebbles; and an upper massive buff or reddish sandstone, which, like the lower member, is locally quartzitic. In places the upper sandstone is overlain by several feet of thin greenish shales, at the top of which a thin sandstone appears here and there.

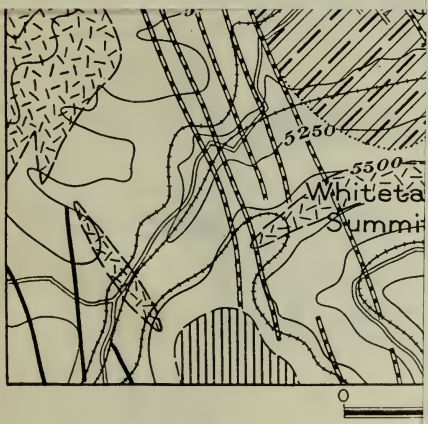
The thickness of the Deadwood ranges from 40 feet (12 meters) or less in the southeastern part of the Black Hills to 500 feet

BIRD'S-EYE VIEW OF THE BLACK HILLS

By Jenney-Newton survey, 1875.

A. RED BUTTE, NEAR THE HEAD OF SALT CREEK, WYOMING
Red Triassic shale capped by 30 feet of gypsum. Photograph by C. C. O'Harra.

B. SPODUMENE CRYSTALS, ETTA MINE
Photograph by C. C. O'Harra.



Tertiary porphyry

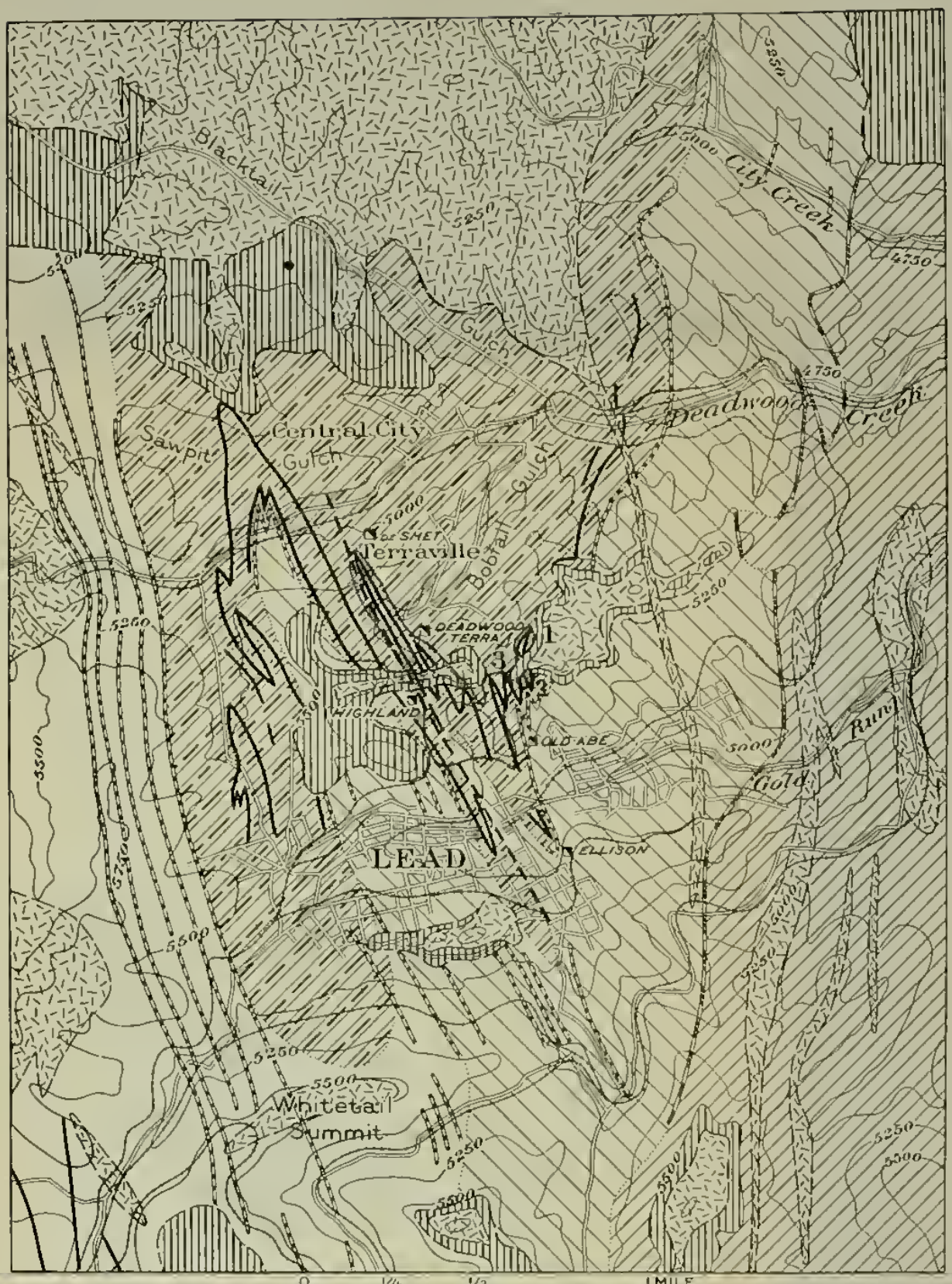
Calcareous and dolomitic schists, including cummingtonite beds shown by solid lines

Cambrian sediments

Biotite schist and slate

GEOLOGIC MAP OF TH

By Sidney Paige, L. B. Wright, a



EXPLANATION

PRE-CAMBRIAN

Tertiary porphyry

Calcareous and dolomitic schists, including cummingtonite beds shown by solid lines

Quartz-pyrite replacement veins accompanied by quartzite

Quartzite beds

Outline of open cuts
1, Caledonia cut
2, Claire cut
3, Hercules cut

Cambrian sediments

Biotite schist and slate

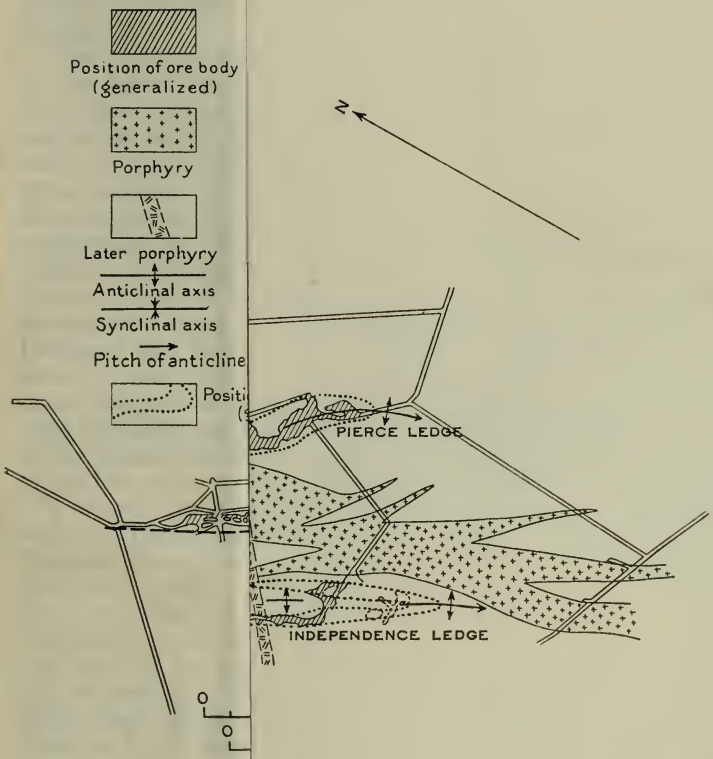
Undifferentiated pre-Cambrian

Garnetiferous biotite schist

Shear zone

GEOLOGIC MAP OF THE VICINITY OF LEAD, SOUTH DAKOTA

By Sidney Paige, L. B. Wright, and Joseph Hosted (U. S. Geol. Survey Bull. 765, pl. 1, 1924).


Position of ore body
(generalized)
Porphyry
Later porphyry
Anticlinal axis
Synclinal axis
Pitch of anticline
N
PIERCE LEDGE
INDEPENDENCE LEDGE
0
0

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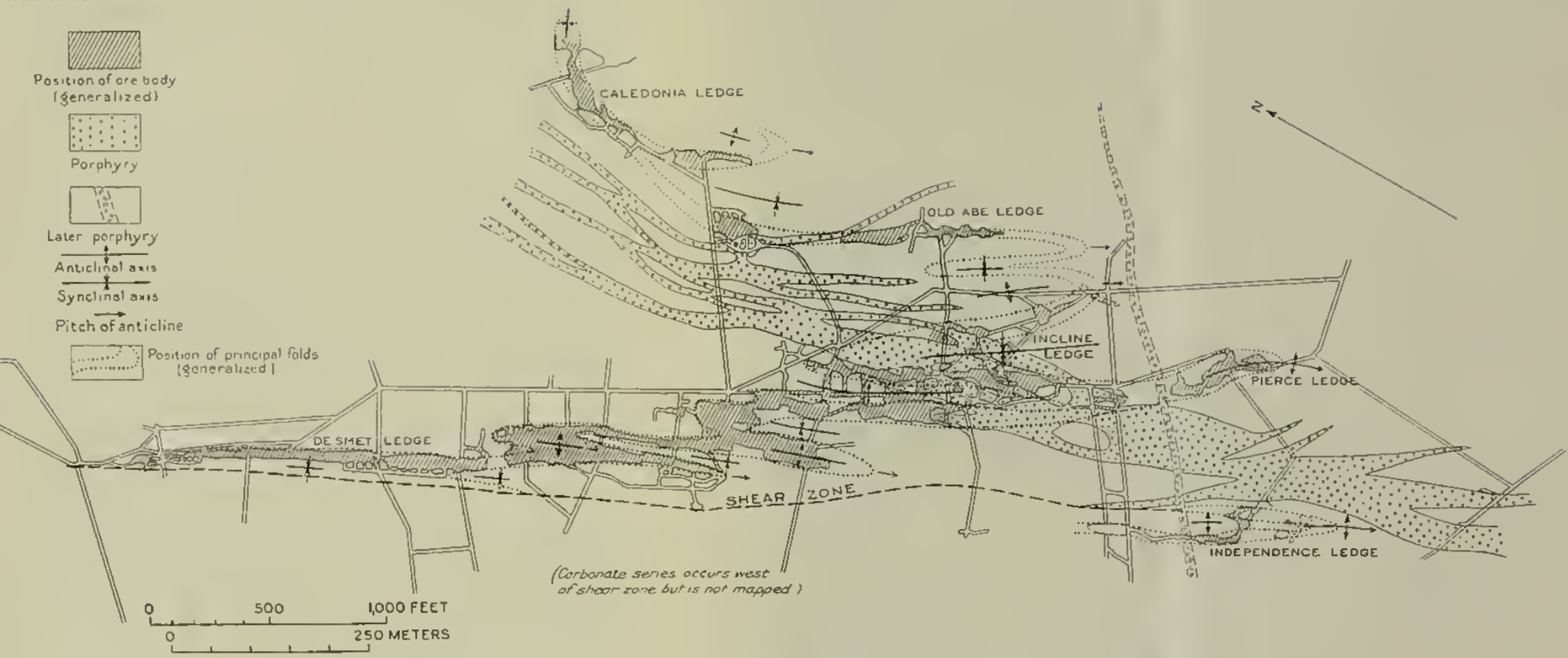


GENERALIZED PLAN OF THE 300-FOOT LEVEL OF THE HOMESTAKE MINE

By Sidney Paige, L. B. Wright, and Joseph Hosted (U. S. Geol. Survey Bull. 765, pl. 8, 1924).

(152 meters) or more in the northern part. Near Deadwood the basal member averages about 40 feet (12 meters), the middle member more than 300 feet (91 meters), and the upper member 50 feet (15 meters). Fossils are abundant and well preserved in many places and occur at many horizons. They are chiefly brachiopods and trilobites and are of Upper Cambrian (St. Croixan) age. The basal sandstone has yielded *Dicellomus*, *Lingulella*, *Hyolithes*, *Ptychoparia*, and fucoids. In the medial member are found *Asaphiscus*, *Ptychoparia*, *Acrotreta*, and *Lingulella*.

Gold, in part free gold in the form of a fossil placer, occurs in the basal conglomerate near Deadwood, and in the early days the conglomerate was extensively mined. Gold occurs also in the middle member, but, unlike that of the basal conglomerate, it is refractory, particularly in the rocks that have not been subjected to oxidizing influences. Gold occurs at several horizons in the dolomitic beds but is most abundant in the dolomitic shales that lie just above the quartzite of the lower member. The ores occurring just above the lower member are called lower contact ores, and those occurring near or at the top of the shales beneath the upper quartzite are called upper contact ores. Ore bodies in the Bald Mountain and Ruby Basin district, southwest of Lead, have been mined for many years and have yielded many millions of dollars. They are less actively worked now than in years gone by, when the oxidized ores were being extensively mined, but there is still a large reserve of material that is of too low grade to constitute ore under present conditions.

The ores are closely associated with the Tertiary intrusive rocks of the district and replace the dolomitic shales. The channels through which replacement was started are numerous fractures, usually vertical, arranged in well-defined systems. The ore bodies are in the form of elongated shoots, or irregular channel-like bodies. The vertical dimension is limited by the thickness of the replaceable beds of rock, rarely more than 20 feet (6 meters). The width may reach many feet, especially where there has been a parallel or interlocking system of fractures, and the length may reach many hundreds of feet. (See fig. 4.)

The Pahasapa limestone has also yielded gold and silver near Spearfish Canyon, and the Deadwood formation in addition to gold has produced more than a million dollars' worth of tungsten.

The Homestake mine, in the pre-Cambrian metamorphic rocks, has been actively and continuously operating for more than 50 years. Its annual output for many years has averaged about $6,000,000 and in 1930 was nearly $8,500,000. The total production to the end of 1930 was $233,631,657.92.

The mine lies almost wholly within the pre-Cambrian metamorphic rocks, chiefly schists, with minor beds of quartzite. (See pls. 3 and 4.) The schists are made up of three main beds and several minor beds. From east to west in descending order, according to Paige (30),[1] they comprise the following members: (1) Biotitic schist and slate, exposed chiefly around Deadwood and farther west. They are generally siliceous with varying proportions of feldspar, biotite, and sericite. They are not generally favorable for ore deposition. (2) A thin layer of quartzite accompanying slate and locally carrying much pyrite. It weathers to a siliceous limonitic gossan and in places stands up above the general surface; hence the local name "iron dike." It is of importance in deciphering the Homestake structure but does not occur within the mine proper. (3) Garnetiferous and

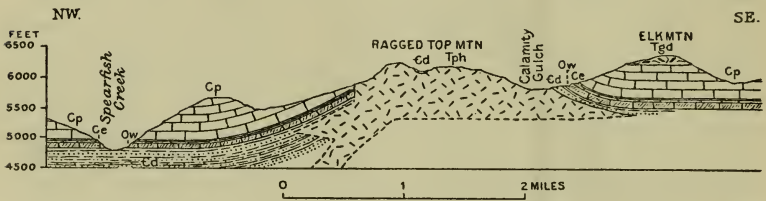


FIGURE 4.—Section from Spearfish Creek through Ragged Top laccolith to Elk Mountain. Cd, Deadwood formation; Ow, Whitewood limestone; Ce, Englewood limestone; Cp, Pahasapa limestone; Tph, intrusive phonolite; Tgd, intrusive grorudite sill

biotitic schists carrying apparently increasing amounts of iron magnesium, and calcium carbonate. (4) Thin layers of quartzite embedded in slate, important as a structural guide and recognized in the mine. (5) A series of argillaceous slate, dolomitic and calcareous slate, and schist. The carbonate schists of this series are of many varieties and besides iron, magnesium, and calcium carbonate carry biotite, sericite, phlogopite, chlorite, amphibole (cummingtonite), garnet, quartz, sulphides, and gold. These schists, the metamorphic equivalents of impure dolomitic iron-bearing rocks, are the main carriers of the gold.

The schists have been compressed into a great complex syncline known as the Lead synclinorium and a great complex anticline known as the Homestake anticlinorium. (See fig. 5.) On the flanks of these major folds are superimposed many folds of secondary, tertiary, and lower orders, which are in

[1] Numbers in parentheses refer to bibliography, p. 27.

some places tightly compressed, drawn thin, or even squeezed out entirely and in other places greatly refolded and thickened.

The gangue minerals of the ore are cummingtonite, chlorite, biotite, quartz, iron-magnesium carbonates, some calcite, a little garnet, and a very small amount of fluorite. The ore minerals are arsenopyrite, pyrrhotite, pyrite, magnetite, specularite, chalcopyrite, gold carrying low silver, and minute amounts of galena, sphalerite, and a bismuth telluride.

The starting point for the formation of this complex assemblage of minerals was a bed of sedimentary iron-magnesium carbonate (30) with some silica in the form of sand grains or

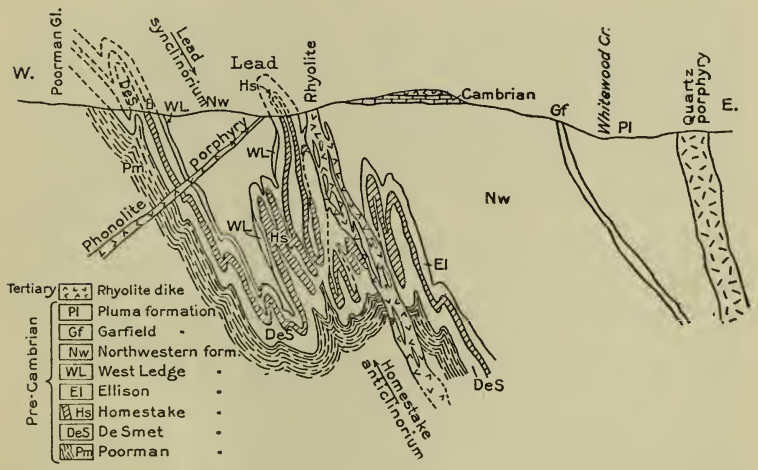


FIGURE 5.—Geologic structure section of the Homestake district. By J. O. Hosted and L. B. Wright (Eng. and Min. Jour.-Press, vol. 115, p. 836, 1923)

chert concretions. During pre-Cambrian time this sedimentary bed, together with adjacent beds, was intensely folded and metamorphosed. It is very probable that simultaneously with the folding and probably after the folding this bed was attacked by mineralizing solutions of the deep-seated type, at high temperatures and under high pressures, which deposited the ore and gangue minerals, chiefly by introduction of the ore-forming constituents but in part, perhaps, by the recrystallization of the siliceous magnesian siderite to form iron-magnesium silicates. Although the sulphide minerals are in general later than the silicates, they clearly belong to the same period of mineralization, as they are overlapped to some extent by the silicates. Most of the gold is contemporaneous with the sulphide minerals, but a small proportion of it is later and may be much later.

Tertiary intrusives that have modified the structure of the northern hills and have been instrumental in forming the so-called siliceous ores of the Deadwood formation and to a lesser extent the Pahasapa limestone are rare in the Homestake ore bodies. Surface flows and several clearly defined dikes are well shown in the big open cut, but it is believed that the gold was deposited at least in chief part, during pre-Cambrian time (3, 15).

In going from Lead down along Gold Run and Whitewood Creek to Deadwood the traveler sees a considerable series of schists, including a pyrite-bearing belt from which pyrite and pyrrhotite were once mined. Near Pluma, at 58.4 miles (94 kilometers), an excellently defined porphyry dike can be seen at the left of the highway. The "White Rocks," first seen straight ahead at 59.1 miles (95.1 kilometers), on the high point east of Deadwood, are remnants of the Pahasapa, and below them the Deadwood formation shows as a projecting brown prominence. East of the Chicago & North Western Railway freight depot at Deadwood (60.1 miles, or 96.7 kilometers), immediately above the rails, the Deadwood-Algonkian contact is clearly shown. Near the lower end of the town the middle beds of the Deadwood are well exposed in a high vertical cliff on the left, and farther down along State Highway 24, which branches to the right from United States Highway 85 at 60 miles (96.6 kilometers), near the old smelter slag pile by Whitewood Creek (61.4 miles, or 98.8 kilometers), there are good exposures of the Whitewood and Englewood formations.

From Whitewood Creek the highway continues east up over an open area capped for 3 or 4 miles (4.8 to 6.4 kilometers) by Oligocene gravel. Later regional tilting here diverted the drainage to the north and formed the lower portion of Whitewood Creek. The anticlinal Rainbow Cliff is seen at 69 miles (111 kilometers). Farther on the route passes successively exposures of the Pahasapa, Minnelusa, Opeche, and Minnekahta, through Boulder Canyon into the open Red Valley to Sturgis, at 72.5 miles (116.7 kilometers). An interesting side trip up over the hill east of Sturgis permits a view of Bear Butte.

From Sturgis the highway goes along the valley in a south-southeasterly direction to Rapid City, with the Minnekahta limestone showing almost continuously on the right side and the main Cretaceous hogback on the left. All the formations concerned conform fairly closely in general character to the descriptions given for the west side of the Black Hills, which need not be repeated. The typical form of the Red Valley and the inclosing heights are well shown, and in many places within the valley there are flat-topped gravel-capped elevations or

terraces that are remnants of Pleistocene stream deposition. In places large boulders have been washed out from the canyons and spread out upon the floor of the valley. South of Blackhawk the highway goes to the west of an elongated fold of the Minnekahta, then turns eastward across the Red Valley and, following Rapid Creek for a short distance, passes through a gap in the Cretaceous hogback and reaches Rapid City.

CENTRAL BLACK HILLS

By Joseph P. Connolly

The excursion to the central part of the Black Hills (fig. 3) goes from Rapid City to Keystone, Mount Coolidge, Mount Rushmore, State Game Lodge, Sylvan Lake, and Hill City and then back to Rapid City. This trip is mainly within the area of pre-Cambrian (Algonkian) igneous and metamorphic rocks that compose the central core of the Black Hills. Brief glimpses of some of the sediments of Paleozoic, Mesozoic and Cenozoic age will be obtained on the way.

The road starts south from Rapid City over the Graneros shale (Upper Cretaceous). Within 0.6 mile (1 kilometer) it turns and begins to climb the slope of the outer hogback ridge that encircles the Black Hills, and in the gulches on each side can be seen exposures of the Fall River sandstone. From the top of the wide, nearly flat-topped ridge at 1.5 miles (2.4 kilometers) an excellent view of the plains country to the east is afforded, and if the day is clear the Badlands can be seen in the distance. The road, following a general southerly direction, passes over a fairly extensive inlier of part of these same Tertiary White River sediments which make up the Badlands and which here lie unconformably upon the upturned and eroded edges of the Mesozoic formations. At 6.5 miles (10.5 kilometers) a descent is made into the valley of Spring Creek, where the Jurassic (Sundance) sandstone and the Triassic red beds are exposed. As the road rises again beyond Spring Creek it goes through the thin-bedded, somewhat crumpled Minnekahta limestone (Permian?) and, running nearly across the strike of the rocks, traverses in turn the Pennsylvanian, Mississippian, and Cambrian formations. Harney Peak and the Needles can be seen in the distance from the higher parts of the road. The outcropping edges of the steeply inclined pre-Cambrian metamorphic rocks are exposed to view just before Rockerville is reached. Rockerville (11.5 miles, or 18.5 kilometers) was the site of important gold mining in the earlier days of Black Hills history. The gold was won chiefly from stream placers but in

part from the Cambrian conglomerates lying on the higher parts of the adjacent hills, unconformably above the pre-Cambrian schists. There is still some placer mining in this vicinity.

At Keystone (23 miles, or 37 kilometers) the oldest country rock consists of the Algonkian metamorphic rocks, slates, schists of various kinds, and quartzites, with some amphibolites. These have a generally northerly strike, with dip of 80° E. to 90°, but there are many local variations in strike, due in part to the intrusions of the pegmatite. Considerable faulting of the rocks, accompanied by much shearing, brecciation, and the formation of gouge, has added to the complexity of the region.

Just before the main part of the town of Keystone is reached (22.5 miles or 36.2 kilometers) there can be seen on the right, part way up the hill, the adit and open cut of the Bullion gold mine, and on the left the headframe at the shaft of the Columbia mine. The Bullion and Columbia ore bodies may be continuous under Battle Creek. These ore bodies are combinations of lenticular veins and replacement deposits in the wall rock in shear zones on the footwall side of amphibolite dikes. The gold occurs as very fine particles of free metal, partly in the quartz-chlorite-amphibole gangue but chiefly as included grains in arsenopyrite.

A little farther along the road (23 miles, or 37 kilometers), on the hill to the right, behind the mill building, is the shaft of the Holy Terror mine, famous for its richness and for the beauty of the gold-quartz specimens it has yielded. All the gold-quartz and gold-arsenic deposits of the district appear to have been formed at the same time and under deep-seated, high-temperature, or hypothermal conditions.

Shortly before Battle Creek is crossed (23.5 miles, or 38 kilometers) there will be seen, on the left, the grinding plant of the Keystone Feldspar Co., a subsidiary of the Consolidated Feldspar Corporation. This mill has an average capacity of about 500 tons (453 metric tons) a month. It is operating chiefly upon feldspar from the Hugo mine.

A little way up the valley of Grizzly Bear Creek there is a distant but excellent view of Mount Rushmore, a mass of granite on which are being carved colossal figures of Washington, Jefferson, Lincoln, and Roosevelt.

The Etta mine (24 miles, or 38.6 kilometers), a little less than 1 mile (1.6 kilometers) south of Keystone, is particularly remarkable because of the occurrence of spodumene crystals of huge size (unequaled in any other known locality) and the many rare minerals that have been found there. More than 60 different species of minerals have been reported from this one mine. The mine is located in a small stock or knob of coarse granite pegmatite intruded into the country rock of mica schist. This knob,

because of its superior hardness, once stood about 300 feet (91 meters) above the adjacent stream valleys. Much of the original height has been destroyed by open-cut mining operations and slumping at the summit. (See fig. 6.) This pegmatite body is roughly circular in plan, somewhat oval (fig. 7), with dimensions of about 200 by 225 feet (61 by 69 meters) on the first underground level. A rude banding or concentric arrangement of the minerals occurs in places, the different bands grading into one another without sharp demarcation. This was particularly true of the upper part of the mass but is not now discernible except for the "mica selvage" zone adjacent to the schist country rock. The mineral of chief commercial importance and of

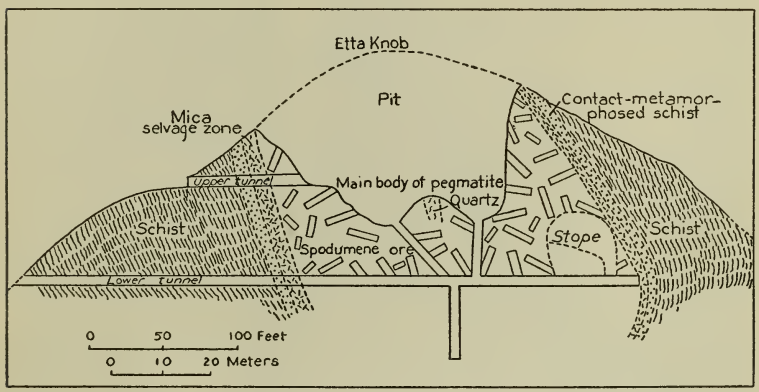


FIGURE 6.—Cross section of the Etta pegmatite along line of lower tunnel. By G. M. Schwartz (Econ. Geology, vol. 20, p. 653, 1925)

greatest interest is the spodumene. This mineral occurs in crystals many of which have well-developed prismatic or pinacoidal faces but few of which show end terminations. They are variable in size: some are only a few inches long, most of them several feet. (See pl. 2, *B*.) Lengths of 8 to 10 feet (2.4 to 3 meters) are very common. The largest crystal on record was uncovered in 1904 and was about 47 feet (14 meters) long. The spodumene crystals lie at all angles in the pegmatite mass, and in the walls of the open cut and the underground workings they look so much like timbers that it has become customary to refer to them as "logs." After the rock is broken down in the mining operations the spodumene is hand sorted and hauled by truck to the railroad station at Keystone. Thence it is shipped to the chemical works at Maywood, New Jersey, where various lithium compounds are manufactured.

Many other minerals of interest have been found in the Etta mine. In the following partial list of those more commonly found the most abundant are indicated by italics: *Albite*, andalusite, *apatite*, arsenopyrite, autunite, barite, beryl, *biotite*, bismuth, *cassiterite*, chalcocite, columbite, corundum, epidote,

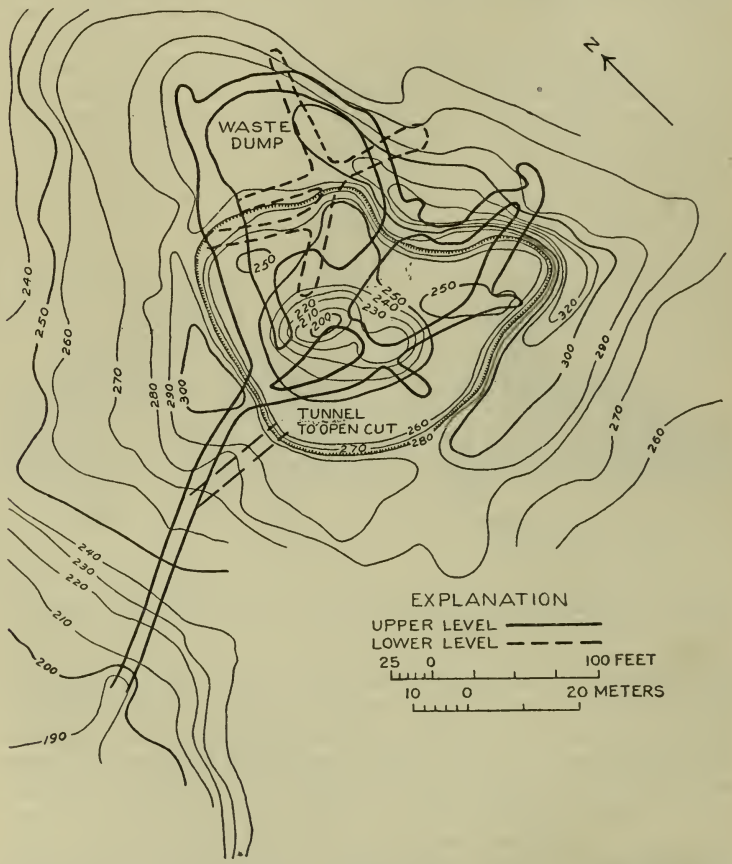
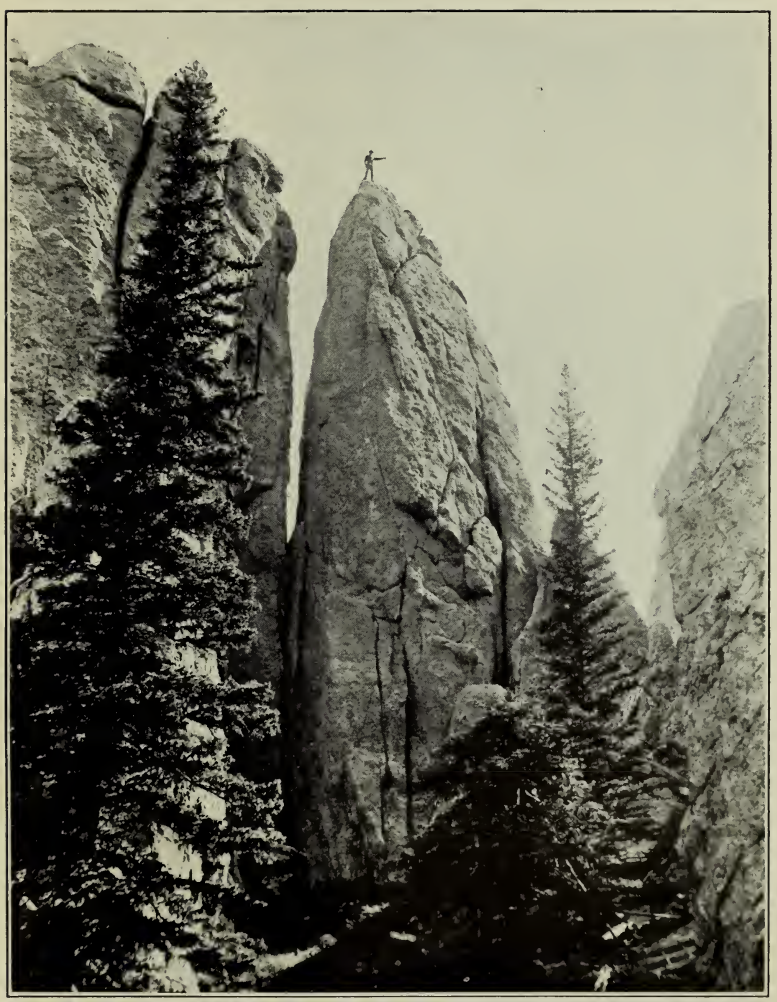


FIGURE 7.—Map of the Etta mine. Surveyed by civil engineering students, South Dakota School of Mines, 1930

graphite, grossularite, heterosite, ilmenite, lepidolite, lithiophilite, *löllingite*, melanite (andradite), *microcline*, molybdenite, monazite, *muscovite*, orthoclase, petalite, *quartz*, rutile, scheelite, scorodite, sphene, spinel, *spodumene*, stannite, struverite, tourmaline, triphylite, triplite, wolframite, zircon.



DETAIL OF THE NEEDLES, SHOWING MANNER OF FORMING BY WEATHERING ALONG JOINT PLANES

Photograph by Henry F. Quiggle.

AIRPLANE VIEW SHOWING GRANITE EXPOSURES ON THE FLANKS OF HARNEY PEAK

VIEW LOOKING SOUTH FROM SHEEP MOUNTAIN, WHITE RIVER BADLANDS

Photograph by Lease, Lead, South Dakota.

About 1,800 feet (549 meters) west of the Etta mine is the Hugo mine, the chief feldspar producer of the Black Hills region. The ore of this mine is a tabular pegmatite body striking nearly east, with a steep dip, averaging about 80°, to the north. The body is somewhat irregular in outline, however, and in places the contact relations are obscure. The Hugo pegmatite differs mineralogically from that of the Etta mine in several respects: there is much less spodumene and a more definite segregation of the feldspar (microcline); amblygonite has been found and mined in notable quantities; there appears to be a somewhat greater segregation of muscovite and coarse black tourmaline near the contacts, especially along the footwall side; and considerable lepidolite has been found. Practically all the minerals that have been found in the Etta also occur in the Hugo, and in addition amblygonite, fluorite, galenite, and uraninite have been reported.

There are other interesting pegmatite bodies in the immediate region—for example, the Bob Ingersoll, with its large beryl crystals and massive ledge of purple lepidolite, and the Peerless, which has afforded some excellent commercial feldspar and considerable columbite-tantalite.

From Keystone the route goes southeastward a short distance to the old mining camp of Spokane (spo-can') (27 miles, or 43 kilometers), situated in a region of schists intruded by many pegmatite dikes. There is a body of complex silver-lead-zinc ore here which has been mined intermittently for a number of years. The ore body is a well-defined vein or system of parallel veins striking northwest and dipping about 80° SW.

From Spokane the route proceeds northwestward and after crossing Iron Creek begins a long climb to the top of Iron Mountain. On this climb and from the top of the mountain some of the finest scenery of the Black Hills will be observed. Beyond the tunnel near the crest there is a striking view of Mount Rushmore. The south side of Iron Mountain consists largely of schists and quartzites that have been impregnated with much secondary quartz, pyrrhotite, pyrite, copper sulphides, and other minerals. At and near the surface these sulphide minerals have been oxidized, and the road cuts show the brilliant yellows and reds of the iron oxides, streaked with the blues and greens of oxidized copper minerals. At certain places on the mountain beautiful iridescent limonite occurs, and many handsome specimens from this locality are found in the museums of the country.

Iron Mountain lies well within the boundaries of Custer State Park, which comprises a little more than 125,000 acres. This park is a game sanctuary and affords frequent glimpses of deer, elk, and other native game.

From Iron Mountain to the State Game Lodge (34 miles, or 55 kilometers), the region is largely granite, but many inclusions of schist or other metamorphic rocks are encountered. Mount Coolidge (43 miles, or 69 kilometers) with an excellent road to the observation tower of the summit, stands a little more than 6,000 feet (1,829 meters) above the sea. The rock is largely hard quartzitic schist, resistant to erosion, intruded in places by granite pegmatite. From this point excellent views are had of the surrounding rugged mountain country, of the south side of Harney Peak, and of the plains country to the east and southeast.

The highway leading to the Needles and Sylvan Lake lies within the outcrop of the Harney Peak batholith. The granite is coarse grained and pegmatitic. Exposures of fresh rock in the road cuts are numerous, and the dominant minerals, feldspar, quartz, muscovite, and occasionally tourmaline, can be recognized. Many inclusions or large xenoliths of schist will be noted and recognized as such because they have no regularity of position or attitude. The topography along this route exemplifies in a remarkable way the result of differential weathering and erosion—high rounded domes, residual boulders of decomposition, and perched and balanced rocks sometimes erroneously suggesting glacial erratics. To many people the climax in scenic effects along this highway is at the Needles. These are slender, lofty pinnacles of granite which owe their form and beauty to the weathering and erosion of once solid masses of granite along two or more sets of vertical fractures or joint planes. (See pl. 5.)

Sylvan Lake (60 miles, or 97 kilometers) is a small but beautiful body of water set on the flanks of Harney Peak, partly surrounded by large masses of granite weathered into curious forms. A wide parklike area near the headwaters of a small stream forms the bed of the lake, the water being held by a narrow dam across a cleft in the granite. In the years since the dam has been built the natural environment has so adjusted itself to the lake that few would suspect its artificial origin. The summit of Harney Peak (see pl. 6), the highest point in the Black Hills, and the fire lookout station can be seen from a point near the Sylvan Lake Hotel.

From the hotel the route descends more than a thousand feet, with many sharp turns, to the valley of Spring Creek. Leaving the main granite mass of the batholith, it passes over a country consisting chiefly of metamorphic rocks, arkosic grits, quartzites, and schists, intruded by many smaller masses of granite pegmatite, evidently apophyses from the main mass. Hill City (68 miles, or 109 kilometers) is one of the older mining towns of the Black Hills. It was at one time the center of the tin excitement, and the old tin mill of the Harney Peak Co.

still stands on the outskirts of the town. At present some gold is being mined in this vicinity, both from lodes and from placer deposits.

The route from Hill City to Rapid City follows the valley of Spring Creek for several miles. The rocks exposed are a rather monotonous series of schists and quartzites, for the most part standing at high angles but in a few places lying nearly horizontal. A nearly recumbent fold in the schist may be observed on the right between Hill City and Sheridan (73 miles, or 117 kilometers). A large dike of much altered amphibolite crosses the road at the beginning of the ascent out of the Spring Creek Valley. A few miles beyond the valley the last of the metamorphic rocks is seen, and the route crosses over the Paleozoic and Mesozoic sediments from the Deadwood to the Graneros, which underlies Rapid City (93 miles, or 150 kilometers).

WHITE RIVER BADLANDS

By Glenn L. Jepsen

GEOLOGY

"Mauvaises terres à traverser" wrote the early French traders about the exceedingly rugged treeless areas near the Black Hills, thus appropriating the Dakota Indian term "Mako Sica" (mako, land; sica, bad). Since then "badlands" has gained a recognized place in geomorphic literature and denotes a region intricately dissected by frequent winds and rare but torrential rains.

The "Big Badlands," drained largely by the White River, lie southeast of the Black Hills uplift. Here (see pl. 7) sandstones, clays, and volcanic ashes of Oligocene age are exposed for hundreds of square miles, sculptured by erosive forces into jagged badlands.

These badland areas fringe fertile grassy plateaus, and, several hundred feet below, the broad erosion flats of the present intermittent streams are spotted with sagebrush and cactus, The complex dendritic drainage pattern of the Badlands has been produced by headward erosion into the table-lands which are remnants of a once continous flank of White River (Oligocene) strata surrounding the Black Hills. That this dissection has been alternately accelerated and retarded (possibly reflecting the pulsations of the Black Hills uplift) is indicated by several broad erosion levels or terraces that buttress the plateaus. Rocks of similar age crop out in parts of Colorado and Wyoming.

Paleontologists have collected more than 150 species of petrified animal remains and a few plants from the White River Badlands. No other rocks yield so many diverse kinds of perfectly preserved skulls and skeletons, many of which are now displayed in American and European museums. The abundance and character of the fossils, aided by a study of the sediments themselves, afford an unusual record of the life and environment of Oligocene time in this region.

Long before, in Upper Cretaceous time, the Black Hills mass rose above the sea. Streams radiating from the highlands truncated the slowly upturning edges of the Paleozoic and Mesozoic strata. A scanty occurrence of Paleocene (Fort Union) sediments and the absence of Eocene deposits indicate a hiatus which is marked by an angular unconformity between the Cretaceous and the Oligocene strata. In early White River time the streams ceased active erosion and began filling the depressions with Black Hills detritus.

Along the broad watercourses, backwashes, reed-fringed lakes, and algae-clogged ponds America's earliest alligators dwelt and preyed upon old-fashioned mammals that came to drink. Some partly digested fossil deer bones have been found in the stomach region of a petrified alligator skeleton. In the streams existed fish, snails, unios, and turtles, while the banks were inhabited by aquatic rhinoceroses and by birds (known chiefly from petrified egg shells). Hackberry (*Celtis*) trees flourished. In their respective realms lived cursorial rhinoceroses, three-toed horses (*Mesohippus*), artiodactyls (oreodons and giant piglike animals, *Archaeotherium*), dogs (*Pseudocynodictis* and *Daphoenus*), the oldest known cats (*Hoplophoneus* and *Dinictis*), lizards, and many other animals. The most distinctive creature, however, was the one after whom the horizon has been named, the huge *Titanotherium*. His racial death, after a long vigorous life begun in the early Eocene, marks the end of the earliest subdivision of Oligocene time in America. This horizon is considered coeval with the Sannoisian stage of Europe, because at both are found the genera *Anthracotherium*, *Ancodus*, and *Hyaenodon*.

The light-gray sediments of the "*Titanotherium* beds," or Chadron formation (pl. 7), appear quite different from the buff clays and sandstones of the overlying second or middle division of the White River group, the "*Oreodon* beds," or Brule clays. The latter indicate a much drier climate. Alligators are gone, but the rich mammalian fauna includes rats (*Ischyromys*), mice (*Eumys*), camels (*Poebrotherium*), tapirs, anthracotheres, lophiodonts, and insectivores. The abundance of *Oreodon* remains leads to the belief that the animals must have lived in vast numbers, comparable to the herds of game in modern African pre-

serves. A collector can fill a knapsack with *Oreodon* bones and teeth during a day's search.

The Brule clays are correlative with the Stampian zone of Europe in the common presence of amynodonts, entelodonts, machaerodonts, hyaenodonts, and other groups of mammals.

The uppermost White River element has been called "*Leptauchenia* beds," from the presence of a curious little oreodont, although most of the fauna is composed of advanced varieties of the genera and species that are found in the "*Oreodon* beds" below. In addition to the clays and sandstones, these strata contain much white volcanic ash, glass, and pumice, easily distinguished in the upper part of the section. Through the "*Leptauchenia* beds" at several horizons ancient stream channels of coarse green sandstone containing a fauna distinct from that of the surrounding clay can be traced for miles. The most abundant fossil of these channels is a strange 6-horned ruminant, *Protoceras*.

In places the Oligocene is overlain by Miocene (Arikaree formation) and more recent deposits.

ITINERARY

On this motor trip from Rapid City to Sheep Mountain and return (fig. 3), the observer enters the Badlands near Scenic, at the type locality of the White River sediments, and can see the stratigraphic elements composing this group as well as the unconformable contact below with the Cretaceous shale and the transition above to the Miocene clays, sands, and volcanic ash. Petrified mammal teeth and bones and turtle remains can be collected south of Scenic in the richly fossiliferous "*Oreodon* beds."

The little gravel-strewn hills north and south of the road between Rapid City and Scenic are flat-topped and obviously were once connected into a broad, flat plain that declined gently away from the Black Hills. The present streams are slowly dissecting this old erosion level, sometimes temporarily hesitating and leaving a shoulder or terrace as evidence.

The road to Scenic alternately follows the Rapid Creek flood plain and ascends to the "tables" between tributaries. At 17.7 miles (28.5 kilometers) from Rapid City, just before the road crosses the tracks of the Chicago, Milwaukee, St. Paul & Pacific Railroad, it is possible to see Mount Rushmore, far to the west. In road cuts and fresh erosion exposures along the road the dark-gray Upper Cretaceous marine Pierre shale can be seen.

About 20 miles (32 kilometers) from Rapid City the buttes south of the road are capped with light-colored rocks, and those

on the right at 27 miles (43 kilometers) are called Railroad Buttes in reference to their remote resemblance to a train. They are composed of Oligocene sediments and rest unconformably upon the black Pierre shale.

The road crosses Rapid Creek at 31.1 miles (50 kilometers) and ascends a hill, and at 32.2 miles (51.8 kilometers) the Cheyenne River comes into view. Its broad flood plain is believed to resemble an Oligocene watercourse. In the railroad cut to the right of the motor road typical Pierre invertebrates—*Inoceramus*, *Scaphites*, and *Baculites*—have been found. The cone-in-cone structure and the dark-brown nodules are also to be noted.

After crossing the river and ascending to the flat top of Kube Table the traveler can see, far to the west, the dark profile of the Black Hills. Also to the west is visible the unconformable contact of the black Pierre shale and the light-colored White River sediments.

At 45 miles (72 kilometers) the road descends into the white basin of Bear Creek, to the locality from which the first White River fossils were collected. On the left are bright pink and yellow sediments. They are probably a weathered phase (sometimes called the "Interior formation") of the Pierre, and an idea of the topographic relief at the beginning of *Titanotherium* time can be gained by tracing the irregular, Cretaceous contact. The characteristic "haystack" erosion form of the "*Titanotherium* beds" (Chadron formation) is conspicuous.

Near Scenic the overlying "*Oreodon* beds." with their sharper, more rugged weathering habit, become prominent. The most fossiliferous zone is from 10 to 20 feet (3 to 6 meters) above their base—the so-called turtle-*Oreodon* or red layer, which has yielded many hundred specimens to collectors.

After ascending to the top of Sheep Mountain, 5 miles (8 kilometers) south of Scenic, the third element of the White River group, the "*Leptauchenia* beds" and the included *Protoceras* channels, can be seen, all overlain by a thin Miocene mantle, the Arikaree formation. This completes the following section:

Tertiary:
- Arikaree formation (Miocene), 500–900 feet (152–274 meters).
- White River group (Oligocene):
  - Brule clays (Stampian), 400–600 feet (122–183 meters), including "*Leptauchenia* beds," "*Protoceras* channel sandstones," and *Oreodon* beds.
  - Chadron formation (Sannoisian), 180 feet (55 meters), "*Titanotherium* beds."

Unconformity (hiatus represents Laramide activity).
Cretaceous: Pierre shale.

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