DEPARTMENT OF THE INTERIOR
HUBERT WORK, SECRETARY
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

GEOLOGIC ATLAS

OF THE

UNITED STATES

CENTRAL BLACK HILLS FOLIO

SOUTH DAKOTA

BY

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GEOLOGIC ATLAS OF THE UNITED STATES.

UNITS OF SURVEY AND OF PUBLICATION.

The Geological Survey is making a topographic and a geologic atlas of the United States. The topographic atlas will consist of maps called *atlas sheets*, and the geologic atlas will consist of parts called *folios*. Each folio includes topographic and geologic maps of a certain four-sided area, called a *quadrangle*, or of more than one such area, and a text describing its topographic and geologic features. A quadrangle is limited by parallels and meridians, not by political boundary lines, such as those of States, counties, and townships. Each quadrangle is named from a town or a natural feature within it, and at the sides and corners of each map are printed the names of adjacent quadrangles.

SCALES OF THE MAPS.

On a map drawn to the scale of 1 inch to the mile a linear mile on the ground would be represented by a linear inch on the map, and each square mile of the ground would be represented by a square inch of the map. The scale may be expressed also by a fraction, of which the numerator represents a unit of linear measure on the map and the denominator the corresponding number of like units on the ground. Thus, as there are 63,360 inches in a mile, the scale 1 inch to the mile is expressed by the fraction $\frac{1}{63,360}$, or the ratio 1:63,360.

The three scales most commonly used on the standard maps of the Geological Survey are 1:31,680, 1:62,500, and 1:125,000, 1 inch on the map corresponding approximately to one-half mile, 1 mile, and 2 miles on the ground. On the scale of 1:31,680 a square inch of map surface represents about one-fourth of a square mile of earth surface; on the scale of 1:62,500, about 1 square mile; and on the scale of 1:125,000, about 4 square miles. In general a standard map on the scale of 1:125,000 represents one-fourth of a "square degree"—that is, one-fourth of an area measuring 1 degree of latitude by 1 degree of longitude; one on the scale of 1:62,500 represents one-sixteenth of a "square degree"; and one on the scale of 1:31,680 represents one-sixty-fourth of a "square degree." The areas of the corresponding quadrangles are about 1,000, 250, and 60 square miles, though they differ with the latitude, a "square degree" in the latitude of Boston, for example, being only 3,525 square miles and one in the latitude of Galveston being 4,150 square miles.

FEATURES SHOWN ON THE TOPOGRAPHIC MAPS.

The features represented on the topographic maps comprise three general classes—(1) inequalities of surface, such as plains, plateaus, valleys, hills, and mountains, which collectively make up the *relief* of the area; (2) bodies of water, such as streams, lakes, swamps, tidal flats, and the sea, which collectively make up the *drainage*; (3) such works of man as roads, railroads, buildings, villages, and cities, which collectively are known as *culture*.

Relief.—All altitudes are measured from mean sea level. The heights of many points have been accurately determined, and those of some are given on the map in figures. It is desirable, however, to show the altitude of all parts of the area mapped, the form of the surface, and the grade of all slopes. This is done by contour lines, printed in brown, each representing a certain height above sea level. A contour on the ground passes through points that have the same altitude. One who follows a contour will go neither uphill nor downhill but on a level. The manner in which contour lines express altitude, form, and slope is shown in figure 1.

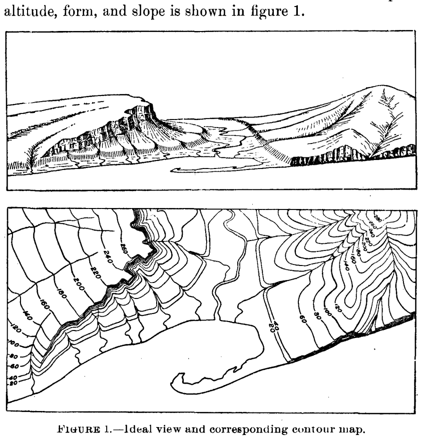

FIGURE 1.—Ideal view and corresponding contour map.

The view represents a river valley between two hills. In the foreground is the sea, with a bay that is partly inclosed by a hooked sand bar. On each side of the valley is a terrace. The terrace on the right merges into a gentle upward slope; that on the left merges into a steep slope that passes upward to a cliff, or scarp, which contrasts with the gradual slope back from its crest. In the map each of these features is indicated, directly beneath its position in the view, by contour lines. This map does not include the distant part of the view.

As contours are continuous horizontal lines they wind smoothly about smooth surfaces, recede into ravines, and project around spurs or prominences. The relations of contour curves and angles to the form of the land can be seen from the map and sketch. The contour lines show not only the shape of the hills and valleys but their altitude, as well as the steepness or grade of all slopes.

The vertical distance represented by the space between two successive contour lines—the contour interval—is the same, whether the contours lie along a cliff or on a gentle slope; but to reach a given height on a gentle slope one must go farther than on a steep slope, and therefore contours are far apart on gentle slopes and near together on steep slopes.

The contour interval is generally uniform throughout a single map. The relief of a flat or gently undulating country can be adequately represented only by the use of a small contour interval; that of a steep or mountainous country can generally be adequately represented on the same scale by the use of a larger interval. The smallest interval commonly used on the atlas sheets of the Geological Survey is 5 feet, which is used for regions like the Mississippi Delta and the Dismal Swamp. An interval of 1 foot has been used on some large-scale maps of very flat areas. On maps of more rugged country contour intervals of 10, 20, 25, 50, and 100 feet are used, and on maps of great mountain masses like those in Colorado the interval may be 250 feet.

In figure 1 the contour interval is 20 feet, and the contour lines therefore represent contours at 20, 40, 60, and 80 feet, and so on, above mean sea level. Along the contour at 200 feet lie all points that are 200 feet above the sea—that is, this contour would be the shore line if the sea were to rise 200 feet; along the contour at 100 feet are all points that are 100 feet above the sea; and so on. In the space between any two contours are all points whose altitudes are above the lower and below the higher contour. Thus the contour at 40 feet falls just below the edge of the terrace, and that at 60 feet lies above the terrace; therefore all points on the terrace are shown to be more than 40 but less than 60 feet above the sea. In this illustration all the contour lines are numbered, but on most of the Geological Survey's maps only certain contour lines—say every fifth one, which is made slightly heavier—are numbered, for the heights shown by the others may be learned by counting up or down from these. More exact altitudes for many points are given in bulletins published by the Geological Survey.

Drainage.—Watercourses are indicated by blue lines. The line for a perennial stream is unbroken; that for an intermittent stream is dotted; and that for a stream which sinks and reappears is broken. Lakes and other bodies of water and the several types of marshy areas are also shown in blue.

Culture.—Symbols for the cultural features and for public-land land lines and other boundary lines, as well as all the lettering and the map projection, are printed in black.

FEATURES SHOWN ON THE GEOLOGIC MAPS.

The maps representing the geology show, by colors and conventional signs printed on the topographic map as a base, the distribution of rock masses on the surface of the land and, by means of structure sections, their underground relations so far as known, in such detail as the scale permits.

KINDS OF ROCKS.

Rocks are of many kinds. On the geologic map they are distinguished as igneous, sedimentary, and metamorphic.

Igneous rocks.—Rocks that have cooled and consolidated from a state of fusion are known as *igneous*. Molten material has from time to time been forced upward in fissures or channels of various shapes and sizes through rocks of all ages to or nearly to the surface. Rocks formed by the consolidation of molten material, or *magma*, within these channels—that is, below the surface—are called *intrusive*. An intrusive mass that occupies a nearly vertical fissure which has approximately parallel walls is called a *dike;* one that fills a large and irregular conduit is termed a *stock*. Molten material that traverses stratified rocks may be intruded along bedding planes, forming masses called *sills* or *sheets* if they are relatively thin and *laccoliths* if they are large lenticular bodies. Molten material that is inclosed by rock cools slowly, and its component minerals crystallize when they solidify, so that intrusive rocks are generally crystalline. Molten material that is poured out through channels that reach the surface is called *lava*, and lava may build up volcanic mountains. Igneous rocks that have solidified at the surface are called *extrusive* or *effusive*. Lavas generally cool more rapidly than intrusive rocks and contain, especially in their outer parts, more or less volcanic glass, produced by rapid chilling. The outer parts of lava flows are also usually made porous by the expansion of the gases in the magma. Explosions due to these gases may accompany volcanic eruptions, causing the ejection of dust, ash, lapilli, and larger fragments. These materials, when consolidated, constitute breccias, agglomerates, and tuffs.

Sedimentary rocks.—Rocks composed of the transported fragments or particles of older rocks that have undergone disintegration, of volcanic material deposited in lakes and seas, or of material deposited in such bodies of water by chemical precipitation or by organic action are termed *sedimentary*.

The chief agent in the transportation of rock débris is water in motion, including rain, streams, and the water of lakes and of the sea. The materials are in large part carried as solid particles, and the deposits they form are called mechanical. Such deposits are gravel, sand, and clay, which are later consolidated into conglomerate, sandstone, and shale. Some of the materials are carried in solution, and deposits composed of these materials are called organic if formed with the aid of life or chemical if formed without the aid of life. The more common rocks of chemical and organic origin are limestone, chert, gypsum, salt, certain iron ores, peat, lignite, and coal. Any one of the kinds of deposits named may be formed separately, or the different materials may be intermingled in many ways, producing a great variety of rocks.

Another transporting agent is air in motion, or wind, and a third is ice in motion, or glaciers. The most characteristic of the wind-borne or eolian deposits is *loess*, a fine-grained earth; the most characteristic of the glacial deposits is *till*, a heterogeneous mixture of boulders and pebbles with clay or sand.

Most sedimentary rocks are made up of layers or beds that can be easily separated. These layers are called *strata*, and rocks deposited in such layers are said to be *stratified*.

The surface of the earth is not immovable; over wide regions it very slowly rises or sinks with reference to the sea, and shore lines are thus changed. As a result of upward movement marine sedimentary rocks may become part of the land, and most of our land surface is in fact composed of rocks that were originally deposited as sediments in the sea.

Rocks exposed at the surface of the land are acted on by air, water, ice, animals, and plants, especially the low organisms known as bacteria. They gradually disintegrate, and their more soluble parts are leached out, the less soluble material being left as a *residual* layer. Water washes this material down the slopes, and it is eventually carried by rivers to the ocean or other bodies of water. Usually its journey is not continuous, but it is temporarily built into river bars and flood plains, where it forms *alluvium*. Alluvial deposits, glacial deposits (collectively known as *drift*), and eolian deposits belong to the *surficial* class, and the residual layer is commonly included with them. The upper parts of these deposits, which are occupied by the roots of plants, constitute soils and subsoils, the soils being usually distinguished by a considerable admixture of organic matter.

Metamorphic rocks.—In the course of time and by various processes rocks may become greatly changed in composition and texture. If the new characteristics are more pronounced than the old the rocks are called *metamorphic*. In the process of metamorphism the chemical constituents of a rock may enter into new combinations and certain substances may be lost or new ones added. A complete gradation from the primary to the metamorphic form may exist within a single rock mass. Such changes transform sandstone into quartzite and limestone into marble and modify other rocks in various ways.

From time to time during geologic ages rocks that have been deeply buried and have been subjected to enormous pressure, to slow movement, and to igneous intrusion have been afterward raised and later exposed by erosion. In such rocks the original structural features may have been lost entirely and new ones substituted. A system of parallel planes along which the rock can be split most readily may have been developed. This acquired quality gives rise to *cleavage*, and the cleavage planes may cross the original bedding planes at any angle. Rocks characterized by cleavage are called *slates*. Crystals of mica or other minerals may have grown in a rock in parallel arrangement, causing lamination or foliation and producing what is known as *schistosity*. Rocks that show schistosity are called *schists*.

As a rule, the older rocks are most altered and the younger are least altered, but to this rule there are many exceptions, especially in regions of igneous activity and complex structure.

GEOLOGIC FORMATIONS.

For purposes of geologic mapping the rocks of all the kinds above described are divided into *formations*. A sedimentary formation contains between its upper and lower limits either rocks of uniform character or rocks more or less uniformly varied in character, as, for example, an alternation of shale and limestone. If the passage from one kind of rocks to another is gradual it may be necessary to separate two contiguous formations by an arbitrary line, and the distinction between some such formations depends almost entirely on the fossils they contain. An igneous formation contains one or more bodies of one kind of rock of similar occurrence or of like origin. A metamorphic formation may consist of one kind of rock or of several kinds of rock having common characteristics or origin.

[Continued on inside back cover.]

When it is desirable to recognize and map one or more specially developed parts of a formation the parts are called *members* or by some other appropriate term, such as *lentils*.

AGE OF THE FORMATIONS.

Geologic time.—The largest divisions of geologic time are called *eras*, the next smaller are called *periods*, and the still smaller divisions are called *epochs*. Subdivisions of the Pleistocene epoch are called *stages*. The age of a rock is expressed by the name of the time division in which it was formed.

The sedimentary formations deposited during a geologic period are called a *system*. The principal divisions of a system are called *series*. Any aggregate of formations less than a series is called a *group*.

As sedimentary deposits accumulate successively the younger rest on the older, and their relative ages may be determined by observing their positions. In many regions of intense disturbance, however, the beds have been overturned by folding or their relations to adjacent beds have been changed by faulting, so that it may be difficult to determine their relative ages from their present positions at the surface.

Many stratified rocks contain *fossils*, the remains or imprints of plants and animals which, at the time the strata were deposited, lived in bodies of water or were washed into them or were buried in surficial deposits on the land. Such rocks are said to be fossiliferous. A study of these fossils has shown that the forms of life at each period of the earth's history were to a great extent different from the forms at other periods. Only the simpler kinds of marine plants and animals lived when the oldest fossiliferous rocks were deposited. From time to time more complex kinds developed, and as the simpler ones lived on in modified forms life became more varied. But during each period there lived forms that did not exist in earlier times and have not existed since; these are *characteristic types*, and they define the age of any bed of rock in which they are found. Other types passed on from period to period and thus linked the systems together, forming a chain of life from the time of the oldest fossiliferous rocks to the present. If two sedimentary formations are geographically so far apart that it is impossible to determine their relative positions the characteristic fossils found in them may determine which was deposited first. Fossils are also of value in determining the age of formations in the regions of intense disturbance mentioned above. The fossils found in the strata of different areas, provinces, and continents afford the most effective means of combining local histories into a general earth history.

It is in many places difficult or impossible to determine the age of an igneous formation, but the relative age of such a formation can in general be ascertained by observing whether an associated sedimentary formation of known age is cut by the igneous mass or lies upon it. Similarly, the time at which metamorphic rocks were formed from the original masses may be shown by their relations to adjacent formations of known age; but the age recorded on the map is that of the original masses and not that of their metamorphism.

Symbols, colors, and patterns.—Each formation is shown on the map by a distinctive combination of color and pattern and is labeled by a special letter symbol.

Patterns composed of parallel straight lines are used to represent sedimentary formations deposited in the sea, in lakes, or in other bodies of standing water. Patterns of dots and circles represent alluvial, glacial, and eolian formations. Patterns of triangles and rhombs are used for igneous formations. Metamorphic rocks of unknown origin are represented by short dashes irregularly placed; if the rock is schist the dashes may be arranged in wavy lines parallel to the structure planes. Suitable combination patterns are used for metamorphic formations that are known to be of sedimentary or of igneous origin. The patterns of each class are printed in various colors. The colors in which the patterns of parallel lines are printed indicate age, a particular color being assigned to each system.

Each symbol consists of two or more letters. The symbol for a formation whose age is known includes the system symbol, which is a capital letter or monogram; the symbols for other formations are composed of small letters.

The names of the geologic time divisions, arranged in order from youngest to oldest, and the color and symbol assigned to each system are given in the subjoined table.

Geologic time divisions and symbols and colors assigned to the rock systems.

Era.	Period or system.	Epoch or series.	Symbol.	Color for sedimentary rocks.
Cenozoic	Quaternary	Recent Pleistocene	Q	Brownish yellow.
	Tertiary	Pliocene Miocene Oligocene Eocene	T	Yellow ocher.
Mesozoic	Cretaceous		K	Olive-green.
	Jurassic		J	Blue-green.
	Triassic		Ꞧ	Peacock-blue.
Paleozoic	Carboniferous	Permian Pennsylvanian Mississippian	C	Blue.
	Devonian		D	Blue-gray.
	Silurian		S	Blue-purple.
	Ordovician		O	Red-purple.
	Cambrian		Ꞓ	Brick-red.
Proterozoic	Algonkian		A	Brownish red.
	Archean		Æ	Gray-brown.

DEVELOPMENT AND SIGNIFICANCE OF SURFACE FORMS.

Hills, valleys, and all other surface forms have been produced by geologic processes. Most valleys are the result of erosion by the streams that flow through them (see fig. 1), and the alluvial plains that border many streams were built up by the streams; waves cut sea cliffs, and waves and currents build up sand spits and bars. Surface forms thus constitute part of the record of the history of the earth.

Some forms are inseparably connected with deposition. The hooked spit shown in figure 1 is an illustration. To this class belong beaches, alluvial plains, lava streams, drumlins (smooth oval hills composed of till), and moraines (ridges of drift made at the edges of glaciers). Other forms are produced by erosion. The sea cliff is an illustration; it may be carved from any rock. To this class belong abandoned river channels, glacial furrows, and peneplains. In the making of a stream terrace an alluvial plain is built and afterward partly eroded away. The shaping of a plain along a shore is usually a double process, hills being worn away (*degraded*) and valleys filled up (*aggraded*).

All parts of the land surface are subject to the action of air, water, and ice, which slowly wears them down, producing material that is carried by streams toward the sea. As this wearing down depends on the flow of water to the sea it can not be carried below sea level, which is therefore called the *base-level* of erosion. Lakes or large rivers may determine base-levels for certain regions. A large tract that is long undisturbed by uplift or subsidence is worn down nearly to base-level, and the fairly even surface thus produced is called a *peneplain*. If the tract is afterward uplifted it becomes a record of its former close relation to base-level.

THE GEOLOGIC MAPS AND SHEETS IN THE FOLIO.

Areal-geology map. — The map showing the surface areas occupied by the several formations is called an *areal-geology map*. On the margin is an explanation, which is the key to the map. To ascertain the meaning of any color or pattern and its letter symbol the reader should look for that color, pattern, and symbol in the explanation, where he will find the name and description of the formation. If he desires to find any particular formation he should examine the explanation and find its name, color, and pattern and then trace out the areas on the map corresponding in color and pattern. The explanation shows also parts of the geologic history. The names of formations are arranged in columnar form, grouped primarily according to origin—sedimentary, igneous, and metamorphic rocks of unknown origin—and those within each group are placed in the order of age, the youngest at the top.

Economic-geology map.—The map representing the distribution of useful minerals and rocks and showing their relations to the topographic features and to the geologic formations is termed the *economic-geology map*. Most of the formations indicated on the areal-geology map are shown on the economic-geology map by patterns in fainter colors, but the areas of productive formations are emphasized by strong colors. A mine symbol shows the location of each mine or quarry and is accompanied by the name of the principal mineral product mined or quarried. If there are important mining industries or artesian basins in the area the folio includes special maps showing these additional economic features.

Structure-section sheet.—The relations of different beds to one another may be seen in cliffs, canyons, shafts, and other natural and artificial cuttings. Any cutting that exhibits these relations is called a *section*, and the same term is applied to a diagram representing the relations. The arrangement of the beds or masses of rock in the earth is called *structure*, and a section showing this arrangement is called a *structure section*.

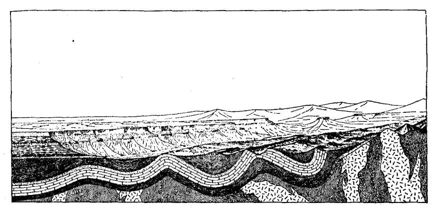

FIGURE 2.—Sketch showing a vertical section below the surface at the front and a view beyond.

The geologist is not limited, however, to natural and artificial cuttings for his information concerning the earth's structure. Knowing the manner of formation of rocks, after tracing out the relations of the beds on the surface he can infer their relative positions beneath the surface and can draw sections representing the probable structure to a considerable depth. Such a section is illustrated in figure 2.

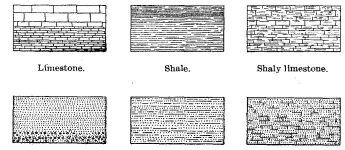

FIGURE 3.—Symbols used in sections to represent different kinds of rock.

The figure represents a landscape that is cut off sharply in the foreground on a vertical plane so as to show the underground relations of the rocks. The kinds of rock are indicated by appropriate patterns of lines, dots, and dashes. These patterns admit of much variation, but those shown in figure 3 are used to represent the commoner kinds of rock.

The plateau shown at the left of figure 2 presents toward the lower land an escarpment, or front, made up of sandstone, which forms the cliffs, and shale, which forms the slopes. The broad belt of lower land is traversed by several ridges, which, as shown in the section, correspond to the outcrops of a folded bed of sandstone that rises to the surface. The upturned edges of this bed form the ridges, and the intermediate valleys follow the outcrops of limestone and calcareous shale.

Where the edges of the beds appear at the surface their thickness can be measured and the angles at which they dip below the surface can be observed, and by means of these observations their positions underground are inferred. The direction of the intersection of the surface of a dipping bed with a horizontal plane is called its *strike*. The inclination of the bed to the horizontal plane, measured at right angles to the strike, is called its *dip*.

In many regions the beds are bent into troughs and arches, such as are seen in figure 2. The arches are called *anticlines* and the troughs *synclines*. As the materials that formed the sandstone, shale, and limestone were deposited beneath the sea in nearly flat layers the fact that the beds are now bent and folded shows that forces have from time to time caused the earth's crust to wrinkle along certain zones. In places the beds are broken across and the parts have slipped past each other. Such breaks are termed *faults*. Two kinds of faults are shown in figure 4.

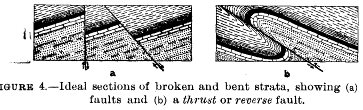

FIGURE 4.—Ideal sections of broken and bent strata, showing (a) *normal* faults and (b) a *thrust* or *reverse* fault.

At the right of figure 2 the section shows schists that are traversed by igneous rocks. The schists are much contorted, and the form or arrangement of their masses underground can not be inferred. Hence that part of the section shows only what is probable, not what is known by observation.

The section also shows three sets of formations, distinguished by their underground relations. The uppermost set, seen at the left, is made up of beds of sandstone and shale, which lie in a horizontal position. These beds were laid down under water but are now high above the sea, forming a plateau, and their change of altitude shows that this part of the earth's surface has been uplifted. The beds of this set are *conformable*—that is, they are parallel and show no break in sedimentation.

The next lower set of formations consists of beds that are folded into arches and troughs. The beds were once continuous, but the crests of the arches have been removed by erosion. These beds, like those of the upper set, are conformable.

The horizontal beds of the plateau rest upon the upturned, eroded edges of the beds of the middle set, as shown at the left of the section. The beds of the upper set are evidently younger than those of the middle set, which must have been folded and eroded between the time of their deposition and that of the deposition of the upper beds. The upper beds are *unconformable* to the middle beds, and the surface of contact is an *unconformity*.

The lowest set of formations consists of crystalline schists and igneous rocks. At some period of their history the schists were folded or plicated by pressure and intruded by masses of molten rock. The overlying beds of the middle set have not been traversed by these intrusive rocks nor have they been affected by the pressure of the intrusion. It is evident that considerable time elapsed between the formation of the schists and the beginning of the deposition of the beds of the middle set, and during this time the schists were metamorphosed, disturbed by the intrusion of igneous masses, and deeply eroded. The contact between the middle and lowest sets is another unconformity; it marks a period of erosion between two periods of deposition.

The section and landscape in figure 2 are ideal, but they illustrate actual relations. The sections on the structure-section sheet are related to the maps in much the same way that the section in the figure is related to the landscape. The profile of the surface in each structure section corresponds to the actual slopes of the ground along the section line, and the depth to any mineral-producing or water-bearing bed shown may be measured by using the scale given on the map.

Columnar section.—Many folios include a *columnar section*, which contains brief descriptions of the sedimentary formations in the quadrangle. It shows the character of the rocks as well as the thickness of the formations and the order of their accumulation, the oldest at the bottom, the youngest at the top. It also indicates intervals of time that correspond to events of uplift and degradation and constitute interruptions of deposition.

THE TEXT OF THE FOLIO.

The text of the folio states briefly the relation of the area mapped to the general region in which it is situated; points out the salient natural features of the geography of the area and indicates their significance and their history; considers the cities, towns, roads, railroads, and other human features; describes the geology and the geologic history; and shows the character and the location of the valuable mineral deposits.

GEORGE OTIS SMITH,
Director.

January, 1924.

DESCRIPTION OF THE CENTRAL BLACK HILLS.

By N. H. Darton and Sidney Paige.

GEOGRAPHY.

POSITION AND EXTENT OF THE AREA.

The area here called the Central Black Hills comprises the Deadwood, Rapid, Harney Peak, and Hermosa quadrangles, the maps of which form separate sheets of the topographic atlas of the United States. It extends from latitude 43° 30′ to 44° 30′ N. and from longitude 103° to 104° W., thus embracing about 3,441 square miles. It includes the greater part of Lawrence, Custer, and Pennington counties and the western part

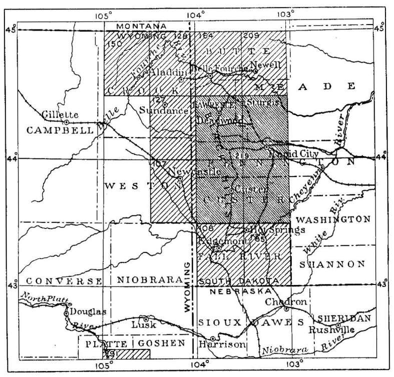

FIGURE 1.—Index map of the Black Hills region, South Dakota and Wyoming.

The area described in the Central Black Hills folio is shown by the darker ruling (219). Published folios that describe other areas, indicated by lighter ruling, are as follows: 85, Oelrichs; 91, Hartville; 107, Newcastle; 108, Edgemont; 127, Sundance; 128, Aladdin; 150, Devils Tower; 164, Belle Fourche; 209, Newell.

of Meade County, in southwestern South Dakota (see fig. 1), comprising much of the Black Hills uplift and, along its eastern margin, a wide belt of plains.

CONFIGURATION OF THE BLACK HILLS.

General features.—The group of mountains in western South Dakota and eastern Wyoming known as the Black Hills rises several thousand feet above the surrounding plains. It is carved from a dome-shaped uplift of the earth's crust and consists largely of rocks that are older and therefore stratigraphically lower than those that form the surface of the adjoining plains. The length of the higher part of the area is about 100 miles, and its greatest width is 50 miles. The salient features of the group are the Hogback Ridge, which forms its outer encircling rim; the Red Valley, a depression that extends completely around the uplift; the limestone plateau, with infacing escarpment; and a central area of high ridges that culminate in the precipitous crags of Harney Peak at an altitude of 7,242 feet. (See Pl. II.) The rainfall is abundant and gives rise to many streams, and the vegetation it produces makes the area an oasis in a semiarid region. Two branches of Cheyenne River nearly surround the hills and receive from them many tributaries.

The central area.—The central area of the Black Hills includes scattered rocky ridges and groups of mountains, most of them 5,000 to 6,600 feet high, interspersed with parklike valleys. The wider valleys are above the heads of canyons that extend from the central area outward to the northeast, east, and south. (See fig. 2.)

The limestone plateau.—The limestone plateau forms an interior highland belt around the central hills, rising considerably above the greater part of the area of crystalline rocks. Its western segment is much broader than its eastern and slopes gently downward near its outer margin but is level near its eastern or inner side, along which extends a line of cliffs that rise in places 800 feet above the central valleys. The plateau attains an altitude of slightly more than 7,100 feet in Crooks Tower and Crows Nest, almost equaling Harney Peak in height, and forms the main divide of the Black Hills. The streams that flow down its western slope are affluents of Beaver Creek, on the southwest, and of the Belle Fourche, on the northwest. They rise in shallow, parklike valleys in the plateau, but in short distances they cut deep canyons that have precipitous walls of limestone hundreds of feet high, notably the canyon of Spearfish Creek, which is more than a thousand feet deep. South of the headwaters of Beaver Creek the limestone plateau swings around to the eastern side of the hills, where, owing to steeper dip of the beds, it narrows to a ridge that has a steep western face and that in great part ranges in altitude from 5,000 to 6,600 feet. This ridge is intersected by several large streams, which rise in the high limestone plateau, cross the region of crystalline rocks, and flow to Cheyenne River through canyons cut in the ridges flanking the eastern side of the plateau. Near the outer margin of the plateau is a low cuesta of Minnekahta limestone marked by a steep infacing escarpment, 40 to 50 feet high, surmounted by a bare, rocky incline, which descends several hundred feet into the Red Valley. This minor escarpment and the slope are sharply notched at intervals by canyons, which on each stream form a characteristic narrows or "gate."

The Red Valley.—The Red Valley extends almost continuously around the Black Hills. It has long, fairly steep limestone slopes on the inner side and a very steep sided hogback ridge on the outer. At some places it is 2 miles wide, at others, where the strata dip steeply, as they do near Crook, it is much narrower. It is one of the most conspicuous features of the

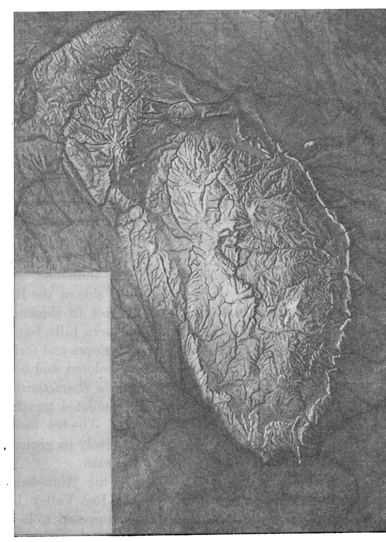

FIGURE 2.—Relief map of the Black Hills.

Shows the rim of hogback ridges or outward-sloping cuestas surrounding the elevated, deeply dissected central portion, with the Red Valley between. Bear Butte is the outlying knob to the northeast. Shaded drawing made by J. H. Renshawe and O. A. Ljungstedt.

Black Hills region, owing in no small degree to the red color of its soil and the absence of trees, the main forest ending at the foot of the limestone slopes. Most of the larger streams that flow out of the hills cross it without material deflection in valleys that lie between divides so low as to make the Red Valley appear continuous. In its middle eastern part, however, northwest of Hermosa and northwest and west of Fairburn, it contains extensive Oligocene deposits. Near Whitewood its course is changed by local flexures. The altitude of the Red Valley along the east side of the Black Hills ranges from 3,300 to 3,500 feet.

The Hogback Ridge.—The Hogback Ridge, which forms the outer rim of the hills, is throughout most of its extent a single-crested ridge of hard sandstone, which differs from place to place in prominence and in steepness of slope. In its northern and southern parts and at places along its middle western part it spreads out into long, sloping plateaus. Nearly everywhere it presents a steep face toward the Red Valley, above the bottom of which its crest rises several hundred feet, but on its outer side it slopes more or less steeply down to the plains that extend far out from the Black Hills. The Hogback Ridge is crossed by many gaps, which divide it into level-crested segments of different lengths. Cheyenne River has cut a tortuous valley through the south end of the ridge, and the Belle Fourche crosses its north end. The altitude of the Hogback Ridge ranges from 3,800 feet near Rapid City to 4,900 feet in Elk Mountain.

Plains east of the Black Hills.—The plains east of the Black Hills slope eastward from altitudes of 3,300 to 3,500 feet along the outer foot of the Hogback Ridge to altitudes of about 2,500 feet near the Belle Fourche and 3,000 feet near Cheyenne River. They consist of broad, low ridges separated by the wide, shallow, terraced valleys of streams that flow out of the east slope of the Black Hills. The surface of these plains is nearly everywhere smooth, but at some places, especially east of Hermosa and Fairburn, it is surmounted by low buttes and badlands, most of them developed in the areas occupied by the White River group. Some features of the terraces in the valleys of the plains region are described under the heading "Older terrace deposits" (p. 15).

SETTLEMENT.

The Black Hills region is scantily populated, because much of it consists of high, forested ridges that are not well adapted to agriculture. The principal industry in the region has always been mining, which has built up the cities of Lead (population in 1920, 5,013) and Deadwood (population 2,403). The large Homestake mine is at Lead. Custer (population 595) and Hill City (population 308) are sustained mainly by the lumber industry and by small farms and ranches in the numerous parks in the surrounding country.

The country near the Black Hills is occupied largely by cattle ranches. Its principal town is Rapid City, which in 1920 had a population of 5,777. It is the seat of Pennington County, is a growing railroad center, and contains the State School of Mines, several small factories, and an Indian school. Sturgis (population 1,250) is the trading place for an extensive ranch country but is partly sustained by the United States Army garrison at Fort Meade, which stands 2 miles east of the town. Spearfish (population 1,254) is the largest town on the northern side of the hills. Whitewood, Hermosa, and Fairburn are smaller places.

The region is traversed by the Chicago, Burlington & Quincy Railroad, which has a branch to Spearfish; the Chicago & Northwestern Railway, which extends along the east side of the Black Hills to Lead and has a line extending from Pierre to Rapid City; and a branch of the Chicago, Milwaukee & St. Paul Railway, which reaches the Black Hills at Rapid City. Several small railroads run through parts of the Black Hills.

TIMBER.

The principal timber tree in the Black Hills is *Pinus ponderosa* (yellow pine), which grows in large forests interspersed with many parks. At some places the timber has been depleted by lumbering, forest fires, and destructive insects. The heaviest forest growth lies within the encircling rim of Minnekahta limestone, for the Red Valley is treeless and only small scattered pines and junipers grow on the Hogback Ridge and in places on the Mowry member of the Graneros shale. The area containing the most valuable timber has been made a forest reserve in order that lumbering may be controlled and closer vigilance exercised to prevent devastation by fire. Besides the yellow pine the most abundant trees in the Black Hills are spruce (*Picea canadensis* Mill), aspen (*Populus tremuloides* Michaux), burr oak (*Quercus macrocarpa* Michaux), box elder (*Acer negundo* Linné), white elm (*Ulmus americana* Linné), ironwood (*Ostrya virginiana* (Miller) Koch), cottonwood (*Populus deltoides* Marsh and *P. angustifolia* James), and "red cedar" (*Juniperus virginiana* Linné).

The tallest pines attain a height of 100 feet, but many are less than 80 feet high and the average height is 65 feet. Large trees are 20 inches in diameter. The largest forests and the largest trees are on areas underlain by limestone and schist. Scattered areas of forest lie north of Custer and southwest of Hill City. Many places in these districts will yield 2,000 to 10,000 feet of lumber, board measure, to the acre. In the vicinity of Harney Peak and for some distance north and south the growth is in general much lighter.

Spruce grows in small groves in the highest valleys, mainly on northward-facing slopes on the higher parts of the limestone plateau, notably near the head of Castle Creek and in the draws that head near Harney Peak. Aspen and birch grow in places, especially where there have been forest fires, The parks in the central area of the Black Hills are generally at the heads of valleys, where the declivity is slight and where there is an accumulation of decomposed rock detritus. There are young pines in these parks, especially around the edges, but the trees do not become mature. The parks do not owe their origin and continuance to fires, as has been suggested, but to the depth of decomposed rock material, which is too soft to supply firm rootage for trees. In the lower parts of the valleys the streams have sufficient volume to clear out the disintegrated rock, so that most of their canyons are well wooded. The softness of the surficial material accounts for the absence of pine in the Red Valley and on the plains east of the Black Hills, although aridity is also a contributing cause. Bear Butte, a rocky eminence which rises only a few hundred feet, bears many pines.

CLIMATE.

The climate of the Black Hills is similar to that of the moderately elevated parts of the northern Rocky Mountain province. The summers are dry and hot, there is considerable rainfall late in the spring, the winters are cold, and the snowfall is moderate. On the higher levels the frosts begin early and continue until very late; at a few places in some years frosts occur even in July and August. Snow remains longer on the Black Hills than on the adjoining plains because the snowfall is heavier and the snow banks are more sheltered from the sun and wind.

At Fairburn and Hermosa the mean annual temperature is about 45° F., at Rapid City and Sturgis about 46°, and at Spearfish 47°. In the highlands the temperature is somewhat lower, the average at Deadwood being about 43°. The average monthly temperatures in Rapid City for many years have been as follows: January, 20°; February, 22°; March, 33°; April, 46°; May, 53°; June, 64°; July, 71°; August, 71°; September, 61°; October, 48°; November, 34°; and December, 31°. The midsummer average is about 70°, and ordinarily July is hotter than August. There is a great daily range of temperature in summer, often from considerably above 100° at midday to below 60° at night. The average winter temperature is usually between 20° and 25°, and there are short spells of zero weather. The small range in the temperatures in the Black Hills as compared with that in the adjoining plains is probably due to the fact that the hills are protected by heavy forests from the strong, cold winter winds and from the hot summer winds that sweep across the plains.

The precipitation in the Black Hills region is extremely variable from year to year and from place to place in the same and in different years. There is a rainy season in the spring, which is usually followed by drought in midsummer, although at that time scarcely a day passes without light local showers, most of which fall out of small clouds moving in narrow zones and are of very little benefit to agriculture. The idea that the climate of the region is changing is not borne out by the records. At Rapid City the mean annual rainfall from 1881 to 1912 was about 17½ inches, and the range was from 9 to 22 inches; at Spearfish the average is 22 inches and the range is from 12 to 29½ inches; at Fort Meade the average is 20 inches and the range is from 13¼ to 30⅓ inches; at Deadwood the average from 1878 to 1912 was about 28½ inches and the range was from 19 to 33 inches.

GEOLOGY OF THE GENERAL REGION.

By N. H. Darton.

The Black Hills uplift is an irregular dome-shaped anticline, embracing an oval area 125 miles long and 60 miles wide, which trends nearly northwest. It was formed in a wide expanse of almost horizontal beds, the uplift of which has brought above the general level of the plains a mass of Algonkian schists, conglomerate, quartzites, limestones, granites, and associated rocks, around which there is upturned a nearly complete sequence of sedimentary formations ranging in age from Upper Cambrian to latest Cretaceous, all dipping away from the central core. The structure along the sides of the uplift is that of a monocline dipping toward the plains. The oldest Paleozoic beds form an escarpment that faces the central area of crystalline rocks, and each bed passes beneath a younger one in regular succession outward toward the margin of the uplift. The Paleozoic and Mesozoic sedimentary formations consist of a series of thick sheets of sandstones, limestones, and shales, all essentially conformable in attitude. The stratigraphy is in general similar to that of the Rocky Mountains in Colorado and Wyoming but shows many local features.

The Cambrian system is represented by the Deadwood formation, the thickness of which is nearly 500 feet in the northern part of the uplift but decreases to 50 feet or less in the southern part and locally to 4 feet southwest of Hermosa. At its base there is a bed of sandstone, in greater part conglomeratic, which rests upon a nearly smooth eroded surface of Algonkian schist and granite. As the formation thickens to the north the sandstone becomes overlain by gray shales and slabby sandstones, partly glauconitic, and slabby limestones, in part broken into a flat-pebble intraformational conglomerate. On the north also there is a top member of 25 to 50 feet of gray to reddish-buff massive sandstone, locally overlain by 20 to 70 feet of green fissile shale, which is regarded as the top of the formation. The Deadwood carries an Upper Cambrian fauna.

The Ordovician deposits are represented by the Whitewood limestone, a massive, hard pale-buff limestone with brownish spots or mottlings of late Ordovician (Richmond) age. There are no Silurian or Devonian formations in the area.

In the Black Hills region the Carboniferous system comprises several formations, which apparently represent long-continued deposition during the early and late parts of the period, though late Mississippian time is unrepresented. Limestone predominates, but a large amount of sandstone occurs in the higher formations. At the base of the system lies the Englewood limestone, 30 to 60 feet thick, which consists of slabby beds of pinkish or buff color and contains Kinderhook fossils. It grades up into the Pahasapa limestone, so named from the Indian name for the Black Hills. The Pahasapa is a massive light-colored limestone, which is 300 feet thick in the southern and central hills, 400 to 500 feet thick about Deadwood, and 630 feet thick on Spearfish Creek. It gives rise to prominent cliffs in the great limestone escarpment and in many canyons. It carries lower Mississippian fossils and is equivalent to the Madison limestone (lower Mississippian) of Wyoming and Montana. Next above, in conformable attitude, lies the Minnelusa sandstone, which also crops out completely around the Black Hills uplift in a broad zone on the outer slope of the limestone ridge. The rocks of this formation are mainly white, buff, and reddish sandstones, which locally contain interbedded limestones. The top member is a thick, massive, cross-bedded, coarse, moderately hard sandstone, which ranges in color from white to buff and here and there is reddish. The lower members are mostly slabby, in places brecciated, and at some places include beds of limestone. A thin but persistent red-shale member occurs at the base. On the northwestern slope of the uplift bodies of gypsum occur at the top. On the western side of the hills the formation is more than 600 feet thick, but on the northern and eastern sides it averages about 400 feet. The formation contains much lime, mostly as matrix in the sandstone. Fossils are rare, but a few impressions in the upper beds indicate Pennsylvanian age. The upper sandstone may represent the Tensleep sandstone and the middle and lower sandstones and limestones the Amsden formation, which are found in the Big Horn and other uplifts in Wyoming.

Upon the Minnelusa sandstone lie red slabby sandstones and sandy shales of the Opeche formation, 100 to 150 feet thick in the southern hills and 70 to 85 feet thick in the northern. This formation yields no fossils but is provisionally referred to the Permian. It is overlain by the Minnekahta limestone, long known as the "Purple limestone," on which is developed the long slope on the inner side of the Red Valley. This limestone averages about 50 feet in thickness in the southern hills and 30 feet in the northern hills, but it is so hard that it persists far and wide up the slopes and forms cliffs in many canyons. The rock is light colored and is in places partly magnesian. Its thin bedding is characteristic, but the layers are everywhere so tightly cemented together that they form ledges which appear massive. The few fossils which this rock has yielded do not fix conclusively its geologic age, but it is provisionally referred to the Permian.

The thick mass of red shale that lies on the Minnekahta limestone and appears at the surface in the Red Valley has been called the Spearfish formation. It is supposed to be of Triassic age but may prove to be Permian in whole or in part. Its thickness ranges from 550 to 695 feet. Its greatest thickness was found in a boring at Fort Meade. It contains gypsum deposits, which are in places more than 30 feet thick, and the most persistent bed lies about 100 feet above the base of the formation. Local deposits of gypsum also occur at other horizons, notably at the top of the formation near Cambria and in the vicinity of Spearfish and Rapid City.

The Sundance formation, of late Jurassic age, overlies the Spearfish red beds unconformably, though without discordance of dip, and crops out along the inner slopes of the Hogback Ridge. It ranges in thickness from 70 to 350 feet and consists mainly of gray shales. A 40-foot bed of buff sandstone lies about 50 feet above its bottom. In most regions the sandy shale in the middle of the formation is reddish. At some places deposits of coarse sandstone lie at the base of the formation. The Sundance contains numerous marine fossils, most of which are found in thin layers of limestone in the shale. In the southeastern part of the uplift the formation is overlain by 100 to 225 feet of massive fine-grained Unkpapa sandstone, most of it pure white or bright pink. The Unkpapa has yielded no fossils, and it is assigned to the Jurassic only because of its close association with the Sundance formation.

The Cretaceous system is represented by about 4,000 feet of beds, apparently in continuous succession. The first formation is the Morrison shale, which is provisionally assigned to the Lower Cretaceous. It consists of massive shale, generally 100 to 150 feet thick, but it is apparently absent in the southeastern part of the uplift. Its predominant color is pale greenish gray, but at some places it is maroon, pink, or chocolate-colored. It includes thin beds of light-colored sandstone and thin local layers of impure limestone. It carries a few fresh-water shells and many bones of dinosaurs. The Lakota sandstone overlies the Morrison but overlaps the Unkpapa in the southeastern part of the hills. It is mostly a hard coarse-grained cross-bedded massive sandstone, 200 to 485 feet thick in the southern hills and 100 feet or less in parts of the northern hills. Generally it forms the crest of the Hogback Ridge. It contains bodies of shale and of coal and near its base some beds of conglomerate. Near Buffalo Gap and Fall River it is overlain by the local Minnewaste limestone, which is 25 feet thick near Hot Springs. The formation next above it is the Fuson shale, which consists of 30 to 188 feet of gray to purple massive shale and local beds of sandstone. The Fuson and Lakota beds contain an extensive Lower Cretaceous flora. The Dakota sandstone, which throughout the uplift lies on the Fuson shale, is mostly a hard massive buff sandstone, slabby at the top. Its thickness in most of the region exceeds 100 feet but decreases to about half that amount in the northeastern part of the hills. Locally the Dakota sandstone extends to the crest of the Hogback Ridge, but ordinarily it crops out on the outer slope. It contains an Upper Cretaceous flora. Upon the Dakota lies a thick series of dark shales—the Graneros, Carlile, and Pierre shales—which underlie the plains at the foot of the Hogback Ridge. The Graneros shale, 900 to 1,150 feet thick, includes the hard Mowry shale member, which weathers light gray and is full of fish scales. The Graneros shale includes also at some places beds of sandstone, one of which lies just beneath the Mowry shale and is the "oil sand" of the Newcastle region. The Greenhorn limestone, which averages 65 feet in thickness, caps the Graneros shale all around the Black Hills and generally gives rise to a low but distinct ridge. At most localities it is filled with a characteristic fossil—*Inoceramus labiatus*—and weathers into thin slabs. In the northwestern part of the uplift it is less conspicuous. The Carlile shale, from 500 to 750 feet thick, contains two thin beds of sandstone at most places and near the top large numbers of lens-shaped concretions, many of which are fossiliferous. Next above lies the impure chalk and gray calcareous shale of the Niobrara formation, which averages 200 feet in thickness and weathers to a bright straw color. This formation contains distinctive aggregations of *Ostrea congesta*. The Pierre shale, overlying the Niobrara, attains a thickness of more than 1,400 feet in the western part of the State. Near the top of the shale there are scattered masses of limestone filled with *Lucina occidentalis*, which on weathering form tepee buttes. Similar masses appear also locally at a lower horizon. Many smaller ovoid concretions filled with molluscan remains occur in the shale. The sandstone of Fox Ridge extends westward to the margin of the Black Hills uplift, capping low ridges of Pierre shale. In a wide area in northwestern South Dakota the sandstone is overlain by the Lance and later formations.

The Tertiary system is represented in the Black Hills region by the Brule and Chadron formations of the White River group, which extend westward from the Big Badlands and originally covered all the lower and middle slopes of the hills. Large areas remain on the divides from Rapid Creek to Beaver Creek, and there are outliers on the ridges as far west as the central area of crystalline rocks. Other outliers occur about Lead, Maitland, and Deadwood and in the Bear Lodge Range. The deposits consist of clay, fuller's earth, sand, volcanic ash, and sandstone and contain remains of Oligocene mammals.

In the northern hills the schists and the overlying beds are at many places penetrated by intrusive rocks. These igneous rocks occur in a broad zone extending from Bear Butte to Missouri Buttes and consist of dikes, stocks, sills, and laccoliths, the laccoliths being developed in the Paleozoic and Mesozoic beds. They are diverse in color, texture, and composition, comprising rhyolite, quartz monzonite, monzonite, phonolite, grorudite, and several porphyritic varieties, all of which are believed to have come from a common magma and at about the same time in the early Tertiary. There are also small areas of lavas and volcanic breccias, which indicate the sites of small volcanoes of early Quaternary time.

DESCRIPTIVE GEOLOGY.

GENERAL CHARACTER OF THE ROCKS.

The area treated in this folio contains three classes of rocks—metamorphic, sedimentary, and igneous. The metamorphic rocks, comprising schists, conglomerates, quartzites, and limestones, are exposed in a wide area in the central part of the region. The sedimentary series, extending from Cambrian to Quaternary, comprises limestones, sandstones, and shales, which have a combined thickness of about 3,500 feet and present the characteristics and relations shown on the columnar section sheet. The igneous rocks include granite and amphibolite of Algonkian age, several intrusive porphyries, monzonites, and rhyolites of early Tertiary age, and a little effusive rhyolite.

PRE-CAMBRIAN ROCKS.

ALGONKIAN SYSTEM.[1]

By Sidney Paige.

GENERAL FEATURES.

The Algonkian rocks exposed in the center of the Black Hills uplift present a considerable variety of igneous and sedimentary rocks in different stages of metamorphism, together with granites and pegmatites. The metamorphosed sedimentary rocks, which greatly predominate over the others, comprise the metamorphic equivalents of conglomerates, grits, sandstones, shales, and pure and impure limestones. The metamorphosed igneous rocks comprise amphibolites derived from intrusives of dioritic and gabbroic composition. The unmetamorphosed igneous rocks comprise granite (which is locally gneissoid) and pegmatite.

On the maps two broad lithologic subdivisions and a number of individual beds have been represented. In so far as possible the coarser-grained rocks—the graywackes, grits, massive quartzites, and quartzitic schists—have been separated as one group and the finer-grained rocks—the slates and schists—as another. Certain beds and successions of conglomerates, quartzites, limestones (or their metamorphic equivalents), quartz-hematite beds, and garnetiferous schists have been mapped separately where prominent. In areas where intrusive and sedimentary rocks are so intricately intermingled that they could not be represented separately on the map they are shown by a special pattern. A number of prominent replacement veins that have stratigraphic significance are also mapped.

METAMORPHOSED SEDIMENTARY ROCKS.

General character.—Structural relations indicate that beds of conglomerate near Este and Greenwood form the lowest member of the Algonkian sedimentary series. The conglomerate grades up through grits into a thick series of beds of slate and schist, which are overlain by alternating beds of coarse and fine grained graywacke, slate, and quartzite. Thin beds of limestone and quartzite occur at several horizons, and quartz-hematite beds are associated with the lowermost grits and conglomerates.

Conglomerates.—The conglomerates are exposed mainly in an area covering somewhat less than a square mile north of Estes Creek, about a mile west of its junction with Boxelder Creek, and near Benchmark and Greenwood, and at other places along the eastern border of the area indicated, where they form narrow lenses and grade into grits. They occur at several horizons and grade upward, downward, and along their strike into arkosic grits of finer texture. They have been deposited as channel fillings of different lengths and thicknesses and contain waterworn pebbles and some boulders, the largest a foot or more in diameter. (See Pl. VIII.) Most of the pebbles are of white quartz, but some consist of blue quartzite, banded quartz and iron oxide, contorted schist, black slate, and cross-bedded siliceous schist or sandstone. The matrix is mainly quartzitic, but it contains much feldspar, mica, and chlorite. The conglomerates when fresh have a distinctly greenish cast, which is due to the micaceous minerals they contain. The beds have been compressed and distorted by crushing, flowage, and recrystallization, and the pebbles and boulders have been squeezed into lenticular forms whose longest diameter lies parallel to the dip of the beds. The feldspathic and clayey material within the matrix has been converted in great part into sericite and chlorite.

Arkosic grit, quartzitic schist, quartzite, and graywacke.—Coarse arkosic grits are abundant in the area between Benchmark and Bogus Jim Creek, where they grade into the conglomerates described above. They were composed originally of quartz and feldspar in various proportions, but most of the feldspar has been altered to sericite and quartz. The chlorite they contain shows that the original sediments undoubtedly included iron and magnesia. That the grains have been mashed can be plainly seen with the microscope. The quartz grains, like the conglomerate pebbles, are roughly lenticular. Much of the débris in the coarse arkose is angular and suggests somewhat rapid accumulation. The schistosity of the rock is caused by the abundant sericite, which in places is wrapped around the more rigid grains of feldspar and quartz. These arkosic rocks have a distinctly greenish hue, which is due to abundant chlorite, but weathered surfaces are red, yellow, or light brown, contrasting sharply with the dark slates and graywackes of the more western areas. The arkoses grade imperceptibly into finer-grained quartzitic schists, which also are characterized by light colors on their weathered surfaces. Some of the arkosic rocks weather into high pinnacled ledges. (See Pl. XII.)

Large areas are occupied by graywacke, a metamorphic impure sandstone that grades on the one hand into nearly pure quartzite and on the other into slate or schist. Because of this intergradation and because of the complex folding of these rocks their boundaries can not be shown precisely on the geologic map. Within the broad area mapped as graywacke, quartzite, and quartzitic schist, which lies north of the mass of granite at Harney Peak, there are many beds of fine-grained slate or phyllite. North of Harney Peak these rocks crop out in a triangular area about 14 miles long, the base extending from St. Elmo Peak to Keystone and the apex lying near Silver City. Many of these rocks have a medium-grained texture and are sufficiently hard to form rugged hills. In the central part of this area massive quartzites are notably well developed and form bold cliffs, which are conspicuous between the old J. R. mill and Sheridan, along the Hill City road. South of the main mass of the granite of Harney Peak there is an area in which graywacke and quartzitic schists are likewise the dominant rocks, though in places they are accompanied by rather fine grained, much metamorphosed conglomerates. This area extends southward and eastward to the Paleozoic rocks, but on the west it is limited by a line that runs nearly southward from a point about 2 miles east of Custer and passes about 2 miles east of Pringle. These rocks are intricately cut by intrusions of granite.

The graywackes and quartzites comprise rocks of many textural gradations, ranging from those in which the individual grains are plainly visible to those in which the grains can hardly be seen. They merge, therefore, on the one hand into grits and on the other into slates and schists, and changes of texture may be noted along the strike as well as across the bedding. Most of the graywackes show cleavage approximately parallel to the bedding, though the perfection of this cleavage varies notably, the finer-grained varieties having it more strongly developed. Its development is also related to the original composition of the rock. Very quartzitic varieties, containing only a small amount of mica and chlorite, appear quite massive. The mashing to which the rock has been subjected, however, is usually shown in a broad way by planes of jointing.

Most of the graywackes, grits, and quartzites were originally arkosic sediments consisting mainly of quartz and feldspar in different proportions. Their metamorphism has caused both mineralogic and mechanical changes. The mineralogic changes consist principally in the formation of sericite, biotite, and chlorite in amounts that differ according to the original composition of the rock and to the degree of internal movement to which the beds have been subjected. The sericite is far more abundant than the biotite. The mechanical changes in the rocks differ likewise in amount according to the nature of the sediment and the degree of squeezing to which it has been subjected. The fine-grained softer varieties yielded readily to pressure and were shortened in one direction and lengthened in another, and the particles composing them have assumed elongated lenslike forms, between which the micaceous minerals have been squeezed into irregular thin layers, so as to produce schistosity. Where pressure has been accompanied by only slight differential movement the dominant result has been recrystallization with cementation.

Thin beds of quartzite.—Besides the massive quartzite associated with graywacke many minor beds of quartzite occur within the schist series. Some of the more extensive of these have been mapped, as near Lead and south of Elk Creek, on the central part of the eastern border, where they assist in interpreting geologic structure.

Some of the beds divide along the strike into two or more beds and some of them become thicker or thinner. Because of such changes and others caused by the squeezing and tearing to which the beds have been subjected their outcrops are irregular and discontinuous.

West of Lead not less than five beds of quartzite were traced almost continuously from the divide north of Sheeptail Gulch to a point east of Whitewood Creek, north of Englewood. The outcrops of these quartzites do not seem to be duplicated by folding. Less than half a mile east of this group of quartzites a second group of similar beds crops out, and the structural relations indicate a closely compressed synclinal fold. Apparently the outer quartzites on the north limb of this fold crop out on the south side of Sawpit Gulch, about half a mile west of Central City. The outcrops of the corresponding part of the fold in the other quartzite beds must be farther south, but they are hidden by porphyry, sandstone, talus, and forest.

Quartzite interbedded with slate extends southward from the region between Elk and Hay creeks, on the east side of the Algonkian area. (See Pls. V and VI.) It becomes very massive just north of Boxelder Creek, and from this point southward for 6 or 7 miles it forms a ridge across which streams have cut steep-walled gorges. Other quartzite beds, roughly paralleling this one, become prominent near Bogus Jim Creek and extend with interruptions to a point south of Rapid Creek, where they merge into a zone of generally quartzitic graywacke rocks. From a point south of Bogus Jim Creek five parallel beds of intricately folded quartzite crop out southward to the edge of the Deadwood formation.

Within the western slate-schist area there are many thin quartzitic beds containing numerous veins and masses of white quartz, some of which crop out in prominent cliffs. These beds are only a few hundred feet long and have not been mapped.

In an area of several square miles around Bucks, on Elk Creek, there are some prominent walls of quartzite, which partly border and are partly inclosed by the amphibolite. The outcrops, although interrupted, indicate flexures. Into this quartzite large quantities of vein quartz have been injected.

The quartzites, which are all much alike, are dark gray to blue black, with vitreous luster on fresh fractures, and generally contain much quartz in networks of veins and veinlets and in masses. This secondary silica is greater in amount in the quartzites than elsewhere, perhaps because of the large quantity of silica of local origin held in solution during their metamorphism. In most places where a great lens of secondary quartz occurs within slates there is also a nucleus of primary quartzite, as in the great quartzite walls within the amphibolite around Bucks. Under the microscope the quartzites are seen to be quartz with a little sericite, and carbonaceous or graphitic matter occurs in lenslike films surrounding aggregates of interlocking quartz grains, each a crushed and recrystallized fragment of quartz. The carbon or graphite gives a dark tint to the rock.

Slates and schists.—Most of the slates and schists are characterized by a well-developed cleavage and fine grain, and they range in color through light hues of gray or green, darker gray, and light and dark brown to black. Some of the very fine grained varieties have a silky luster and wavy cleavage surfaces. Although the cleavage is generally parallel to the bedding planes a well-developed cleavage cuts across those planes at many places. In soft rocks that are folded and crinkled the cleavage crosses the bedding planes on and near the axial plane of the fold. The mineral components of the slates and schists comprise quartz, feldspar, sericite, biotite, chlorite, calcite, garnet, and iron oxide. Staurolite and tourmaline occur sparingly. The different varieties of the rocks are due in part to differences in original composition and texture and in part to differences in the degree of metamorphism to which the beds have been subjected.

Calcareous rocks and their metamorphic equivalents.—Calcareous rocks are found at many horizons throughout the Algonkian sedimentary succession, though they form only a very small part of it. They are valuable horizon markers, by which structure can be determined, and in them has been developed the great Homestake ore body, near Lead. Calcareous beds crop out between Benchmark and Bogus Jim Creek, on the eastern border of the Algonkian area; in the Terraville-Central City region, north of Lead; and at a few other places where the beds are thin and greatly metamorphosed. The more prominent calcareous members between Benchmark and Bogus Jim Creek are shown on the areal-geology map. They are fine grained, in part apparently fairly pure dolomites, and at many places contain iron. Most of them show light hues of yellow, brownish white, or blue, which on weathering become darker brown and yellow. With increase in silica or alumina they grade into the fine-grained arkosic schists. Where originally mixed with fine aluminous sediment they have become sericite phyllites, and where mixed with sand they grade into siliceous schists. On weathered surfaces most of these limestones show fine ridges of siliceous material, a feature that is very distinctive.

In general the limestones are massive rather than schistose, so that they show the effect of metamorphism less than the more sandy beds. In places, however, impurities that are present in layers have been altered to sericite and chlorite, and the rock cleaves readily along the planes of these layers.

The calcareous beds differ in thickness and in persistence along the strike. The most persistent bed extends from the overlap of the Deadwood formation about a mile north of Benchmark to Estes Creek, south of which it ends either because of faulting or because it grades into siliceous schist. It includes 700 feet of limestone at its thickest part, between South Boxelder and Estes creeks.

Of other thin beds of limestone in this vicinity, the most prominent consists of several parallel layers that crop out just west of the road on Boxelder Creek, in a zone extending from Estes Creek to a point half a mile south of Nemo. Three of these bands are shown on the areal-geology map; the others are too narrow to be shown on the map.

The calcareous dolomitic rocks that occur north of Terraville and east of the Homestake fault are very impure and are interbedded with and grade downward into calcareous and siliceous slates. In most places the schists derived from impure calcareous or dolomitic sediments bear little resemblance to the original limestone. Where carbonaceous matter and silica were the principal impurities the schist is graphitic, is dark blue to black, and resembles graphitic slate, but on weathered surfaces the fine ridges of silica that stand out give an unmistakably characteristic appearance. Fairly pure calcareous rock crops out in the railroad cut in Deadwood Creek opposite the mouth of Blacktail Gulch and at several points in Bobtail Gulch near Terraville.

[1] The reports by Hayden, Winchell, Newton and Jenney, Crosby, Van Hise, Irving, and Jaggar included in the bibliography at the end of this text contain observations on the Algonkian rocks of the Black Hills.

A greatly metamorphosed bed that crops out a short distance below the mouth of Blacktail Gulch and that can be traced with interruptions to the machine shops in Lead, has been described as the "Upper conglomerate" by the writer.[2] This bed is peculiar in that it contains many small flattened lenses and bands of sugar-grained quartz set in a compact matrix of amphibole and garnet. The amphibole proves to be cummingtonite, and the garnet is a lime-iron-aluminum garnet. The development of these silicates suggests that the bed may be the metamorphic equivalent of a sideritic dolomite and that the quartz pebbles may be residual masses of chert. Possibly, however, the quartz fragments and bands were pebbles and sandy layers. A second similar bed occurs 350 feet lower in the section but can not be traced so far. For convenience in mapping, the top of the calcareous series is placed at the bottom of the quartzite, which lies a few hundred feet stratigraphically above the upper cummingtonite-garnet bed.

The series of calcareous rocks that contains the Homestake ore body includes many metamorphic varieties in which biotite, sericite, phlogopite, chlorite, amphibole, garnet, quartz, and sulphides make up various proportions.

Near Rochford calcareous beds, highly metamorphosed into a rock composed essentially of quartz and actinolite, are interbedded with slates. The quartz in this rock occurs in disconnected, twisted, folded, narrow bands and patches, which are set in a compact mat of dark-green interlocking actinolite. The principal bed extends from a point half a mile southwest of Rochford northwestward through a series of close folds nearly to the Bulldog ranch, beyond which it is difficult to trace. Four beds of similar character are mapped within a mile and a quarter east of Rochford. The twisted and broken bands of quartz suggest that the sedimentary layers were torn apart by the folding and metamorphism, producing results that are common in folded limestone beds that contain sandy or cherty layers. The abundance of actinolite indicates that a magnesian iron-bearing limestone was involved in the folding, a view supported by examination with the microscope. Within many of the quartz stringers small patches of dolomite and abundant actinolite occur in interlocking radiating groups. In other places large blades of actinolite are set in a matrix of quartz, biotite, and dolomite, and residual crystals of calcite are inclosed in the blades of actinolite. In still another place the groundmass is dominantly dolomite shot through with blades of actinolite.

West of Hill City, near the western edge of the pre-Cambrian area, close to a mass of intrusive granite, another highly metamorphic bed made up of garnet, amphibole, and quartz is exposed, but it contains no layers of pure quartz. Although no residuals of carbonate appear, the bed probably represents an impure and sideritic dolomite.

A common type of calcareous schist is the light to dark green chlorite-biotite variety, which in places has a decidedly micaceous appearance and a moderately well developed cleavage. It bears little resemblance to limestone, though it may carry as high as 50 per cent of carbonate. A variety noted at several places in the northern hills is a light silver-green, red-spotted schistose rock, which is composed of quartz and chlorite and contains patches of ferriferous dolomitic carbonate. The red spots are due to iron oxide formed from the iron carbonate. Ledges on False Bottom Creek consist of chlorite, carbonate, and quartz and contain layers of iron oxide, the exposed edges of which form gently undulating bands.

Some sericite appears in many of these carbonaceous siliceous limestones, notably in a bed near Rochford that is jet black and of glistening luster, like a biotite schist.

Quartz-hematite beds.—Banded beds of quartz-hematite crop out west of the conglomerates on Estes Creek and along the northward-trending ridge just east of Benchmark and north of Boxelder Creek. These beds grade both along the strike and across it into the other rocks of the series, and they occur either below, above, or partly in beds of limestone. At both localities black specular hematite and crystalline quartz occur in alternating layers a fraction of an inch to a few inches in thickness. In many places abundant chlorite and green mica are also present. On Estes Creek the hematite is interlayered with limestone. At both places the beds have been crumpled and broken, the banding has been destroyed, the quartz layers are discontinuous, and in cross section the rock presents the appearance of a flattened-pebble conglomerate. (See Pl. IV.) It is difficult to decide whether the rock in these places is a conglomerate or a breccia, but many of the bodies are certainly breccias, the stiff layers of quartz having been parted and drawn out into lenslike forms by the close folding. This fact is clearly shown in some beds on the ridge just east of Benchmark, where the broken pieces are still angular, only slightly separated, and of such shape as to show their former continuity. At some other places, however, they are rounded.

Correlation.—The pre-Cambrian rocks of the Black Hills can not be precisely correlated with those of other pre-Cambrian terranes. The area is completely isolated and is more than 300 miles distant from other bodies of pre-Cambrian rocks with which these can be compared. Possibly they could be most reasonably correlated with the pre-Cambrian rocks lying south and west of Lake Superior. In the Keewatin, which is the basal complex of that region, igneous material, partly basic and partly acidic, is dominant, but there is evidence that in Canada the Keewatin contains thick sedimentary formations. It is unconformably overlain by sedimentary beds of lower, middle, and upper Huronian age, all separated by unconformities, and unconformably upon these beds lie rocks of Keweenawan age. In the Black Hills the conglomerate contains no granite nor basic igneous rock. This fact indicates that the series is younger at least than the lower Huronian of the Lake Superior region, the basal conglomerates of which everywhere contain an abundant and varied assortment of igneous material.

That the pre-Cambrian sediments of the Black Hills are intricately intruded by granite does not afford a basis for correlation, for although the upper Huronian in the Cuyuna and Mesabi ranges is intruded by granite, much of the Animikie group (upper Huronian) in the Lake Superior region is not so intruded. The next higher series, the Keweenawan, apparently is not represented in the Black Hills, as it carries many characteristics of terrestrial sedimentation and is strikingly lacking in carbonaceous material or other evidence of the presence of life.

These comparisons lead to the conclusion that the pre-Cambrian rocks of the Black Hills are probably older than Keweenawan and younger than lower Huronian and may therefore be either middle or upper Huronian. The presence of lean iron-bearing formations in the series is another feature in which they are similar to rocks of that age in the Lake Superior region.

IGNEOUS ROCKS.

The schists of the Black Hills are penetrated by an earlier group of dioritic intrusives, now highly metamorphosed to amphibolites, and a later group of unmetamorphosed granite and pegmatite.

AMPHIBOLITE.

Distribution.—Amphibolites are abundant in the eastern part of the area from Elk Creek nearly to Keystone, near Rochford, and on its western border west-southwest of Hill City. Many thin masses or narrow dikes also occur throughout the region, but only the more extensive ones are shown on the map. In the eastern area the amphibole occurs both in thin parallel bodies which approximately follow the schistosity and in irregular masses which break across the schistosity. Some of the thin bodies divide into two or more. The great width of the mass west of Bucks is probably due to folding. At Rochford a relatively thick mass is folded with the strata, but it becomes much thinner toward the north. A stocklike mass south of Rochford has been deformed but retains in large part its massive character. In the area west of Hill City several bodies are interbedded with schists and lie parallel to a granite contact.

Character.—The amphibolites are derived from igneous rocks of dioritic composition. Their color ranges from light gray to deep green or nearly black. Where they occur in large intrusive bodies they have a massive appearance, but they are schistose at their borders, and they include many thin sills that closely resemble chlorite or biotite schist of sedimentary derivation. They range from medium to fine grained, their texture showing close relation to that of the original rock. Hornblende and feldspar, plainly visible in the coarser grained varieties, show that the rock was a diorite. The massive varieties of the finer-grained rocks resemble metadiabase, but the schistose varieties closely resemble sedimentary schists. The amphibolites are composed of amphibole, feldspar, quartz, chlorite, zoisite, epidote, calcite, a little apatite, and possibly some pyrite. All these minerals, except some of the feldspar and perhaps some of the amphibole, have been derived in the main from the breaking down of the feldspar, augite, and hornblende of the original dioritic rocks by dynamic metamorphism. Augite was not recognized with certainty, metamorphism having proceeded too far to leave any of this common constituent of diorites and diabases. However, rocks showing every degree of alteration may be observed, from those which are unquestionably igneous to those in which no traces of igneous texture remain.

Origin.—As the amphibolites are included in generally steep-dipping sedimentary strata they are exposed in cross section, so that all their relations are not apparent. Most probably they were intrusive sills and dikes of basic rocks injected into the sedimentary series and not extrusive lava flows. This origin is indicated by their petrography and their relations, especially by the presence of crosscutting dioritic and diabasic masses and of narrow sills that contain minor intercalations.

GRANITE AND PEGMATITE.

Distribution.—Granites occur mainly in the southern part of the Algonkian area, but a small mass of gneissoid granite is exposed on Little Elk Creek, 3 miles north of Nemo, and a mass of granite extends for about 2 miles along the western border west of Oreville.

The largest mass of granite unmixed with schist is a nearly circular mass about 10 miles in diameter that lies south of Hill City. The schist to the east, south, southeast, and southwest of this mass is cut by numberless masses and dikes, large and small. In places the intricacy is so great that separation on the map is not possible, and distinctive patterns are used to show the dominant rocks.

The principal mass of granite is surrounded by a zone of irregular width in which the schistosity follows the contact and along which numerous parallel dikes have been injected. These dikes range in width from a few feet to several hundred feet, and some of them are more than a mile long. They are not mapped, for many are very narrow and are separated from one another only by thin bands of schist. At other places, notably south of Sylvan Lake, there are zones of intricate intrusion and impregnation, in which included blocks of schist present every stage of change from those that are clearly recognizable as fragments to those that have lost their original character. In these places the contact of the schist and granite could not be mapped.

Topographic expression.—The areas occupied by granite are very rugged, in strong contrast to the more parklike areas occupied by the schists. (See Pl. I.) In the country of mixed schist and granite, near Custer and to the southwest, the larger granite dikes give rise to walls and pinnacles, some of which are of considerable prominence, notably in the country around Keystone and Spokane. (See Pls. II and III.) Most of the dikes in the schist areas follow the foliation of the schist, so that many of them are in line with one another or are parallel, but in the quartzite areas southeast of Custer, where granite and quartzose schist are intermingled, the rough, irregular contour of the country is due as much to the quartzite as to the granite.

Character.—The granite of the Black Hills is a muscovite granite that carries an unusual amount of tourmaline. The feldspars, named in the order of their abundance, are microcline, orthoclase, albite, and oligoclase. Muscovite is almost invariably present, and biotite, though not an abundant mineral, appears in some places. Tourmaline occurs in black, blue, or brown crystals and grains. In thin sections apatite, magnetite, zircon, and titanite are seen to be common accessory minerals, and garnet also occurs.

In coarse varieties microcline is perthitically developed with albite and intergrown graphically with quartz. When thus developed, the crystals are large, some of them many inches long. Albite, oligoclase, and orthoclase also occur as individual crystals. Some of the pegmatite dikes carry a great variety of minerals, many of them rare. (See p. 30.) The finer-grained varieties are granular rocks of similar mineralogic composition, in which quartz, microcline, and muscovite are almost everywhere prominent. A little biotite may be intergrown with muscovite.

Much of the granite is so very coarse grained that it may be called pegmatite. This is true of a great part of the large mass surrounding Harney Peak, where, except at the borders, the granite is but little admixed with schist. Most of the numerous dikes in the schists are pegmatite, but in places, particularly in the complexly intruded region east and southeast of Harney Peak, there are dikes and masses of medium to coarse and locally even fine grained granite.

Perhaps the most striking characteristic of the granite is the almost invariable presence of more or less tourmaline, and this mineral is very abundant in the pegmatite. In many places it is one of the major constituents of the rock. In the finer-grained granite it occurs as fine grains or as slender prismatic crystals with quartz and feldspar, and it may be the only dark constituent of the rock. Other varieties may contain a little biotite or muscovite or both.

The coarse-grained granite of the great mass around Harney Peak is composed of quartz, feldspar, tourmaline, and muscovite. Its texture is notably irregular. The feldspar is micrographically intergrown with quartz, and its individual crystals, some of them very large, are literally filled with quartz. Irregular masses of quartz are also abundantly but sporadically distributed through the rock. Tourmaline or muscovite or both, disseminated or in bunches of large crystals, may occur throughout the rock. This central mass presents a rude layering, visible only on a large scale and due in a broad way to the arrangement of the minerals of the rock. This layering dips outward with the dip of the schist and becomes flatter as it approaches the summit of the mass. It was probably developed by the pressure of intrusion.

Mechanics of the granite intrusions.—An igneous mass may advance in at least three ways—it may occupy fractures in the invaded rock, it may incorporate the invaded rock within its margin by solution or assimilation, or it may occupy space vacated by blocks that fall from the roof into the mass. Various phases of all these ways of advance are seen in the Black Hills, and each phase is generally in part dependent on the nature of the invaded rock. The granite has been intruded into the country rocks in a few large masses and in numberless minor dikes, and the rocks invaded are in part relatively plastic schistose rocks and in part brittle rocks. The form of

[2] Paige, Sidney, Pre-Cambrian structure of the northern Black Hills, S. Dak., and its bearing on the origin of the Homestake ore body: Geol. Soc. America Bull., vol. 24, pp. 293-300, 1913.

the intrusive body is different in these two kinds of rock. In general the structural planes of the plastic schistose rocks have had great influence on the shape of the intrusive masses. They were the paths of easiest ingress, and the magma, which formed bodies ranging from dikes a few feet in width to masses of great size, invariably followed these planes. (See Pl. XI.)

The intensity of the effects of the intrusion gradually increases toward the main granite mass of Harney Peak. Near the contact many successive closely spaced sheets of granite follow the schistosity, which is parallel with the contact; farther out these sheets become progressively less numerous. (See Pl. IX.) The schist between these sheets is in places filled with extremely narrow parallel veinlets of quartz and feldspar. In places within the main contact the invaded rocks have been so completely assimilated by the granite that only dim outlines of the inclosed fragments of schist are visible, the process having progressed beyond the mechanical subdivision of the layers to a chemical absorption of the minerals themselves. (See Pl. X.) In the brittle rocks the dikes and masses do not generally follow the bedding planes of the invaded rock; they nearly everywhere cut across those planes. The sedimentary rock is thus broken into numberless fragments that are enmeshed within the intrusive mass, stratigraphic sequence is destroyed, and blocks of strata have been uplifted and eroded away or have sunk far below the surface.

The conditions under which the magma advanced to its present position and the cause of its congelation are probably related to the character of the invaded rocks. The schists in the zone of intricate injection were evidently folded and mashed by pressure caused by the advance of magma sufficiently viscous to deform the softened schist. Many of the contacts are long, irregular wavy surfaces, the inequalities of which are followed by a schistosity locally superinduced in the strata. That this pressure was exerted at late stages of intrusion, when the magma was viscous, is indicated by a rude banding of the granite in some places near the contacts. This feature also appears in other places, far from the present contact but probably near a former one. There are also two areas of gneissoid granites. Folded quartz veins and folded dikes likewise indicate compressive movements at a late stage of the intrusion.

The evidences of minor movements of the schist caused by the pressure of the magma suggest a like origin for the zone of parallel schistosity that encompasses the main granite contact, with a width of half a mile or more. The development of this zone is related to the development of a series of close recumbent folds, whose axial planes lie approximately parallel to the dipping surface of the granite contact. They are especially well displayed on the road from Hill City to Keystone, north of Harney Peak. As the general trend of the regional axis of folding is northward the divergent course of these contact folds indicates that the intrusion of the granite produced the contact folds in opposition to the forces then acting to produce the northward-trending folds.

In the brittle rocks the upward-moving magma has caused breaks instead of flexures, so that there are many detached blocks intersected by granite.

The effects of the congelation of the magma are indicated by some of the structural relations. The Harney Peak mass is bordered on three sides at least by a zone containing many parallel dikes, which doubtless connect with the main mass of granite and are wedgelike projections into the schist. If the granite resumed its upward motion and possessed the same physical qualities as it did when these narrow wedgelike dikes were being injected, the schists that surround the granite would suffer further distension, and, if the motion continued, any selected area of the crust would consist dominantly of granite interleaved with minor slabs of schist. In this border zone the thickness of the pegmatite dikes and the schist layers ranges from a few feet to 100 feet or more. The schist layers are obviously not supported solely at their juncture with the main body of the schist, where they are very thin in proportion to their length and depth. Evidently the conditions of the intrusion and the relative specific gravities of the invaded and invading rocks prevented the fragments from sinking into the pegmatites. However, even if the specific gravity of the invading magma was less than that of the schist it is not evident that the schist would always tend to sink, for the magma might exert a pressure which, if applied only to the surface of a schist layer, would afford it considerable support. The mechanical conditions under which the magma proceeded in its intrusion in the brittle distended quartzite blocks must also be considered. Blocks of quartzite could scarcely break from their roof support, sink into the magma, and become incorporated in it at depth, because the specific gravity of the magma could hardly be materially less than that of the quartzite. If the quartzite was of higher specific gravity than the molten magma the forces that tended to prevent sinking were the strength of the block at its junction with the main body of quartzite and in some measure the support of the magma, the latter a factor of great significance. Therefore the magma probably advanced by the distension of the crust and not necessarily by continuous upward movement nor along one path. It might have followed a great unconformity or fault plane, or developed enormous laccoliths, or constituted a batholith.

The petrographic character of the granite near its contacts throws some light on the mechanics of intrusion. The granite of Harney Peak is so coarse that it might properly be termed pegmatite, and the rock of the dikes that radiate from it is a perfect pegmatite. Many rare minerals occur in these dikes, and the magma evidently contained an abundance of such mineralizers as boron and water. The fused silicates formed a homogeneous solution with water and other volatile substances. The temperature of a magma that formed a granite so coarse grained was probably between 560° and 580° C., a temperature too low to permit extensive assimilation of the invaded rocks. Although the impregnated fragments formed near contacts indicate a general process that begins with the injection of large sills and ends with a permeation so complete that only an outline of a fragment of schist remains, it is highly probable that this process is largely mechanical up to an advanced point, when it becomes in part chemical. It consists essentially of the injection of magmatic fluid along each individual cleavage plane. A fragment of schist so injected becomes plastic and becomes impregnated across its layers as well as between them. It may even break down molecularly, go partly into solution, and recrystallize.

These changes tend to bring the invaded rock and the injected rock to a similar chemical and physical condition. The injection of granite into schist is therefore likely to produce equal density in the material invaded and in the invading granite, so that any tendency to sink or rise that an individual block might have by reason of its greater or less density would be diminished by the injection of the fluid magma. Therefore such injection may prevent the sinking of large blocks of roof. A somewhat similar view, that intricate injection tends to neutralize differences in specific gravity, was reached by Fenner,[3] who considered the problem from the physicochemical side. He says:

> The invasion of the magma is preceded by the advance of a wave of metamorphism into the wall rock, by which the character and composition of the original material are radically altered. By the deposition of magmatic minerals and by the removal in solution of certain of the previous constituents the composition tends to approach that of the magma itself, and when blocks of wall rock are finally engulfed in the magma their composition may be so changed that their assimilation effects but little change in the composition of the latter.

It is a striking fact that in the Haliburton-Bancroft area,[4] where the rocks have been generally invaded and assimilated by the magma, disruption and injection "bed by bed" have proceeded on a grand scale. Here the beds have been invaded across and along the bedding planes and thus intricately broken. Because of a myriad of feeders tenuous magmatic material is able to permeate the rocks. The injection up to an advanced point is, however, effected by the actual physical disruption of the rocks. It is a most direct effect of the proximity of an engulfing magma.

The relations of the rocks indicate that the granite of the Black Hills came into its present position in the main by distension of the older rock body under great pressure. The schists, deformed by the advance of the magma, were forced into closely appressed recumbent folds. The schistosity produced during this folding favored further injection by the magma through great numbers of parallel dikes and by intricate intrusion "bed by bed." The harder quartzites were distended and broken apart by the intrusion, and the magma flowed in between the blocks. Several lines of evidence indicate that the magma was intruded at a relatively low temperature, that it contained considerable water, and that it acted as a relatively mobile mass. The relation of the dikes to the layers of schist, the fact that injection "bed by bed" tends to neutralize the physical and chemical differences between the magma and the invaded rock, the probable low temperature of the magma, and the lack of positive evidence of much assimilation all support the belief that the magma moved forward mainly by displacing the country rock and only in small part by assimilating it. The possibility that large blocks of the roof have been engulfed in the magma must remain an open question.

PALEOZOIC TO CENOZOIC SEDIMENTARY ROCKS.

By N. H. Darton.

CAMBRIAN SYSTEM.

UPPER CAMBRIAN SERIES.

DEADWOOD FORMATION.

Outcrop.—The outcrop of the Deadwood formation encircles the area of schist and granite. To the south, where the dips are steep, the outcrop lies mainly at the foot of limestone cliffs and is largely covered by talus, but north of Rapid Creek the outcrop widens greatly. The formation is exposed in the uplifts of Crow Peak, Whitewood Peak, Citadel Rock, Polo Peak, and Kirk Hill, on Iron Creek, and in the walls of the canyons of Spearfish, Little Spearfish, Whitewood, Two Bit, and Little Elk creeks. There are small outcrops in Stage Barn Canyon east of Nemo and in Coldbrook Canyon, Bear Springs Canyon, and other deep canyons in the limestone escarpment.

Relations.—The Deadwood formation lies on the edges of the schists and granites on a plane which is relatively smooth except for a few local shallow channels and low projecting ridges.

The formation is overlain by Englewood limestone except in the northern Black Hills, where the Whitewood limestone intervenes. In both areas there is no appreciable difference in attitude and no notable channeling of the old surface, although the hiatus represents a large part of early Paleozoic time. The formation becomes much thinner toward the south, apparently because the upper beds become thinner in that direction. Possibly this thinning is due in part if not entirely to increasing pre-Carboniferous erosion toward the south, especially in the area where the Whitewood limestone is absent. It is possible also that the medial members become sandy and overlap far to the south. The section in Figure 3 shows the general stratigraphic relations.

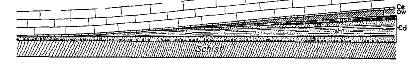

Figure 3.—Diagrammatic section showing unconformity at the top of the Deadwood formation; the overlying beds overlap southward.

Ꞓd, Deadwood formation composed of a lower sandstone (ls), shale (sh), upper sandstone (us), and upper shale (ush). Ow, Whitewood limestone; Ce, Englewood limestone; Cp, Pahasapa limestone.

Thickness.—The thickness of the Deadwood formation at some representative localities is shown in the list below.

Thickness of Deadwood formation in the Black Hills.

	Feet.
Bear Butte Creek canyon	500
Deadwood region	389–400
Spearfish Canyon	450
Elk and Little Elk creeks	250
Rapid and Squaw creeks	200
Hat Mountain	180
West of Hill City and Custer, north and southwest of Otis, and on Lightning Creek	100
Spring Creek northwest of Hermosa to French Creek	100
Wind Cave	60
Pringle	50
Lame Johnny Creek	4

General character.—The Deadwood formation consists largely of hard brown or dusky buff sandstone, and it includes a widespread basal conglomerate. To the north it contains limestone and much green shale. Where the formation is thin it is all sandstone and conglomerate or conglomerate alone.

In the northern hills the formation consists of a basal member, about 25 feet thick, composed of hard, massive reddish-brown sandstone, mostly quartzitic, in places having a conglomerate at its base; a medial member of greenish sandy shale, which includes layers of flaggy dolomitic limestone and local limestone conglomerates and interbedded slabby sandstones, some of them bearing fucoid markings; and an upper member of brown or buff sandstone, which presents a strong reddish-brown tint in the Elk Creek region. It usually shows worm borings (scolites) or casts of annelids. Many beds contain considerable glauconite in disseminated grains. In the Deadwood region and for some distance to the south there is a thin top member of greenish papery shale, which is at some places capped by a bed of sandstone.

Basal conglomerate.—In the northern hills the basal conglomerate is found mainly in a belt that extends from an area east of Roubaix northwestward to Blacktail Gulch. It caps the spur between Blacktail and Deadwood creeks, the hills on both sides of Bobtail Gulch, and the hill southwest of the Homestake mine and thence extends westward, but it is thin in the hills west of Maitland. It appears also near Iron Creek. This zone of its outcrop is only about 2 miles wide, and in general it trends northwestward. On either side of it the conglomerate decreases in thickness to only a few inches or gives place to a thin layer of conglomeratic sandstone, and in some places it is absent. The rock is hard and consists largely of small rounded pebbles of white quartz, mostly from veins in the underlying schist, together with a varying proportion of angular fragments of schist in a brown sandy matrix, mainly quartzitic. Near the Homestake lode part of its matrix contains pyrite, which at the surface is weathered to iron oxide. In places the pebbles are large, some of them being 4 to 6 inches in diameter. The conglomerate averages 5 or 6 feet in thickness, but in places it is 20 feet thick. It merges upward and laterally into reddish-brown sandstone or quartzite, and in many areas the base of the formation is a massive quartzite 5 to 40 feet thick.

A view of the basal conglomerate is given in Plate XIII, and a characteristic outcrop of the upper sandstone member in Deadwood in Plate XIV.

Medial member and its limestone conglomerate.—The middle member of the Deadwood formation in the northern Black

[3] Fenner, C. N., The mode of formation of certain gneisses in the highlands of New Jersey, Part II: Jour. Geology, vol. 22, p. 701, 1914.

[4] Idem, p. 700.

Hills consists mainly of gray shale, but it includes considerable reddish-brown or dusky-buff sandstone and limestone and limestone conglomerate and breccia—rocks that are also characteristic of the formation in the Big Horn Mountains and other localities. It is especially prominent in the Two Bit district and on Little Spearfish Creek. This conglomerate occurs in irregular deposits and locally merges into or alternates with beds of flaggy limestone, generally interbedded with greenish shale. Most of the limestone pebbles are flat and long and are covered with glauconite, and as some of them contain Cambrian fossils they must be of contemporaneous origin. In places the pebbles are bent, broken, and even contorted and lie at various angles in the matrix, which consists of calcium carbonate. The conglomerate appears to consist of layers of limestone, broken when soft, somewhat eroded by flowing water or on beaches, and evidently not far away from the original ledges.

Local features.—The Deadwood formation presents many variations from place to place, but only its more notable features can be described here. At the type locality, on Whitewood Creek below Deadwood, it includes the following strata:

Section of Deadwood formation at Deadwood, S. Dak.

	Feet.
Sandstone, buff and gray, slabby, with fucoids; overlain by Whitewood limestone	20
Shale, olive green, soft and flaky	25
Sandstone, white, quartzitic; contains annelid trails and borings	15
Sandstone, red, more massive in upper portion, with interbedded green shale and dolomite breccia; contains much glauconite and many fucoid markings	100
Limestone, flaggy, dolomitic, gray, with scattered lenses of flat-pebble limestone conglomerate; interbedded with green fissile shale	220
Sandstone, red, limy, and soft brown shale	17
Sandstone, brown to buff, quartzitic above, cross-bedded in places; 3 inches of conglomerate of quartz pebbles and green shale, with fragments of *Obolus* shells, at the base; lies unconformably on schist	32
	429

The contact at the base of the formation is well exposed in the cliff along the railroad in the lower part of Deadwood. Here the conglomerate, only 3 inches thick, lies at the base of a thick member of brown ferruginous sandstone and consists of partly rounded quartz pebbles and schist fragments in a matrix of green chloritic matter that contains distinctive fossils.

In mines and outcrops in the Nevada Gulch district the basal member of the formation consists of about 20 to 30 feet of quartzite. Next above this member comes dolomitic limestone in flaggy layers 2 to 3 inches thick, which weather dark red and are separated by thin beds of greenish-black shale. Alternations of these dolomite flags with green shales and red sandstones occur throughout the Deadwood formation in Nevada Gulch and vicinity, where many thin sills of porphyry are intruded in them.

Section of lower members of Deadwood formation on railroad on northeast slope of Terry Peak, near Englewood, S. Dak.

	Feet.
Sandstone, gray to brown, glauconite in some beds, part massive, part slabby	122
Shale and slabby limestone, mostly brecciated	57
Sandstone, slabby	8
Shale and interbedded slabby limestone and flat-pebble limestone breccia	29
Sandstone and shale, with fossils	2
Shale, dark	5
Limestone, slabby, with breccia of flat pebbles of limestone	2
Sandstone, brownish to buff, part slabby	17
Shale and flaggy limestone layers	6
Sandstone, hard, massive, resting on schist	42
	290

Around Lead all the basal beds differ in thickness and character. The conglomerate is absent at the north end of the Homestake cut, where sandy shales and layers of brecciated limestone lie directly on the hard Homestake lode, which formed a ridge at the beginning of Deadwood time. On either side of this buried ridge the conglomerate fills channels 2 to 30 feet deep and grades up into cross-bedded sandstone, in part quartzitic, with some admixture of conglomerate. The conglomerate crops out in Cole Creek, north of Richmond Hill, but is not conspicuous on the eastern side of the Ragged Top plateau between Squaw Creek and Bald Mountain, where there is a marked westward thinning of the Deadwood formation to 200 or 300 feet. On the spur east of West Strawberry Creek the conglomerate is 20 feet thick, and on the next spur to the southeast it is only 4 feet thick. It consists everywhere of rounded and subangular quartz pebbles and some slate pebbles, and it grades up into massive sandstone. On Strawberry Ridge the basal quartzite is exceptionally thick and massive and forms a cliff 40 feet high.

From Whitewood Creek to Spring Creek the conglomerate is generally about 3 feet thick and the overlying beds 380 feet. In the vicinity of Bear Butte Creek and south of it to Elk Creek the conglomerate has an average thickness of 15 feet, and the overlying beds gradually become thinner to the south. On both sides of the pre-Cambrian quartzite ridge 2 miles west of Elk Creek post office the conglomerate is very coarse and lies in irregular hollows. Its character is shown in Plate XIII. The boulders in the conglomerate, many of which are 3 feet in diameter, consist chiefly of banded black and white quartzite derived from the adjacent ridge, but some of the smaller ones consist of schist and amphibolite. Some are rounded, others angular, and they greatly preponderate over the red or brown silicified sandy matrix. Conglomeratic beds occur on the opposite side of Elk Creek to the south and east, but the material is finer grained. To the south the zone of basal conglomerate, about 4 miles wide, extends to the head of Meadow Creek, and to the north it caps the north end of Windy Flats and extends up the gulch south of Strawberry Ridge and thence by West Strawberry Creek to Lead and Blacktail Gulch. Along the creek south of Strawberry Ridge its thickness is 3 to 10 feet, and most of the pebbles, which are composed of quartz, are small. In general this zone of conglomerate follows the trend of the Black Hills uplift and probably represents a beach deposit, which was covered later by fine material as marine submergence increased or extended westward. The basal conglomerate along the creek south of Strawberry Ridge is 3 to 10 feet thick and consists chiefly of small quartz pebbles. In the slopes north of Sugarloaf Mountain it is thin and consists of pebbles of angular quartz and schist, a quarter of an inch to an inch in diameter, in a red matrix. It is overlain by quartzite and shale.

On Spearfish Creek, where the formation is about 450 feet thick, it consists at both top and bottom of quartzite and brown sandstone, which are separated by a thick member of shale and flaggy dolomite.

Near Englewood the upper sandstone member is about 115 feet thick; some parts of it are softer than others, some of it is glauconitic, and some beds are slabby. Here and around Crown Hill it is overlain by about 70 feet of pale-green fissile shales. The medial member of the formation consists of an alternation of sandstone, shale, and slabby limestones, and some of the beds show mud cracks and fucoids. The basal quartzite is hard and forms a tabular bench on a cliff about 12 feet high. The upper beds of the Deadwood formation along Bear Butte Creek near Galena are similar to those in the region on the west, but the upper shale member is thin and of lighter color and is not everywhere present.

Section of upper beds of Deadwood formation east of Galena, S. Dak.

	Feet.
Sandstone, in part hard, mostly white, some of it pink, yellow, brownish; overlain by Englewood limestone	14
Shale, gray, limy; contains scolithus borings throughout	6½
Sandstone, massive, brown	25
Sandstone, soft, thin bedded, very glauconitic	38
Shale, yellow and green, glauconitic; a few layers of sandstone; fucoids	71
Sandstone, hard, light gray; fucoids	1
Limestone, shaly and slabby; some glauconite; fucoids	9
Talus	40
Limestone, gray, slabby; contains glauconite, fucoids, and flat-pebble conglomerate	8 +
	212½+

In the region near Elk Creek and for some distance to the south the top member of dark shale is underlain by 20 to 50 feet of red sandstone, the medial member, consisting of sandy shales and limestone breccia, is about 100 to 150 feet thick, and the basal member, of massive brown sandstone, is about 40 feet thick. (See Pls. XIX and XXVIII.) West of Kirk Hill, where the top shales are 15 feet thick, they are greenish gray. In places the basal sandstone is quartzitic, and much of it is conglomeratic, especially the lower beds, which in places consist of 15 to 20 feet of conglomerate of angular, subangular, and large well-rounded boulders, as described above. The thickness of the medial member diminishes steadily toward the south. It is composed mainly of limy and sandy shales, which in most places contain much glauconite. The shales are green when fresh, but on weathering most of them become dull red, owing to oxidation of the iron and glauconite. These shales include the highly characteristic flat-pebble limestone conglomerates, mostly in layers a few inches thick but locally in beds 6 to 10 feet thick.

The two following sections are representative for the region from Elk Creek to Rapid Creek:

Section of Deadwood formation near mouth of Little Elk Creek canyon, S. Dak.

	Feet.
Shale, soft, dark gray	25±
Sandstone, hard, massive, purplish brown, partly cross-bedded	35
Sandstone, flaggy, glauconitic; some flat pebble conglomerate	30
Sandstone, thin bedded, glauconitic	20
Shale, red, green, and yellow; some beds highly glauconitic; layers of limestone breccia	80
Sandstone, snuff-colored, mostly thin bedded, and purple and buff shale	35
Sandstone, massive, hard, brown, lying on granite	25
	250

Along Victoria Creek, about 2 miles above the point where it enters Rapid Creek Canyon, the basal conglomerate is 10 feet thick and consists largely of subangular to well-rounded boulders, 6 inches in diameter, which were derived from the underlying crystalline rocks. It is overlain by 10 feet of flaggy sandstone or quartzite.

Section of Deadwood formation on Rapid Creek, 7 miles west of Rapid City, S. Dak.

	Feet.
Sandstone, massive, brownish red	22
Sandstone, thin bedded, reddish brown	20
Shale and shaly sandstone, reddish brown	50
Shale, glauconitic, and layers of limestone breccia	70
Sandstone, shaly, green and yellow, glauconitic	15
Sandstone, coarse, with a few pebbles	8
Conglomerate with small pebbles	3
Sandstone, coarse, with scattered small and large pebbles	6
Conglomerate of large boulders; lies on granite	6
	200

Along the eastern side of the uplift, in the region west of Hermosa and Fairburn, notably from Hayward to a point beyond French Creek, where the dips are steeper, the hard quartzitic basal member gives rise to knobs or long, bare rocky slopes of considerable prominence. It is also conspicuous on the west side of the central area. On Spring Creek at a point north of Rockerville, where the formation is 150 feet thick, it becomes more glauconitic and less quartzitic. Its basal sandstone member, locally conglomeratic, is 20 feet thick and is overlain by a thick mass of alternating thinner and thicker layers of brown sandstone containing many fossils. Some of the layers are covered with impressions of large fucoids. Near Rockerville and Hayward the basal bed carries free gold, which has been mined to some extent. Along Battle Creek in the vicinity of Hayward the dark-reddish basal quartzite, about 30 feet thick, crops out in cliffs and long rocky dip slopes. It is overlain by 30 feet of sandy shale and thin sandstone, which ranges from reddish brown to grayish brown and grades up into 10 feet of softer lighter reddish-brown or dusky-buff sandstone. This top sandstone member thins to the south and in the slopes 2 miles south of Hayward is only 2 feet thick.

About 3 miles below Spokane the formation consists of 30 feet of thin-bedded red to brown sandstone and shale on 30 feet of brownish-red massive hard quartzite. In bluffs on Squaw Creek below Otis the basal quartzite is overlain by thin-bedded partly red sandstone and shale, and the top member, 20 feet thick, is composed of massive soft gray sandstone. The total thickness is about 105 feet. About 3 miles northeast of Otis the formation consists of 30 feet of basal quartzite, 80 feet of thin-bedded glauconitic sandstones with interbedded green shale and flat-pebble limestone conglomerate, 8 feet of massive light-brown sandstone, and a top member of gray shale 10 feet thick.

In French Creek Canyon the formation has 45 feet of reddish quartzite at the base, above which lies 30 to 40 feet of thin-bedded or slabby sandstone with sandy shale and local layers of flat-pebble limestone conglomerate, and at the top 16 to 20 feet of massive buff sandstone.

On Lame Johnny Creek the formation is about 40 feet thick and consists of coarse brown fossiliferous sandstone with a few intercalated layers of pinkish limy beds. On a branch of the same creek 2 miles farther north the formation consists of 4 feet of coarse conglomerate. At another place in the vicinity it consists of 16 feet of red sandstone, grading down into 4 feet of basal conglomerate.

On Beaver Creek 2 miles north of Wind Cave the basal conglomerate lies against a granite slope, evidently an old shore cliff. A section farther down the canyon shows a 20-foot lower member of dark-brown sandstone, conglomeratic at base, and an upper member of light-colored thin-bedded sandstone, shale, and limestone. Two sections here are given below:

Section of Deadwood formation on south side of Beaver Creek, 1½ miles north-northwest of Wind Cave, S. Dak.

	Feet.
Sandstone, flaggy to massive, greenish, limy	4
Sandy beds, soft, chiefly concealed	5
Sandstone, massive, coarse, quartzitic, glauconitic, fossiliferous	8
Sandstone, coarse, red	4
Shale and soft sandstone, fossiliferous, chiefly concealed	22
Sandstone, massive, dark buff	5
Sandstone, shaly, and sandy shale	10
Sandstone, conglomeratic, thin-bedded, and conglomerate	1–2
	60

Section of Deadwood formation 1½ miles above the mouth of Reaves Gulch, T. 5 S., R. 5 E., S. Dak.

	Feet.
Sandstone, massive, limy	10
Soft layers, concealed	8
Sandstone, coarse, quartzitic, fossiliferous	8
Shale, soft, knotty, and shaly sandstone	7
Sandstone, massive, conglomeratic, fossiliferous	9
Sandstone, soft, shaly	2
Sandstone, massive, conglomeratic	10
Sandstone, soft, conglomeratic; coarse conglomerate at base	2
	56

A boring in Martin Valley (sec. 20, T. 6 S., R. 6 E.) penetrated hard brown sandstone at depths of 1,320 to 1,417 feet, lying on granite.

In the uplift on Coldbrook Canyon, in T. 6 S., R. 5 E., the formation consists of coarse buff to brown sandstone, 45 feet thick, overlain by 5 feet of slabby sandstone and gray shale, and rests on jointed pre-Cambrian schist. (See Pl. XV.)

Around Pringle the formation consists of 50 feet of moderately hard red-brown sandstone, which contains many fossils. There are extensive exposures in the canyons at the head of

Pleasant Valley, notably near Ninemile ranch, where the lower sandstone, 50 feet thick, is highly fossiliferous. It is overlain by 30 feet of slabby sandstone containing layers of flat-pebble limestone conglomerate and having a top member of buff sandstone. Red sandstone crops out at intervals below cliffs of Pahasapa limestone west of Custer, and north and east of Bull Springs there is considerable basal conglomerate. Northward from the head of French Creek the formation gradually increases in thickness, and the upper and lower sandstone members and intermediate shaly member are present. Northwest of Hill City the upper member, consisting of brown sandstone, about 60 feet thick, is underlain by 110 feet or more of sandy shale and soft sandstone, in part glauconitic, brownish buff in the upper part and reddish brown below. The base is conglomeratic, and the medial beds contain layers of flat-pebble limestone conglomerate.

Fossils.—In the Deadwood formation fossils occur most abundantly in sandstone near the base and in the slabby limestone layers. The upper members have yielded only casts of worm borings (scolites), which they nearly everywhere contain.

C. D. Walcott has determined the following species from the basal sandstone: *Dicellomus pectenoides, D. politus, D. nanus, Lingulella cuneolus, L. similis, Lingulella* (*Lingulepis*) *acuminata, Hyolithes primordialis*, and *Ptychoparia oweni*.

These fossils were collected near Deadwood, on Whitewood Creek northwest of Central City, at Lead, at Citadel Rock, on Spruce Creek, near the head of Meadow Creek, in Whitetail Gulch, near Galena, and 3 miles west of Savoy. At Deadwood the basal conglomerate yielded *Dicellomus pectenoides, Lingulepis*, and fragments of trilobites. *Asaphiscus, Ptychoparia oweni, Acrotreta*, and *Lingulella* were collected in the flaggy limestones and green shales of the medial member.

At Hat Mountain fossils occur at several horizons, notably in the lower member, where *Lingulepis, Obolella*, and fucoids were collected. Good specimens of these genera and many fragments of trilobites were collected near Eightmile ranch.

These fossils are classed as Upper Cambrian (St. Croixan) and are found at several horizons, which will be separated when the formation is studied in detail.

ORDOVICIAN SYSTEM.

UPPER ORDOVICIAN SERIES.

WHITEWOOD LIMESTONE.

Outcrop and character.—The typical exposure of the Whitewood limestone is on Whitewood Creek below Deadwood, where it is underlain by a slabby light-colored sandstone showing fucoid markings and worm burrows, which was originally assigned to it but is now regarded as a local top member of the Deadwood formation. The limestone is 60 to 80 feet thick around Deadwood and in Spearfish Canyon. It thins southward and disappears in the southeastern part of Lawrence County. On Bear Butte Creek and Elk Creek its thickness is about 50 feet. It appears in the uplifts of Crow Peak, Citadel Rock, Ragged Top, Whitewood Peak, Kirk Hill, Deadman Mountain, and south of Bear Gulch.

The limestone occurs in hard and massive beds, mostly buff or pinkish, with pale-brownish spots. Around Deadwood this rock is overlain by several feet of gray and yellow shale, which is regarded as the base of the Englewood limestone. The Whitewood limestone crops out as a prominent bench below cliffs of Pahasapa and Englewood limestone and above slopes of the Deadwood formation. The limestone lies on the Deadwood formation without discordance of dip, but the two formations represent separated stages of deposition.

Local features.—At the quarry on Whitewood Creek about 2 miles below Deadwood, the upper member of the limestone is 40 feet thick and is a very pale buff massive rock with reddish spots. It contains large fossils and lies on 20 feet of pale reddish-yellow beds that weather to small rectangular blocks and slabs. These beds lie on 20 feet of limy flaggy sandstone with fucoid markings, regarded as a local top member of the Deadwood formation. This sandstone is underlain by the dark shale member, which is well exposed near the smelter. The limestone is exposed near the tunnel a mile northwest of Whitewood Peak and in Spearfish Canyon at the mouth of Iron Creek, where it makes a 70-foot ledge. Near the mouth of Little Spearfish Creek 80 feet of the light-colored limestone forms a cliff above a slope of green sandy fucoid beds (Deadwood). Part of it contains egg-shaped nodules of chert, and most of it is pitted and mottled buff. The top beds crop out farther up this creek above the mouth of Dry Creek. The limestone thins southward and disappears near Spearfish Crossing. Its outcrop extends up Annie Creek and Lost Camp Gulch, where its buff tint and reddish mottlings are conspicuous. Near Crown Hill and Carbonate it is from 60 to 80 feet thick, and at the mouth of Jackass Gulch it is 70 feet thick. In Spearfish Canyon and the slopes farther east it lies on 10 to 15 feet of gray sandstone, which contains fucoids and worm burrows and is regarded as the top member of the Deadwood formation. In this canyon, south of the mouth of Sweet Betsey Gulch, the rock is light brown and siliceous. South of Crown Hill station it crops out as a 20-foot ledge of buff to pinkish limestone with darker blotches and contains many fossils. At Maurice, in Spearfish Canyon southwest of Spearfish Peak, it consists of an upper member, 50 feet thick, of massive pale-buff limestone with irregular network of purplish stains and pitted weathered surface, and a basal member, 15 feet thick, of vertically jointed buff limestone, which lies on white sandstone at the top of the Deadwood formation. The overlying fine-grained pinkish limestone with light purplish-pink blotches is regarded as basal Englewood. On the north slope of the Crow Peak intrusive mass the limestone consists of 40 feet of massive rock with purplish mottling, and in the ridge between Peedee Gulch and Two Bit Canyon it consists of about 65 feet of pinkish and pale orange-tinted limestone, which lies on a 12-foot sill of porphyry. Bear Butte Creek shows 50 feet of the typical massive spotted sandy limestone with some yellowish and brownish sandy beds at the top. Near the site of Elk Creek post office about 65 feet of the mottled limestone lies on the olive fissile shales at the top of the Deadwood formation. A mile east of this place it is only about 25 feet thick, and on the west side of Kirk Hill and in the upper part of Deadman Gulch it presents 40 feet of the usual buff massive limestone with pinkish blotches. Near the mouth of Meadow Creek there is a 10-foot ledge of hard yellow rock, which grades down into softer limestones of yellowish, brownish, and purplish tints, mottled with darker shades and highly fossiliferous. It is cut off by the intrusive mass north of Runkel and on Alkali Creek. It thins out and finally disappears under talus north of Little Elk Creek, about 3 miles southeast of Runkel, but apparently there is a small, thin outlier of the formation in the ridge a mile northeast of Nemo.

Fossils.—The Whitewood limestone, especially the massive spotted member, contains many large fossils, which have been identified by C. D. Walcott as follows: *Receptaculites* near *R. oweni, Maclurina manitobensis, Endoceras annulatum, Halysites gracilis, Dalmanella testudinaria, Buthotrephis* like *B. succulens*, and *Hormotoma major?*. These fossils have been collected at the quarry on Whitewood Creek 1½ miles below Deadwood, near the tunnel a mile northwest of Whitewood Peak, on the west branch of Meadow Creek, in Spearfish Canyon south of Crown Hill, on Annie Creek, and northwest of Pillar Peak.

The thin outlier a mile northeast of Nemo yielded fragments of fish bones similar to those in the sandstone west of Canon City, Colo.[5]

The fauna is Upper Ordovician, representing approximately "Richmond" time, the same as the Big Horn dolomite of the Big Horn Mountains. The hiatus between the Whitewood and Deadwood formations represents earlier Ordovician time.

CARBONIFEROUS SYSTEM.

In the Black Hills region the Carboniferous system comprises several formations, which represent the earlier and later parts of the period, but a long interval of late Mississippian time is not represented.

MISSISSIPPIAN SERIES.

ENGLEWOOD LIMESTONE.

Outcrop.—The pale-pinkish to buff slabby Englewood limestone crops out in slopes at the foot of Pahasapa limestone cliffs, where, however, it is mostly covered by talus. It is revealed by erosion along Coldbrook Canyon and at Bear Springs, 10 miles northwest of Custer. Its thickness is 30 to 60 feet, and the minimum is at the mouth of Little Spearfish Creek. It is 42 feet thick on Elk Creek.

Relations.—Although the Englewood limestone is separated from the Whitewood by a break representing Devonian, Silurian, and a large part of Ordovician time, the contact shows no evidence of unconformity. In the region north of Deadwood the limestone grades into 15 feet of gray and yellow shale, regarded as a lower member. This basal shale and the Whitewood limestone become thinner to the south, where the Englewood slabby limestone lies on shale at the top of the Deadwood formation; and where the shale is absent it lies on sandstone of the Deadwood formation. It merges into the overlying Pahasapa limestone in places through a few feet of buff limestone, but in a railroad cut 2 miles south of Englewood there is an abrupt change in lithology between the two formations, which suggests local unconformity.

Local features.—On Whitewood Creek above Englewood station the limestone has a deep pinkish-purple tint. Its upper part is thin-bedded, but it is more massive below. It shows purple spots or blotches elongated parallel to the bedding and contains cavities lined with calcite. At many places fresh surfaces are gray. South of Englewood its lower surface shows knobs, 1 to 3 inches in diameter, of concretionary nature. In this region the Englewood lies on greenish-gray shale at the top of the Deadwood formation. In the vicinity of Bear Butte Creek the formation consists of about 50 feet of pink or purplish thin-bedded limestone with red iron-stained fossils. In Spearfish Canyon, where the thickness at most places is 40 feet, the beds consist of dove-colored slabby limestones with purplish concretions, merging upward into purplish-gray shale. Along Whitewood Creek below Deadwood, where the formation is 50 feet thick, it consists of purple shaly limestone bearing yellow stains, which merges upward into gray slabby limestone, streaked with dark red and containing many druses of calcite. These beds grade downward into 10 feet of shale, gray at the top and yellow below, which lies on Whitewood limestone. On Rapid Creek the formation consists of about 45 feet of pinkish to buff slabby limestone.

[5] Darton, N. H., Discovery of fish remains in Ordovician of the Black Hills, S. Dak.: Geol. Soc. America Bull., vol. 19, pp. 567-568, 1908.

Fossils.—Many fossils have been collected from the Englewood limestone, notably in a quarry by the road a quarter of a mile south of Galena, in the gulch west of Pillar Peak, in upper Spearfish Canyon near the mouth of Raspberry Gulch, and in basal shales in road cuts about a mile north of Deadwood. G. H. Girty has identified the following forms: *Zaphrentis* several sp., *Enchostoma* sp., *Fenestella* several sp., *Rhombopora* sp., *Lingula* sp., *Leptaena analoga, Schuchertella* aff. *S. chemungensis, Schizophoria* aff. *S. swallowi, Chonetes* aff. *C. gregarius, C. logani, Productella* aff. *P. pyxidata, Productus* aff. *P. blairi, P.* aff. *P. ovatus, P.* aff. *P. mesicostalis, Camarotoechia* sp., *Pugnax* sp., *Seminulina globularis, Spirifer* aff. *S. striatiformis, S. shepardi?, S.* aff. *S. subrotundatus, S.* aff. *S. disjunctus, Spiriferella* aff. *S. plena, Syringothyris* aff. *S. extenuata, Pseudosyrinx* aff. *P. missouriensis, Cyrtina* aff. *C. burlingtonensis, Composita humilis?, Pterinopecten* sp., and a fish tooth.

The facies of the Englewood fauna is markedly different from that of the Pahasapa and Madison limestones. The formation is correlated provisionally with the Kinderhook group of the Mississippian of the Mississippi Valley.

PAHASAPA LIMESTONE.

Outcrop.—The outcrop of the Pahasapa limestone encircles the central part of the Black Hills uplift, and as the rock is resistant it makes high ridges margined by cliffs. Along the central divide it forms a broad plateau, which is 10 miles wide west of Hill City and is prominent in the high front ridge on the north and east sides of the uplift. It presents great cliffs for many miles along Spearfish Canyon (see Pl. XVII) and many other canyons, including those of Whitewood, Bear Butte, Elk, Little Elk, Boxelder, Rapid, French, Hell, West Fork of Lightning, False Bottom, and Little Spearfish creeks. (See Pls. XIX and XXVIII.) Its outcrop encircles Crow Peak, Citadel Rock, Whitewood Peak, and Deadman Mountain, and it constitutes an uplifted block on the east side of Bear Butte. It is brought up in the Crook Mountain dome and by the anticline crossed by Bear Butte Creek 4 miles southwest of Sturgis. It is not far beneath the surface under the uplift of Elkhorn Peak. At a point on Rapid Creek 3 miles above Canyon Lake, on Little Elk Creek, and southeast of Whitewood Peak, where the dips are very steep, the entire outcrop is revealed in ledges and cliffs about 500 feet wide. Outliers cap the high ridge north of Bogus Jim Creek, Green Mountain, and White Rocks, at Deadwood. A small but very remarkable outlying mass occurs on Meadow Creek a short distance southeast of the southwest corner of Meade County. It lies below its normal position and evidently is the remnant of a slide which slipped down from a cap that formerly covered the ridge to the east.

Character.—The limestone is mostly fine grained and massive bedded. Its light-gray to dove-colored cliffs are of picturesque irregular shapes, and it forms the surfaces of large and high plateaus. It contains cavities, generally lined with crystals of calcium carbonate, as well as many caverns, some of them very large. The principal caverns are Wind Cave, northwest of Buffalo Gap; Crystal Cave, on Elk Creek southeast of Runkel; and Jewel Cave, west of Custer, each of which has several miles of galleries. Onyx Cave, on Cold Brook, and Jasper Cave, west of Jewel Cave, are also noteworthy.

Most of the limestone is a pale-buff to light-gray or white fine-grained rock consisting of calcium carbonate, though in some places it contains considerable magnesia. At most places the upper part is the more massive and weathers to a dove color; the lower part is pale buff and is thinner bedded, notably in the region southwest of Custer. Here and there it includes thin members of shale or thin slabby limestone. At some places it contains a little chert, and locally the upper beds are stained red from the wash of the overlying red shale.

Relations.—The Pahasapa appears to merge into the underlying Englewood limestone, but the transition takes place in a zone a few inches in thickness, and the contact is sharp on Elk Creek near the site of Elk Creek post office and in railroad cuts 2 miles south of Englewood. In a wide area the Pahasapa is overlain by red shale, arbitrarily regarded as the basal member of the Minnelusa sandstone, but where this shale is absent there is uncertainty as to the plane of division. Although a long time elapsed between the deposition of the Pahasapa and the Minnelusa sediments no difference is perceptible in the attitude of the beds.

Thickness.—The thickness of the Pahasapa limestone ranges from 300 feet on Whitewood Creek to 630 feet in Spearfish Canyon and Robinson Gulch. It is 550 feet in Crow Peak uplift, 300 feet in Polo Gulch and on Whitewood Peak, 500 feet on Bear Butte Creek, about 600 feet on Elk Creek and southward for some distance, 300 feet on Rapid Creek, about 300 feet on French Creek, 350 feet on Spring Creek southwest of Rapid City, and 500 feet in the plateau west of Custer and Hill City. In the partial section on the east end of Bear Butte, 300 feet or more of beds are exposed. A boring in Martin Valley, in sec. 20, T. 6 S., R. 6 E., penetrated light-colored limestone from 1,011 to 1,300 feet doubtless the Pahasapa limestone.

Local features.—The color of the Pahasapa limestone in some beds varies locally from light gray to a light brown, yellow, or pink. Most of the chert, which occurs in places, is black and forms egg-shaped masses or lenses arranged parallel to the bedding. One lenticular layer on McKinley Creek south of Ragged Top is 5 feet thick. Here and there incipient spheroidal structure is perceptible in the weathered limestone. A 3-foot bed of fine-grained gray sandstone occurs in the upper part of the formation three-quarters of a mile southeast of Pillar Peak. On Rapid Creek the top beds are brecciated at some places, and at others the top member consists of 40 feet of slabby pink compact limestone. On Elk Creek southeast of Runkel the middle of the formation consists of a cherty member, of which the top beds present black, gray, brown, and pink tints and include some shale and earthy beds.

Caves.—Wind Cave, 7 miles northwest of Buffalo Gap and 12 miles northwest of Hot Springs, on the Chicago & Northwestern Railway, is included in a national park. Here a small vertical opening leads into extensive underground passages and chambers in the Pahasapa limestone, some features of which are shown in Figure 4.

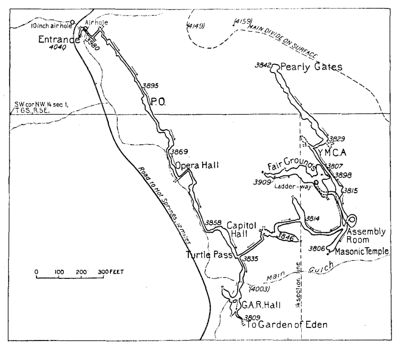

FIGURE 4.—Map of Wind Cave, showing principal underground passages. Elevation of cave floor above sea level shown by figures; elevation at surface shown by figures in parentheses. Arrows indicate direction of slope of the floor.

The main passageways and the many abrupt offsets closely follow the major joints of the limestone and in general trend southeastward down grade to a crevice into which the cave finally narrows. This point is about 250 feet below the entrance and about 200 feet below the surface. The cave has been developed by solution of the rock by underground water containing carbonic acid gas and soil acids, which formerly flowed through crevices along the joint planes and gradually enlarged them into tunnels but which now follows other courses at deeper levels. Probably the present outlet is in the great springs at the upper end of Buffalo Gap, where the land is about 300 feet lower than the lowest part of the cave. One notable cross passage just beyond Turtle Pass closely follows a joint plane leading northeast to another main joint, along which the eastern part of the cave has been excavated. This eastern part, about 900 feet long, slopes up to a chamber just above the Pearly Gates, where it dwindles to a crevice through which most of the water entered that dissolved out this branch of the cavern. It flowed out through a small crevice at the south end of Masonic Temple, about 36 feet lower than the Pearly Gates. The Fair Grounds, a branch chamber about 100 feet higher than adjacent parts of the cave, was developed by water that entered from other sources.

This cave, like others in limestone, illustrates not only the solvent action of water but also the redeposition of some of the calcium carbonate as stalactites and other deposits on the walls, including superb groups and incrustations of beautiful crystals of calcite. The "box work" that is a characteristic feature in Wind Cave consists of deposits of calcium carbonate formed in joint cracks that bounded rectangular masses of limestone, the thin walls of the new deposit remaining when the limestone was dissolved or disintegrated.

The water that made this cavern came from the surface through crevices, most of which now are filled with earth that has been washed into them, though some are open, notably the one used as an entrance by visitors. Through these crevices passes the remarkable circulation of air which has given the cave its name. Nearly always a current of air blows out of the openings, but sometimes the current moves in the opposite direction.

Onyx Cave, a small cavern in the Pahasapa limestone 3 miles southwest of Wind Cave, contains stalagmites of onyx.

Jewel Cave, 13 miles west-southwest of Custer, has also been set aside as a national monument. The opening, which stands high in the east wall of Hell Canyon, leads into several miles of narrow passageways, along which there are irregular wide chambers similar to those in Wind Cave. It also is in the upper part of the Pahasapa limestone. The walls are at many places incrusted with crystals of dogtooth spar.

Jasper Cave, a mile west of Jewel Cave, in the same reservation, is a similar but smaller cavern, which has not been fully explored.

Crystal Cave, which is not often visited, is in the canyon of Elk Creek near Runkel. It contains several miles of very beautiful passageways and chambers like those of Wind Cave and the others, and its walls are in some places covered with crystals of calcite, which have given the name to the cave.[6]

Fossils.—Fossils abound in the Pahasapa limestone. G. H. Girty has identified the following forms: *Syringopora aculeata*, *S. surcularia*, *Syringopora* sp., *Zaphrentis* several species, *Granatocrinus?* sp., *Leptaena analoga*, *Schuchertella* aff. *S. chemungensis*, *Chonetes loganensis*, *Productus semireticulatus*, *Pustula?* sp. (probably related to *P. vittata*), *Camarotoechia* cf. *C. metallica*, *Spirifer centronatus*, *Spirifer* aff. *S. keokuk*, *S. striatus* var. *madisonensis?*, *Syringothyris* aff. *S. texta*, *Cliothyridina* aff. *C. glenparkensis*, *Bellerophon* sp., *Euomphalus* cf. *E. obtusus*. The corals, chiefly *Syringopora*, are found almost exclusively in basal beds, and a peculiar form, apparently of this genus, occurs on Elk Creek near Runkel and on the west fork of Meadow Creek.

According to Girty, the fauna as a whole is that of the Madison limestone of the Rocky Mountain region, of lower Mississippian age, equivalent in general to the Burlington and Keokuk limestones of the Mississippi Valley.

PENNSYLVANIAN SERIES.

MINNELUSA SANDSTONE.

Character and outcrop.—The Minnelusa sandstone consists mainly of white and reddish sandstone, but some limestone beds are included in the medial and lower members, and some of the unweathered sandstones contain calcareous cement. The upper member, of moderately coarse grained light-colored massive sandstone, forms high cliffs, which are striking features in the walls of many canyons by which the formation is traversed. (See Pl. XXII.) Softer fine-grained thinner-bedded sandstones, some of them red, lie below. This lower series contains several beds of limestone and some sandy shales. Generally the base is marked by bright-red shales that carry layers of white limestone. Some chert occurs, especially in upper beds west of Crook and on Elkhorn Peak, and in places there are a few thin beds of coaly shale. Minnelusa is the Indian name of Rapid Creek, the type locality of the formation, and was applied to it by Winchell in 1875.

The formation crops out in a wide belt that encircles the Pahasapa limestone area in the Black Hills uplift. South and southwest of Sturgis, south and southeast of Crow Peak, and north of Deadwood the outcrop is broad and extends nearly to the summit of Bear Den Mountain; but south of Sturgis it exceeds a width of 2 miles at but few places, and in the zone of steep dips north of Stage Barn Canyon it is less than a mile wide. On the southwest slope of the Black Hills it is uniformly about 3 miles wide. It is trenched to its base in Gillette and Redbird canyons and along the fault near Jewel Cave and is exposed in Elkhorn Peak and Bear Butte.

The rocks of the Minnelusa formation are less resistant than those of the underlying Pahasapa limestone, but the sandstones form steep walls in most of the canyons. Much of the area consists of elevated slopes surmounted by low hills and ridges which mark the harder layers and is characterized by thin sandy soil.

Relations.—The limits of the formation are defined by abrupt changes in the character of material but without evident unconformity. The contact of the Minnelusa formation with the Pahasapa limestone is not marked topographically either on the plateaus or in the many canyons that are cut through the formation.

Thickness.—The average thickness of the formation in this area is about 450 feet. In the canyon south of Spearfish it is 405 feet; on Whitewood, Bear Butte, and Boxelder creeks, 450 feet; at the tunnel north of Deadwood, 400 feet; in Little Elk Canyon, where the beds are vertical, 450 to 500 feet; on Rapid Creek, about 400 feet; and on Spring Creek northwest of Hermosa, 460 feet. Near Wind Cave and in the plateau along the western slope of the Black Hills uplift, west of Pringle and Custer, it is about 500 feet.

Local features.—Near Deadwood and Sturgis the Minnelusa sandstone comprises four distinct members. The highest one, which is perhaps the most conspicuous, consists of 125 to 190 feet of white to coffee-colored sandstone in massive beds, commonly cross-bedded and generally rather hard. The member next below is a variable series of about 250 feet of slabby fine-grained sandstones, in part red and brecciated, containing beds of impure limestones. This member is underlain by light-colored sandstone, in part massive, which contains local beds of impure limestone. The basal red shale member is 30 to 60 feet thick and carries thin beds of white compact limestone in its upper part. On Spearfish Creek the top member, a hard massive gray sandstone 150 feet thick, is underlain by about 190 feet of sandstone that is partly thin bedded and locally carries beds of limestone. On this creek the basal red shale member is 60 feet thick and carries several thin beds of fine-grained white limestones in its upper part. This member, 60 feet thick, is also well exposed on the southern and eastern sides of the Citadel Peak uplift.

In the long exposures on the north side of Whitewood Creek northwest of Crook Mountain the top member, about 200 feet thick, consists of massive sandstones, mostly brownish or dirty gray. Next below come 14 feet of white sandstone, in part conglomeratic, 10 feet of limestone, 35 feet of light-colored pinkish sandstone with two thin layers of limestone, 100 feet of impure limestone and sandstones, 50 feet of cream-colored sandstone, and a basal member of about 30 feet of red shale with several thin layers of white compact limestone.

On Polo Creek considerable gray to buff sandstone near the base of the formation lies on the basal red shale, a member about 50 feet thick, which is in part sandy and carries two beds of light-gray compact limestone 5 to 8 feet thick. In the railroad tunnel north of Deadwood there is a basal breccia composed of fragments of white limestone and sand. The top bed here, which is composed of sandstone containing nodules of flint, gives place gradually to the Opeche beds.

In the ridges west and northwest of Sturgis, where the formation has a thickness of 500 feet, it consists of a massive top member of white or light yellowish-brown granular sandstone, a second member of alternating sandstone and limestone with some shale, a third member of white sandstone, and a basal member of red shale with thin beds of pure limestone. The following section of the formation on Bear Butte Creek, west of Sturgis, was measured by T. A. Jaggar, jr.:

Section of Minnelusa sandstone on Bear Butte Creek southwest of Sturgis.

	Feet.
Local cherty bed	5–6
Sandstone, white, sugary, with quartz layers and veinlets; becomes more yellowish or coffee-colored, calcareous, and cross-bedded in the lower portion	188
Limestone, purplish, shaly; some soft massive beds	30
Sandstone, purplish, calcareous; fine grained and white at base	27
Sandstone, alternating beds of yellow, salmon, purple, and red; in some places cross-bedded and ripple marked; partly calcareous and shaly	45
Limestone, gray, light purple, and drab, very fine grained; calcite druses	5
Sandstone, fine, yellow-gray above, massive and purplish below	11
Limestone, pink, brown, and gray, rather gritty at top and bottom	22
Sandstone, fine, salmon-colored; cross-bedded and calcareous	4
Limestone bands, pink, purple, yellow, and brown, some spotted; shaly and hackly; rectangular joints	31
Sandstone, massive, salmon-colored, calcareous	10
Limestone, purple and brown	1½
Sandstone, white; weathers red on surface	37
Shale, red, with thin limestone layers; rests on Pahasapa limestone	25+
	450

In Stage Barn Canyon, south of Piedmont, the top member is massive sandstone, 125 feet thick, in part distorted and somewhat brecciated, containing chert and calcite. It is underlain by 60 feet of massive reddish-yellow sandstone, 25 feet of red sandstone, somewhat brecciated and impure, and a basal member of red to gray flaggy sandstones, in part calcareous.

On the slopes of Bear Butte, where the beds are upturned at a steep angle, the Minnelusa sandstone is mostly a light-colored moderately hard rock, but parts of it are stained dark brownish gray and have greater hardness, probably due to the heat of the intrusive mass. About 300 feet of beds are exposed on the north side and 20 to 40 feet on the west side of the butte.

The basal red shale member is well exposed in a small canyon in sec. 35, T. 5 N., R. 5 E., 1 mile south of bench mark 3622, 3 miles northwest of Tilford, and in the canyon of Little Elk Creek at places where the beds are vertical. It consists of about 50 feet of red shale and brown sandstone containing several thin beds of limestone.

West and northwest of Rapid City and on Spring Creek northwest of Hermosa the Minnelusa rocks are predominantly sandy and reddish. The top member, 100 feet thick, is massive soft red to brownish sandstone, some of which weathers brick-red. In most ledges the beds are considerably broken into an irregular coarse breccia, which in places carries much calcite in veins and geodes. The second and third members consist of alternations of limestone, sandstone, and sandy shale in beds ranging in thickness from 1 to 20 feet and presenting much local variation in character and succession. A typical section, measured by C. C. O'Harra, follows.

[6] Hovey, E. O., The Crystal Cave of South Dakota: Sci. Am. Suppl., vol. 57, pp. 23657-23658, 1904.

Section of Minnelusa sandstone on Rapid Creek, 5 miles west of Rapid City, S. Dak.

	Feet.
Sandstone, red, crinkled and brecciated	110
Sandstone, soft, yellowish gray, cross-bedded	20
Sandstone, gray, flaggy, cross-bedded; massive near base	16
Sandstone, rough, limy	10
Concealed	8
Limestone, pink, sandy	2
Sandstone and gray sandy limestone	8
Concealed	20
Limestone, sandy	3
Sandstone, thin bedded and concealed	14
Limestone, sandy, fossiliferous	2
Sandstone, red, thin bedded	8
Limestone, fossiliferous	3
Sandstone, soft, thin bedded, gray; massive in middle	26
Limestone, sandy; contains many fragments of fossils	6
Sandstone, thin-bedded to shaly, soft, yellow	11
Sandstone, gray, massive	8
Sandstone, yellow, thin bedded, soft; mostly massive below	40
Limestone, pink, sandy	4
Sandstone, gray; massive above, thin bedded below	8
Limestone, gray; massive above, thin bedded and pink calcareous shales below	6
Sandstone, massive	5
Limestone, pink, fossiliferous	2
Sandstone and sandy limestone	40
Shale, red, on Pahasapa limestone	20
	400

On Spring Creek northwest of Hermosa the upper member, consisting of brecciated red sandstone, is underlain by gray to red flaggy sandstone, 40 feet; massive, soft brecciated sandstone, mostly red, gray in middle, 120 feet; gray, in part massive and in part flaggy sandstone, 100 feet; massive and shaly yellow sandstone containing some layers of limestone, 80 feet; and a basal member of red sandy shale 20 feet thick. On Battle Creek the top member consists of 50 feet of red sandstone, which grades down into 150 feet of brown sandstone, in part slabby. South of Hayward this member consists of 25 feet of thin-bedded red sandstone, 75 feet of coffee-colored to red-brown massive sandstone, and at the base 3 to 10 feet of thin-bedded purplish limy sandstone.

On French Creek the medial member, 100 feet thick, consists of thin slabby beds of buff sandstone, and the top member is red to yellow sandstone with a limy layer at the top. The basal red shale is not well exposed. On Lame Johnny Creek the formation contains red sandstone, and on Squaw Creek the top member is 50 feet of buff granular sandstone.

In the region southwest of Hermosa and on the southwestern slope of the Black Hills the top member consists of about 100 feet of buff or brownish-gray massive sandstone, generally uniform in character. This member is underlain by 300 feet or more of alternating beds of limestone, sandstone, and sandy shale, which vary considerably from place to place in character and thickness. Nearly all the sandstone contains more or less calcium carbonate, which is leached out by weathering, so that the remaining rock is a fine-grained sandstone. Several deep borings have shown that many of the beds are calcareous, especially those in the thick medial member, and some samples of the rock from a railroad cut near Argyle contained from 30 to 40 per cent of calcium carbonate.

The basal red shale member is widespread and in most places carries a thin, compact bed of light-gray to white limestone in its middle. Toward the east it becomes a brownish sandstone. At the bottom of the red shale in many places there are hard siliceous concretions of oval form, ranging in diameter from a few inches to 3 feet. In some places, especially on long dip slopes, they are abundant, but in others they are rare or absent. At some localities they remain on the limestone surface, from which the red shale has long since been removed by erosion. On the eastern side of the uplift the basal member consists of red shale or sandstone, and limestone lies on top of it instead of being interbedded with it. Near Wind Cave part of this basal red member, mainly a fine-grained sandstone, is locally bleached white and has at its base a limestone breccia, which lies on an irregular surface of Pahasapa limestone.

In the ridges east and north of Loring Siding the basal red shale is about 40 feet thick. Some of it is soft, but it contains hard nodular parts. Next above lies slabby and massive limestone, in part interbedded with shale and layers of chert. This member is well exposed in the railroad cut half a mile northeast of Loring, where the beds lie in a shallow syncline. Near Pleasant Valley the bed of limestone in the basal red shale member is thinner and purer than in the area southeast of that place. This member is especially well exhibited in Hell Canyon, south of Jewel Cave, where a deposit of red shale 60 feet thick lies on the Pahasapa limestone. Next above this red shale lies 10 to 17 feet of light-gray massive limestone, similar to the Pahasapa in appearance, which is succeeded by about 100 feet of red shale, in part nodular and containing several layers of dolomite. Then follow 20 feet of massive impure limestone, 20 feet of coarse calcareous sandstone, and a thick series of alternations of slabby limy sandstone and impure limestone that extends far down Hell Canyon. These limestones contain from 65 to 95 per cent of calcium carbonate.

A boring in Martin Valley, in sec. 20, T. 6 S., R. 6 E., is said to have penetrated Minnelusa beds from 337 to 1,011 feet, largely limy, with red shale from 872 to 915 and from 970 to 1,000 feet, and with 11 feet of white sandstone at the base. A boring in sec. 15 of the same township penetrated the Minnelusa from 150 feet to the bottom, at 962 feet.

Section of Minnelusa sandstone in Beaver Canyon near Wind Cave, S. Dak.

Shale, red, Opeche formation.	Feet.
Limestone, impure, gray	4
Sandstone, orange, limy	15
Sandstone, yellow to buff, limy	50
Sandstone, red	20
Limestone, purplish, sandy	10
Beds mostly covered; shales above, sandstone below	60
Sandstone, buff, limy	10
Sandstone, massive, reddish; contains flint nodules	3
Sandstone, light yellowish, buff, and pinkish, mostly thin-bedded, with a few half-inch beds of light-colored flint	50
Limestone, pinkish, fine grained; contains a few beds of clay and two 8-inch beds of black shale about 10 feet apart; 3-inch layer of black flint at base	30
Quartzite and covered slope	25
Sandstone, massive, brownish and buff, with mudstone	50
Shale, buff, sandy	12
Sandstone, buff	25
Limestone, drab, with flint streaks	30
Sandstone, massive, pink, limy, with calcite veins	15
Mudstone, purplish drab	12
Sandstone, massive, pink, limy, with calcite veins	25
Limestone, massive, drab	18
Limestone, slabby, pink, sandy	8
Sandstone, red, shaly; lies on Pahasapa gray limestone	25
	497

The limestone bed in the lower member forms a prominent ledge in Hell Canyon near bench mark 5090 and the main road crossing and in Redbird Canyon, notably in slopes 2 miles northwest of Buck Spring and northward into sec. 34, T. 1 S., R. 1 E., where it lies above a 10-foot ledge of hard quartzitic sandstones. Below this limestone lies 50 to 60 feet of red shale at the base of the formation. In Gillette Canyon, 2½ miles east-southeast of Buck Spring, this basal red shale is 40 feet thick and is in part sandy. At its base lies a deposit of pure hematite from 1 to 3 inches thick, which appears at other places in neighboring areas. Above the red shale member in this vicinity lies 20 feet of red and white mottled massive sandy shale capped by 4 feet of the same quartzitic sandstone referred to above. The sandy shale is overlain by the lower limestone bed, here 20 feet thick, white to gray, partly pure, partly cherty, and mostly in massive layers. This limestone is capped by red shale, and next above it lies a thick succession of impure slabby limestones and sandstones.

Fossils.—Few fossils have been obtained from the Minnelusa sandstone. The upper limy beds near Hot Springs, about 8 miles southwest of Buffalo Gap, yielded forms believed to be Pennsylvanian. From the lower limestone in the basal red beds near Loring siding and on the creek 2 miles to the east were obtained *Hydreionocrinus?* sp., *Spirifer rockymontanus*, *Composita subtilita*, and *Euphemus nodicarinatus?*, and in ledges 1 mile north of Loring *Spirifer rockymontanus* and *Composita subtilita*. These forms were determined by G. H. Girty, who regards them as probably Pennsylvanian, though the *Spirifer* may be *S. increbescens* and the *Composita* may be *C. subquadrata* of the upper Mississippian.

Fossils from medial beds northwest of Hermosa were identified by G. H. Girty as a species of *Fusulina* that has not been found in the Mississippian and is regarded as characteristic of the Pennsylvanian. The concretions in the basal red shale carry fossils which R. S. Bassler found to be an undetermined species of *Leperditia*, of a type characteristic of the Mississippian at about the horizon of the St. Louis limestone, though the concretions may be residual from an earlier deposit removed by erosion. The formation is classed as Pennsylvanian. No late Mississippian rocks have been found in the Black Hills.

A few fossils collected by W. W. Rubey 1¼ miles west of Englewood are regarded by G. H. Girty as upper Pennsylvanian. They may indicate the presence of an outlier of the Minnelusa formation not shown on the maps in this folio.

PERMIAN (?) SERIES.

OPECHE FORMATION.

Outcrop and character.—The Opeche formation consists of 70 to 115 feet of red shale and sandstone. It is exposed mainly in a narrow but nearly continuous zone of outcrop in the slopes beneath an escarpment of overlying Minnekahta limestone. Opeche is the Indian name for Battle Creek, the type locality of the formation. It crops out also in the uplift at Elkhorn Peak, and 10 to 30 feet of crushed beds is exposed near Bear Butte. It underlies the areas of Minnekahta limestone in Boulder Park, south of Crow Peak, northeast of Spearfish Peak, and east of Whitewood Peak. Extensive exposures are found in canyons from Sturgis to Cold Brook Canyon and in Hell Canyon and Gillette Canyon. The rock is soft bright brownish-red sandstone, mainly in beds from 1 to 4 inches thick, and red sandy shales. The shales at the top have a strong purple tint for a few feet below the Minnekahta limestone. A 6-foot bed of gypsum lies in the middle of the formation in Hell Canyon, in the southwest corner of T. 5 S., R. 2 E. Ordinarily the lower beds are more massive than the upper ones. The rocks are so soft that extensive outcrops of them are rare. White River and terrace deposits hide the formation at intervals west and northwest of Hermosa and Fairburn.

Thickness.—On Spearfish Creek the thickness of the formation is 75 feet; on Tetro Creek, 70 feet; on Whitewood Creek, 85 feet; from Elk Creek to Rapid Creek, 90 feet; and on Spring Creek, Battle Creek, and French Creek, 100 feet. Near Wind Cave, where the formation is 115 feet thick, it consists of 5 feet of purple clay, 50 feet of sandy shale, and at the base 60 feet of red sandstone in beds mostly 1 to 4 feet thick, with red clay partings. In the region between Hell Canyon and Gillette Canyon the thickness is 70 to 80 feet.

Age.—No fossils have been found in the Opeche formation, but as the overlying Minnekahta limestone contains fossils regarded as probably Permian, and as there are red deposits in the upper part of the Permian in other regions, the Opeche formation is provisionally assigned to that series.

MINNEKAHTA LIMESTONE.

Character and outcrop.—The Minnekahta limestone averages ess than 40 feet in thickness, but it is so hard that it gives rise to prominent ridges or mesas whose escarpments reveal nearly its entire thickness. "Minnekahta" is the Indian name of the hot springs in Fall River County. Ordinarily the limestone forms a rocky slope bearing much brush and a few junipers and pines, which rises gradually from the Red Valley and constitutes the outer margin of the limestone front ridge. In most of the cross canyons the limestone causes a narrow constriction or "gate," notably in the region between Sturgis and Spearfish (see Pl. XXI), at the mouth of Stage Barn, Little Elk, Boxelder, Squaw, Beaver, Battle, and Lame Johnny canyons, and in several canyons in the southwestern slope of the Black Hills. Long slopes of this limestone adjoin Crow Peak uplift and Spearfish Canyon, and others lie south of Centennial Valley, west of Spearfish, west of Martin Valley, and on both sides of Hell, Schenck, and Gillette canyons. (See Pl. XVIII.) The limestone encircles Elkhorn Peak uplift and part of Bear Butte, occupies the syncline of Boulder Park, and appears on the crest of an anticline in the middle of the Red Valley, northwest of Rapid City. North of Tilford, where the dips are steep, and near Rapid Creek and southward the outcrop is narrow, but it widens somewhat from Elk Creek to Rapid Creek. It is covered by White River beds near Lame Johnny Creek and southeast of Rockerville.

The limestone is light gray with a light pinkish or purplish tinge that suggested the old name "Purple limestone." Its cliffs are massive, but close examination shows that the layers are thin and are clearly defined by slight differences in color. It weathers into slabs, generally 2 to 3 inches thick. In most places, especially on the east side of the Black Hills, 2 or 3 feet of the medial beds are softer and weather out more rapidly than the adjoining beds. Much of the rock has a bituminous odor when struck or broken. In its contacts with adjoining formations there is an abrupt change in material but no evidence of unconformity.

Thickness.—The thickness of the Minnekahta limestone is 45 feet at Rapid City and southward; 40 feet on Elk, Bear Butte, and Battle creeks; 30 feet on Whitewood, Spring, and Spearfish creeks; and 40 feet in Bear Butte. In Red, Hell, and Gillette canyons the thickness is 45 to 50 feet.

Composition.—The Minnekahta limestone contains varying amounts of magnesium carbonate, which in some places is abundant, and of clay and fine sand. Some beds are mottled by flakes of clay. Analyses of several samples of the limestone are given below:

Chemical composition of Minnekahta limestone in southwestern South Dakota.

	1	2	3	4
Lime (CaO)	31.51	54.65	53.40	52.85
Magnesia (MgO)	19.85	.41	1.57	.72
Alumina, iron (Al_2O_3, Fe_2O_3)	.36	.63	1.10	.51
Water (H_2O)	1.25	.81	.20	.10
Carbon dioxide (CO_2)	44.66	42.30	42.92	42.78
Sulphur trioxide (SO_3)	.07	.21	.12	.12
Silica (SiO_2)	1.12	1.21	1.08	1.42
Manganese oxide (MnO)	.00	.00	.46	.11
Soda (Na_2O)		Trace.	.36	.30
Potash (K_2O)		Trace.	.16	.10
	98.82	100.13	100.37	100.24

1. From locality near Hot Springs. George Steiger, U. S. Geological Survey, analyst.
2. From locality 4 miles west of Rapid City. M. F. Coolbaugh, South Dakota School of Mines, analyst.
3. From east side of Stockade Beaver Creek. P. H. Bates, analyst.
4. From east side of Stockade Beaver Creek. A. J. Phillips, analyst.

The Minnekahta limestone is a relatively hard bed of homogeneous rock that lies between soft beds whose plasticity favored local flexing and warping, and thus the thin layers are generally minutely crumpled and broken.

Fossils and age.—The few fossils found in the Minnekahta limestone have long been regarded as indicating probable Permian age, but growth of knowledge as to their identity and significance has made this classification uncertain. Concretions found near the base of the formation at a point half a mile south of the sawmill 5 miles northwest of Tilford contain abundant pelecypods, one form of which, according to G. H. Girty, suggests the genus *Pteria* (*Avicula*) and doubtless belongs to the Pteriacea; it is probably not *Bakewellia*. The hinge characters and muscular impressions are not shown, except perhaps a linear posterior tooth. Another form may be provisionally referred to *Sedgwickia*, and a third suggests *Schizodus* or *Myophoria*. Fossils obtained on the Iron Creek road near Spearfish, on Bear Butte Creek in the southeast corner of Boulder Park, and at a point a few miles south of Argyle were determined by Schuchert as the *Pteria* above described, *Yoldia?* cf. *Y. subscitula*, and *Edmondia?* sp.

According to Girty these fossils are too few and too imperfect to prove the age of the Minnekahta limestone. If the area is regarded as belonging to the basin of the Mississippi they might be classed as Permian; but they have so much in common with the Triassic of basins that lie farther west that they more probably belong to that period.

Some fragmentary remains of fossil fish from the middle beds in a quarry 3 miles north of Rapid City have been identified by Hussakof[7] as palaeoniscids, which are well represented in the Carboniferous and Permian of Europe and Africa but which have not been found elsewhere in North America.

TRIASSIC (?) SYSTEM.

SPEARFISH FORMATION.

Character and outcrop.—The Spearfish formation, or "Red Beds," consists of 600 to 700 feet of red sandy shale and soft red sandstone, which nearly everywhere contain beds of gypsum. The formation consists predominantly of red sandy shale but contains some soft massive sandstone and slabby sandstone. Its principal component is fine sand, with which are mixed varying proportions of clay and of mica in small flakes. Its outcrop ranges in width from 1 to 2 miles along the east side of the Black Hills and from 2 to 3 miles on the southwestern slope but is very narrow in the region of steep dips west of Crook and on the east side of Elkhorn Peak. There is an outlier in the Boulder Park syncline, and a small area is exposed by the anticline north of Bear Butte. In many parts of the Red Valley region the formation is covered with alluvial deposits and in Boulder Park with some older gravels and sands. Northwest of Hermosa and northwest, west, and southwest of Fairburn it is buried beneath the White River deposits. Nearly everywhere in the Red Valley, however, the bright red of the shales and the snow white of the gypsum are striking features.

Relations.—The formation is separated from the underlying Minnekahta limestone by an abrupt change of material and from the overlying Sundance formation by planation, which in places, notably in Hell Canyon, shows slight channeling.

Thickness.—In the boring at Fort Meade the formation was penetrated from 745 to 1,440 feet, a thickness of 695 feet, but generally its thickness is somewhat less. A boring a mile east of Spearfish entered Minnekahta limestone at a depth of 453 feet, which indicates a thickness of about 650 feet. North of Tilford the thickness is 630 feet, but near Piedmont it appears to decrease. The nearly vertical beds in the gap north of Elkhorn Peak are 550 feet thick but are crushed.

Gypsum members.—The gypsum beds range in thickness from less than an inch to 25 feet. (See Pl. XX.) Most of the gypsum is pure white, but some of it is gray to dirty blue; nearly all is massive. There are many small secondary veins.

From Spearfish to Rapid City there are two continuous beds of gypsum. One bed, from 100 to 120 feet above the base, is generally 6 to 10 feet thick; the other, very near the top, is 8 to 15 feet thick near Spearfish, 25 feet in the northern part of Centennial Valley, including some red shale near the top, 6 to 8 feet near Whitewood, 12 feet near Sturgis, and 25 feet north of Tilford. On slopes north of Tilford the lower bed, 12 feet thick, is 340 feet below the upper one, and there is a thin local bed of gypsum about halfway between them.

Section of upper beds of Spearfish formation at Lookout Peak, east of Spearfish, S. Dak.

	Feet.
Shales, pink and green, with some gypsum (overlain by Sundance formation)	12
Shale, light red, sandy	2
Gypsum, massive	2
Shale, light red and green, sandy	4
Gypsum	$\frac{2}{3}$
Shale, light red, sandy; contains 4-inch bed of gypsum	10
Gypsum, massive	22
Shale, red; contains thin layers of gypsum	10
Gypsum, massive	10
Shale, deep red down to alluvial flat; contains several thin beds of gypsum	100

The top gypsum member disappears in the region south of Rapid City, but the gypsum bed about 100 feet above the base of the formation continues for many miles and has a thickness of 15 feet west of Hermosa. It thins south of Hermosa and at some places near Fairburn it appears to be absent. Near the north end of Elk Mountain the succession, beginning at the base, consists of red shale, 150 feet; gypsum, 30 feet; red shale with thin gypsum beds near top, 50 to 60 feet; gypsum, 30 feet; and, at the top, 200 feet of red sandy shale. In Hell Canyon, in sec. 29, T. 5 S., R. 2 E., a basal bed of gypsum 12 feet thick rests on the Minnekahta limestone over a considerable area. At Soper's ranch, just west of Hell Canyon, several beds of gypsum, 4 to 5 feet thick, lie 300 feet above the base of the formation. A short distance above these beds lies a 25-foot bed of gypsum, which is overlain by 125 feet of red shale that is capped by another 25-foot bed of gypsum.

Age.—No fossils have been found in the Spearfish formation. From the fact that it lies on beds probably of Permian age and is overlain by Jurassic beds it has been regarded as of Triassic age. The unconformity at its top represents all of earlier Jurassic and probably part at least of Triassic time.

JURASSIC SYSTEM.

UPPER JURASSIC SERIES.

SUNDANCE FORMATION.

Outcrop.—The buff sandstones and shales of the Sundance formation crop out continuously around the Black Hills uplift and in most places form part of the slope that rises from the Red Valley to the crest of the Hogback Ridge. Outliers occur in the Lookout Peak ridge and west of Sturgis. Small exposures occur on the crest of the anticline 3 miles southeast of Piedmont Butte, in the slopes north of Sturgis and east of Whitewood, and in the Bear Butte uplift. Generally the outcrop zone is narrow and is more or less covered with talus. It is wide on the southeast slope of the Black Hills near Red Canyon and Hell Canyon, but it narrows in the eastern slope of the Elk Mountains.

Thickness.—The average thickness of the Sundance formation is about 250 feet, except near Fairburn, where it ranges from 70 to 115 feet, and near Elk Mountain, where it is 110 feet. Near Rapid City the thickness is 275 feet; on the north side of Centennial Prairie it is 285 feet; and near Hell Canyon it is 300 feet.

Relations.—The Sundance beds lie unconformably on the red shale of the Spearfish formation, and although there is no noticeable difference in dip the contact is abrupt and shows irregularities due to erosion. In Hell Canyon and Centennial Prairie a basal sandstone 5 to 6 feet thick, with reddish layers and streaks of red grains, lies on the eroded surface of the Spearfish formation. Apparently the Sundance formation grades into the Unkpapa sandstone, but where that sandstone is absent it makes an abrupt contact with the Morrison shale.

General character.—The Sundance formation consists of the following members, some of which are almost invariable, whereas others present considerable local variation:

Members of the Sundance formation in the Black Hills.

	Feet.
1. Sandstone, buff, hard, slabby, grading into sandy shale	0–20
2. Shale, dark gray to greenish gray, with concretions; hard beds of fossiliferous limestone and thin beds of sandstone; layer of quartzite in places east of Elkhorn Peak	100–125
3. Sandy shale or impure sandstone of reddish color	50
4. Buff sandy shale, merging down into fine sandstone	20
5. Sandstone, fine, moderately hard, buff to faintly reddish; massive to slabby beds, strongly ripple marked; cliff maker	10–40
6. Shale, dark gray or greenish	50
7. Sandstone, buff, massive	0–8

Local features.—Some typical sections of the formation in the northeastern part of the Black Hills are shown in the following detailed sections:

Section of Sundance formation on north side of Centennial Prairie, S. Dak.

	Feet.
Sandstone, buff, slabby, possibly Unkpapa	1
Shale, with fossiliferous concretions	10
Limestone, sandy, hard, fossiliferous	4
Shale, dark	100
Sandstone, soft, red	50
Shale, sandy, buff	40
Sandstone, hard, slabby, buff to pale red, ripple marked	10
Shale, dark	65
Sandstone, soft, buff; rests on Spearfish formation	5
	285

Section of Sundance formation in Lookout Peak, east of Spearfish, S. Dak.

	Feet.
Shale, sandy; overlain by Morrison shale	5
Limestone, very fossiliferous; two layers	3
Shale, green fossiliferous; contains concretions	100
Sandstone, soft, red	50
Sandstone, buff, slabby	20
Shale, green, and thin sandstone	15
Sandstone, buff, massive to slabby, rippled	20
Shale, green; rests on red shale of Spearfish formation	60
	273

Section of Sundance formation 3 miles south of Fort Meade, S. Dak.

	Feet.
Shale, sandy; overlain by Unkpapa sandstone	5
Limestone, hard fossiliferous	1
Shale, greenish gray; hard fossiliferous layers in upper part	125
Sandstone, soft, red	30
Shale, sandy	10
Sandstone, buff, massive; cliff maker	30
Shale, dark	25
Sandstone, buff, massive	8
Shale, gray, and thin sandstones	80
Sandstone, soft, buff	6
	320

From Whitewood to and beyond Sturgis the basal sandstone is 6 to 8 feet thick. The medial red member is well developed, and there are some notable exposures of it in the railroad cut north of Alkali Creek and $1\frac{1}{2}$ miles north of Tilford. The overlying gray shales, from 125 to 150 feet thick, carry two hard fossiliferous layers near their top.

For much of the distance between Tilford and Whitewood one of these beds of oyster-bearing limestone, 20 feet below the Unkpapa, forms a well-defined bench on the smooth slope. Southeast of Piedmont there is at the top of the formation a 30-foot member of hard gray sandstone and limestone underlying the Unkpapa sandstone. Near Rapid City and northward for some distance the sandstone member near the middle of the formation lacks much of its characteristic red tint; in this region also it contains considerable shale. On Rapid Creek the top shales are light green.

Section of Sundance formation 7 miles south of Rapid City, S. Dak.

	Feet.
Sandstone, mostly flaggy	16
Limestone with fossil shells	$\frac{1}{2}$
Sandstone, flaggy	5
Limestone with fossil shells	2
Sandstone, massive	8
Limestone, fossiliferous	2
Shale, light colored	3
Limestone, sandy, fossiliferous	$\frac{1}{2}$
Shale and concealed beds, apparently some fossils	16
Sandstone, flaggy	4
Beds mostly concealed, apparently shale containing harder layers that carry belemnites	70
Sandstone, yellow, massive, partly concealed	18
Beds concealed	30
Sandstone, flaggy	10
Shale, red	30
Sandstone, flaggy	10
	235

A top sandstone member, presumably Sundance, appears a few miles south of Rapid City and is conspicuous as far as the area beyond Squaw Creek. It consists of about 25 feet of moderately hard and slabby beds that give rise to a distinct bench or cliff, which lies under Unkpapa sandstone and surmounts slopes of shale and greenish-buff sandstone.

On Spring Creek the following beds are exposed:

Section of Sundance formation on Spring Creek, 8 miles south of Rapid City, S. Dak.

	Feet.
Sandstone, buff, massive above, slabby below; cliff maker; overlain by Unkpapa sandstone	25
Shale, green, with a 1-foot bed and a 2-foot bed of hard highly fossiliferous limestone, 6 feet apart	25
Shale, green, with thin layer of sandstone, all highly fossiliferous	40
Sandstone, massive; contains pale-greenish soft clay	25
Sandstone, soft, pinkish, massive	20
Talus	50
Sandstone, slabby, buff, ripple marked; cliff maker	12
Shale, green	25
Sandstone, buff; rests on red shale of Spearfish formation	3
	225

In the slope 4 miles southeast of Otis the top member, 20 feet thick, is overlain by white Unkpapa sandstone.

Near Spring Creek a thick bed of hard, impure, highly fossiliferous limestone appears in the upper shale member, giving rise to a small, sharp ridge, which extends nearly to Battle Creek and is especially conspicuous 5 to 8 miles northwest of Hermosa. There the red sandstone member is exposed for some distance, and the lower shale member is underlain by a basal member of 2 to 10 feet of reddish to buff massive sandstone. South of Squaw Creek the thickness of the formation decreases greatly, and it is only 60 to 80 feet on Dry Creek northwest of Fairburn. There it comprises flaggy sandstone at the top, green shale with fossiliferous layers in the middle, and a few feet of greenish-buff slabby sandstone at the base, lying on the red shale of the Spearfish formation.

Sections on French Creek show the following beds:

Section of Sundance formation on French Creek 4 miles west of Fairburn, S. Dak.

	Feet.
Sandstone, buff, slabby, with some red shale near middle (cliff)	20
Shale, green, with thin fossiliferous sandstone layers	80
Sandstone, buff, soft, with shaly layers	20
Sandstone, massive, buff to red; rests on red shale of Spearfish formation	30
	150

Section of Sundance formation 1 mile south of French Creek, S. Dak.

	Feet.
Shale, dark, and sandstone, gray, with reddish layers	25
Sandstone, buff, ripple marked	25
Sandstone and dark-gray shale alternating, ripple marked	8
Shale, dirty gray, buff, with thin layers of sandstone; contains fossils	30
Sandstone, buff, with ripple marks, some thin beds and reddish layers; rests unconformably on Spearfish red shale	24
	112

In this section the upper shales are exceptionally thin and contain many layers of sandstone. Here, as on Dry Creek, the medial red member and the basal shale member are absent. Near Fuson Canyon the massive basal buff sandstone is 8 feet thick, the lower shale member about 15 feet thick, and the massive to slabby buff sandstone member 20 to 25 feet thick. Ripple marks are abundant. Above these beds in succession come 50 feet of red sandy shale, 40 to 50 feet of soft thin-bedded greenish-buff sandstone, about 125 feet of grayish-green

[7] Hussakof, L., Note on a palaeoniscid fish from a Permian formation in South Dakota: Am. Jour. Sci., 4th ser., vol. 41, pp. 347-350, 1916.

shale with buff to greenish intercalated sandstone beds 3 to 20 feet thick, and at the top 10 to 15 feet of buff slabby moderately hard sandstone.

Section of Sundance formation 2 miles north of Fuson Canyon, S. Dak.

	Feet.
Sandstone, buff, thin bedded; overlain by Unkpapa sandstone	15
Shale, dark, with fossiliferous concretions	65
Shale, green, sandy; part concealed	30
Sandstone, buff, soft	50
Shale, red, sandy, with thin sandstone layers	125
Sandstone, buff, with ripple marks	6
Shale, black	8
Sandstone, buff; very thin bedded near base	15
Shale, dark, with thin sandstone layers	8
Sandstone, massive red to buff; lies on red shale of Spearfish formation	8
	330

Section of Sundance formation in Buffalo Gap, S. Dak.

	Feet.
Shale, green, with thin layers of fossiliferous limestone; overlain by Unkpapa sandstone	100
Shale, red, sandy and soft sandstone	65
Shale, greenish buff, sandy and thin sandstone	15
Sandstone, buff, slabby, with ripple marks	40
Sandstone, pale red, massive, soft, cross-bedded	7
Clay, purplish and buff, sandy, on 6-inch bed of gray hard sandstone; rests on red shale of Spearfish formation	4
	231

On the southwest slope of the Black Hills the formation presents the same general succession as in the outcrops along the eastern side of the uplift. A typical section follows:

Section of Sundance formation near Pass Creek, S. Dak.

	Feet.
Shale, greenish gray, with thin fossiliferous layers; overlain by Morrison shale	125
Sandstone, red, with some red and green shale	75
Sandstone, pale greenish buff, thin bedded	10
Shale, pale grayish green	10
Sandstone, buff, flaggy, with ripple marks	35
Shale, gray	40
Sandstone, red, coarse, massive; rests on red shale of Spearfish formation	5
	300

In Hell Canyon the lower members include 40 feet of black shale and 5 to 6 feet of buff to gray slabby to massive sandstone with red streaks and grains, which lies unconformably on the channeled surface of red shale of the Spearfish formation.

In the slopes 11 miles west by south of Argyle the top member of the formation is a 6 to 8 foot bed of pale-greenish sandstone containing hard fossiliferous layers, which is underlain by olive-green shale that includes a few thin layers of sandstone. A mile farther west a 2-foot limestone member containing many fossils lies near the top. Below this limestone comes 100 feet of gray to greenish shale, grading down into the usual pale-buff sandstone member, 25 feet thick, and next below comes 30 to 40 feet of dark shale, which lies on a basal member of orange to red massive sandstone 10 to 15 feet thick, of wide extent.

Fossils.—Fossils are abundant in the Sundance formation, especially *Belemnites densus*, a cigar-shaped form composed of heavy, hard calcium carbonate, smooth on the outside and having a radiated structure within. This fossil occurs most abundantly in sandy layers in the lower part of the upper shale member, and at some places it weathers out in large numbers. In concretions or hard layers in the upper shale member occur the following species, determined by T. W. Stanton:

Ostrea strigilecula.	Tancredia inornata.
Avicula mucronata.	Tancredia corbuliformis.
Lingula brevirostris.	Tancredia bulbosa.
Camptonectes bellistriatus.	Tancredia postica.
Astarte fragilis.	Dosinia jurassica.
Trapezium bellefourchensis.	Saxicava jurassica.
Pleuromya newtoni.	Ammonites cordiformis.

In some areas layers of fossiliferous limestone occur in the lower shales. They yielded the following species:

Pentacrinoides asteristicus.	Pseudomonotis curta.
Ostrea strigilecula.	Psammobia prematura.
Camptonectes bellistriatus.	Belemnites densus.

The Sundance fauna is of Upper Jurassic age, and the formation is believed to be equivalent to the Ellis formation of Montana and the Yellowstone Park region.

UNKPAPA SANDSTONE.

Outcrop and character.—The Unkpapa sandstone is prominent on the eastern side of the Black Hills uplift, but north of Sturgis and in the Bear Butte uplift, as well as in the southwestern slope of the hills, it is either absent or represented by a few feet of yellowish sandstone at the top of the Sundance formation. For a short distance in the region southwest of Fairburn it is covered by Tertiary deposits, and at many other places it is hidden by talus. It appears in the small anticline 3 miles southeast of Piedmont Butte. The sandstone is characteristically massive, fine grained, and of remarkably uniform texture. (See Pl. XVI.) In color it ranges from white to purple and buff but is predominantly pure white. Cross-bedding is general, in places made conspicuous by thin sloping brown layers of oxide of iron on the cross-bedding planes. The rock is soft as compared with most of the overlying Lakota sandstone and forms but few cliffs.

Relations.—South of Battle Creek, where the Morrison beds are absent, the Unkpapa sandstone is overlain unconformably by the Lakota sandstone. At the contact of the Unkpapa sandstone with the Morrison shale the character of the materials changes abruptly, and the change probably marks a break in deposition. Apparently the Unkpapa grades downward into the Sundance formation.

Thickness.—From Buffalo Gap to French Creek, and also near Rapid City, the thickness of the formation ranges from 140 to 150 feet, with local exceptions. One mile south of French Creek the thickness is 150 feet; on French Creek, 100 feet; and on Dry Creek northwest of Fairburn, about 90 feet. On Battle Creek 30 feet of distinctive Unkpapa sandstone is overlain by 50 feet of doubtful beds. Northwest of Hermosa, on Spring Creek and thence nearly to Rapid City, the thickness is 40 to 60 feet, and 3 miles south of Rapid City it is 30 feet. In the gap at Rapid City it is 125 feet; on the slopes $1\frac{1}{2}$ miles farther north, 140 feet; $1\frac{3}{4}$ miles north of Blackhawk, 100 feet; and near Piedmont and Tilford, 40 feet. Near Sturgis and north of it the formation ceases to be conspicuous, although a few feet of the characteristic white sandstone appears from place to place.

Local features.—In some localities portions of the rock are beautifully banded in various colors, generally parallel to the bedding planes but in some places diagonal to them. This banding is well shown in the extensive exposures at an old quarry in Calico Canyon, 2 miles northwest of the town of Buffalo Gap, where the banded beds afford fine illustrations of minute block-fault phenomena. Plate XXIX represents a typical specimen of the faulted rock. In the first canyon south of French Creek, where the Unkpapa sandstone is 150 feet thick, its upper half is red and its lower half is pure white, and the two are sharply separated. On French Creek the rock is mostly white, and on Dry Creek, northwest of Fairburn, 90 feet of white massive sandstone crops out between ledges of Lakota sandstone above and a 10-foot talus slope that extends to ledges of sandstone below. In slopes east of bench mark 3780, in this vicinity, some of the sandstone is bedded, a most unusual feature.

On Squaw Creek the formation consists of 25 feet of fine-grained massive sandstone that lies on slabby sandstone which is believed to be the top member of the Sundance formation. The color ranges from buff to light gray. The sandstone is overlain by 10 feet of sandy shale, probably Unkpapa but possibly Morrison.

On the southern side of Battle Creek the Unkpapa sandstone directly underlies Lakota sandstone, but on the northern side a few feet of Morrison shale intervene. Here the top member, 50 to 60 feet thick, consists of massive fine-grained buff sandstone and is separated by a few feet of slabby buff sandstone from the 30-foot lower member of massive, compact cross-bedded pure-white sandstone. This lower member makes a prominent cliff that rises above a shelf formed by 25 feet of hard slabby sandstone, regarded as the top member of the Sundance formation. In the bluff south of Battle Creek the upper member is only 30 to 35 feet thick and consists of 20 feet of fine massive red sandstone, which grades up into 10 to 15 feet of fine massive buff sandstone, on the channeled surface of which lies the Lakota sandstone.

In the slopes 5 miles northwest of Hermosa 20 feet of moderately hard white sandstone is overlain by 40 feet of soft thin-bedded red sandstone, which is not typical of the Unkpapa but doubtless represents that formation. On Spring Creek the Unkpapa consists of 40 feet of rather crumbly white sandstone, in part stained buff, which lies on hard slabby buff sandstone at the top of the Sundance formation, as in the region on the south.

Three miles south of Rapid City the Unkpapa formation consists of 50 feet of soft, crumbly sandstone, pink above and white below. Two miles southeast of Tilford slabby fossiliferous sandstone at the top of the Sundance formation is overlain by 20 feet of fine, soft sandstone, white and creamy, and, at the top, 4 inches of buff sandstone. Next above comes the Morrison shale. A mile north of Rapid City the formation consists of 140 feet of soft, fine white massive sandstone, some of which has been quarried. Here and to the north it lies on a fossiliferous limestone layer at the top of the Sundance formation. In exposures $1\frac{3}{4}$ miles north of Blackhawk it comprises a lower white or buff member, 70 feet thick, and an upper red member, about 30 feet thick, resembling the red member in the middle of the Sundance formation. Three miles southeast of Blackhawk the formation becomes somewhat thinner, and the upper member is red. Opposite Stage Barn Canyon the basal member, 40 feet thick, is cream to white massive soft sandstone. It is overlain by 3 feet of slabby gray sandstone and 30 feet of soft light-red sandstone, which becomes thinner and disappears to the north. Near Sturgis and farther north a thin body of white to buff massive sandstone intervenes between the Sundance and the Morrison, but it is generally hidden by talus. This rock may be an upper member of the Sundance formation.

Age.—No fossils have been found in the Unkpapa sandstone, but from its close association with the Sundance formation it is provisionally classed in the Jurassic system.

CRETACEOUS (?) SYSTEM.

MORRISON SHALE.

Character and outcrop.—The Morrison shale consists of about 100 to 150 feet of massive shale or clay, prevailingly light gray or greenish gray merging into maroon, brown, buff, and purple, and includes thin beds of fine-grained gray sandstones and layers of calcareous nodules. In places the calcareous layers develop into beds of limestone, which locally are 4 to 40 feet thick. Some sandy beds are buff, and in places, especially north of Sturgis, the upper beds are black and somewhat carbonaceous. The massive structure and chalky appearance of the shale are distinctive.

The shale crops out below escarpments of Lakota sandstone in a narrow zone high up on the inner slope of the Hogback Ridge and is hidden by talus at many places. It occurs in outliers west of Elkhorn Peak and on Lookout Peak. A small area is exposed in the crest of the anticline 3 miles southeast of Piedmont, and there are extensive exposures around Bear Butte. The outcrop extends southward to Battle Creek and possibly to Squaw Creek, where the formation thins out. It reappears in the southwestern part of the Black Hills along the eastern slope of the Elk Mountains and on the northern and eastern slopes of the ridge east of Pass Creek.

Thickness.—The thickness of the Morrison shale generally ranges from 100 to 150 feet, but 2 miles north of Piedmont it is 220 feet. In Lookout Peak, near Spearfish, it appears to be 110 feet, but it diminishes to less than half as much in the ridges north of Centennial Prairie and around Whitewood. North of Sturgis it averages about 100 feet and south of Fort Meade 70 feet. In the Tilford region it is 100 to 110 feet; 2 miles north of Piedmont, 220 feet; near Piedmont Butte and southward, 130 feet; 1 mile north of Rapid City, 170 feet. The formation is apparently only 40 feet thick opposite the mouth of Stage Barn Canyon. It becomes thinner and disappears 2 miles north of Rapid City but reappears half a mile north of the gap of Rapid Creek, where it thickens to 110 feet in a short distance. A mile south of Rapid City it is 90 feet thick; 3 miles south of Rapid City, 165 feet; and on Spring Creek, south of Rapid City, 100 feet. West of Hermosa it disappears and is absent for many miles south of this locality. In the slopes of the Elk Mountains the thickness is about 150 feet. In the center of T. 6 S., R. 2 E., it is about 100 feet.

Relations.—The Morrison shale is sharply separated from the Sundance formation and the Unkpapa sandstone by an abrupt change in the character of the sediment and a probable unconformity, although there is no difference in dip or noticeable channeling at these contacts. At the top of the formation the shale gives place rather abruptly to the massive basal sandstone of the Lakota, but there is no suggestion of unconformity at the contact, and precisely similar shale appears higher up between the sandstone beds of the Lakota. The absence of the formation in the southeastern part of the Black Hills is due either to its nondeposition or to its removal in a locally uplifted area in early Lakota time. Erosion in this area is indicated by the superposition of Lakota sandstone on the channeled surface of the Unkpapa sandstone, but whether this channeling was pre-Morrison, Morrison, or post-Morrison is not known.

The formation presents some local variation in character, but throughout its area the massive texture of the shale and its chalky appearance and pale-greenish tint distinguish it from the Sundance formation.

Local features.—On Spring Creek, north of Sturgis, where the formation is 100 feet thick, the shale near its base is bright green and at one point includes a 4-foot bed of limestone. Three miles north of Piedmont and in the vicinity of Tilford a deposit of impure fire clay occurs near the middle of the formation. The impurities are largely calcite and silica.

Section of Morrison shale and associated beds 3 miles due north of Piedmont, S. Dak.

[By G. R. Wieland.]

	Feet.
1. Sandstone (Lakota), massive, more or less cross-bedded, flesh-colored; crest of Hogback Ridge	60
2. Sandstone (Lakota), deeply iron stained; contains much silicified wood	20
3. Shale, gray to blue; silicified wood	20
4. Sandstone, soft, white	12
5. Talus (shale)	60
6. Sandstone; contains two hard ledges	20
7. Shale containing limestone layers; contains ostracods and fish teeth	20
8. Shale, containing silicified wood and *Barosaurus*, *Morosaurus*, and other large dinosaurs; nodular limy layers near base	80
9. Sandstone, drab to white, cross-bedded; belongs to Unkpapa formation	75

Opposite the mouth of Stage Barn Canyon the formation consists of 3 feet of green shale, 6 feet of dark-red shale, and, at the top, 30 feet of pale greenish-gray massive shale. Two miles southeast of Tilford a 4-inch bed of buff sandstone, at the base, lies on the Unkpapa sandstone. This basal bed is overlain by 50 feet of pale-green shale, mostly chalky, which is capped by a lenticular bed of limestone that is of no great extent and that ranges in thickness from a few inches to 40 feet. The top member consists of 50 feet of dark shale, which extends to the base of the Lakota sandstone.

North of Tilford there is considerable chert in the upper part of the upper shale member, and a bed of pinkish limestone a foot thick occurs near the middle of the formation. At a locality 1½ miles south of Piedmont the basal member, 30 feet thick, is decidedly red, resembling somewhat the red member of the Sundance formation. On the slope 1¾ miles north of Blackhawk this member consists of 20 feet of greenish shale on 5 feet of reddish shale, which lies unconformably on Unkpapa sandstone. Three miles southeast of Blackhawk the formation consists of 20 feet of bright-green shale. At a place 1½ miles north of Rapid City the upper 65 feet of the formation consists mostly of dark-greenish shale and the lower 35 feet of moderately massive and sandy shale, which lies on Unkpapa white sandstone. Half a mile to the south this lower member has at its base some breccia, which at Rapid City gives place to a thick bed of clay that has been used for making fire brick.

Section of Morrison shale 3 miles south of Rapid City, S. Dak.

[By C. C. O'Harra.]

	Feet.
Beds concealed to base of Lakota sandstone	20
Mostly green shale, partly concealed	46
Sandstone, massive, gray	5
Shale, green and purple, with some sand, iron stained	16
Sandstone, soft, green and gray	12
Shale, green, with some sand	12
Shale, soft, green and purple, with several calcareous nodular layers 8 to 20 inches thick	6
Sandstone, massive but soft; mostly white, light red, and brown at bottom; slightly brecciated near top	20
Shale, soft, red, with some sandy layers	12
Shale, soft, purple and yellowish, with calcareous nodules	5
Shale, soft, bright red	3
	167

In the region 5 to 8 miles south of Rapid City the top member is a 10-foot bed of fire clay that merges downward into 50 feet or more of greenish shale.

In the NE. ¼ sec. 26, T. 1 S., R. 7 E., 11 miles south of Rapid City, the Morrison formation is 40 feet thick and consists of pale-green shale that contains a 3-foot bed of fire clay 15 feet above its base. In the slopes 5 miles northwest of Hermosa the typical Lakota sandstone is separated from soft red Unkpapa sandstone by 40 feet of dark shale, which carries thin layers of sandstone, probably Morrison, which is overlain by 20 feet of massive buff sandstone that may be either Morrison or Lakota. On the south side of Battle Creek this 20-foot sandstone member is represented by 45 feet of buff and greenish-buff thin-bedded soft sandstone capped by 5 feet of massive red fine-grained sandstone. This 50-foot thickness of beds may include the Morrison and the top of the Unkpapa.

On Squaw Creek 3 miles southwest of Hermosa 10 feet of buff sandy shale that separates the Unkpapa and Lakota sandstones may be Morrison. On French Creek west of Fairburn the Lakota sandstone is underlain by considerable shale, which may possibly be a local remnant of the Morrison. In the Elk Mountain region, in the southwest corner of the area considered in this folio, the Morrison formation presents its typical features and is about 150 feet thick. In exposures a mile south of the center of T. 6 S., R. 2 E., the Morrison is a pale-greenish massive shale containing nodules and thin layers of limestone, one of the layers being a foot thick. Here the Morrison appears to grade through soft slabby sandstone and sandy shale into Lakota sandstone. On Pass Creek the top member consists of 30 feet of dark fissile shale.

Fossils.—Many bones of large saurians have been obtained from the Morrison shale, notably from the north side of Piedmont Butte, in a 6-foot layer of dark clay 10 to 15 feet above the base of the formation, and similar remains have been found at other places. Some geologists consider them late Jurassic; others believe that they are early Cretaceous—a belief that is strengthened by the fact that stratigraphically the formation is generally well separated from the Sundance and Unkpapa rocks and is closely connected with the Lakota. Three miles north of Piedmont great numbers of fossils about the size of a pinhead were found by C. C. O'Harra in the upper 10 or 12 feet of the Morrison shale and in the lowest beds of the Lakota sandstone. They were identified by T. W. Stanton as the remains of an ostracode crustacean belonging to the family Cypridae, somewhat similar to fossils found in Morrison beds at Canon City, Colo.

CRETACEOUS SYSTEM.

LOWER CRETACEOUS SERIES.

LAKOTA SANDSTONE.

Outcrop and character.—The Lakota sandstone constitutes a large part of the prominent Hogback Ridge that extends around the Black Hills and includes the Elk Mountains and the high ridge east of Pass Creek. It appears also in the small uplift at the west end of Bear Butte, and in outlying areas it caps Lookout Peak and the summits northwest of Elkhorn Peak. Where the dips are steep, as they are in the vicinity of Fort Meade, northeast of Piedmont, and near Rapid City, the outcrop is very narrow. In the syncline and anticline southeast of Piedmont Butte and the syncline west of Whitewood it is spread out widely, in places forming a plateau that is deeply trenched by canyons.

The formation consists mainly of moderately hard, massive, coarse-grained, cross-bedded gray sandstone but includes at some places greenish-gray shale members, some of which, near Buffalo Gap, Rapid City, and Sturgis, are 10 to 20 feet thick. (See Pl. XXX.) The basal beds are at many localities conglomeratic. Some beds are slabby, and some contain nodules of oxide of iron. The sandstone varies in hardness and in places is much disintegrated. It contains abundant petrified wood which in some areas accumulates on the surface.

Thickness.—The thickness of the Lakota sandstone differs greatly from place to place. Its average is about 150 feet in the northern part of the region, and it gradually increases to more than 400 feet in the region south of Fairburn. In the ridges near Whitewood it is about 75 feet; on Spring Creek, near Sturgis, 235 feet; south of this place to Rapid City and beyond it averages 200 feet. On Squaw Creek and Dry Creek it is 300 feet thick; on French Creek, 320 feet; and at Fuson Canyon it reaches a maximum of 485 feet. On Pass Creek and in the Elk Mountains it is about 200 feet.

Relations.—The Lakota sandstone lies conformably on the Morrison shale, although the two formations are sharply separated in places, especially where the basal bed is conglomeratic. At some places the two formations merge. South of Battle Creek and for a short distance north of Rapid City the Lakota sandstone overlaps on the Unkpapa sandstone, on which it lies with marked erosional unconformity. The top is defined by a rather abrupt change to Fuson sediments except at a few places where there appears to be transition through sandy shale. In the vicinity of Buffalo Gap the Minnewaste limestone separates the Lakota and the Fuson.

Local features.—In the plateau northeast of Whitewood the formation consists of a top member, a massive buff sandstone, 25 feet thick; a medial member, a soft flaggy sandstone, 30 feet thick, locally quartzitic and containing here and there layers of coarse conglomerate; and a basal member, a soft flaggy sandstone, in part irregularly bedded, 15 feet thick.

At Sturgis there is a 25-foot green shale member in the middle and a similar bed near the base of the formation. Lookout Peak is capped with a remnant of 30 or 40 feet of the sandstone, mostly coarse grained and quartzitic. The top beds 2 miles southeast of Piedmont Butte contain petrified wood and include scattered pebbles, some of them 3 inches or more in diameter. These pebbles consist of various materials, some of them similar to the Algonkian rocks in the central part of the Black Hills uplift.

Section of Lakota sandstone on Spring Creek north of Sturgis, S. Dak.

[By C. C. O'Harra.]

	Feet.
Sandstone, buff, in part cross-bedded; bears ripple marks	94
Sandstone, mostly purple, rusty to gray, slabby at base	8½
Sandstone, massive, buff, pitted; has shaly partings	30
Talus	35
Shale, white	1
Shale, lilac, hackly	6
Sandstone, brick-colored	10
Sandstone, massive, cross-bedded, buff to variegated; bears ripple marks	15
Sandstone, buff	25
Sandstone, white above, dark buff below; rests on Morrison green shales	11
	235½

Section of Lakota sandstone on south side of Piedmont Butte, S. Dak.

	Feet.
Beds concealed, but petrified wood scattered on surface	40
Sandstone, massive	10
Sandstone, soft, white	24
Sandstone and conglomerate, massive; contain well-rounded pebbles less than half an inch in diameter	10
Beds concealed	8
Sandstone, with 2-foot bed of conglomerate containing small rounded pebbles and a few boulders 2 inches or more in diameter	8
Sandstone, reddish, irregularly bedded, in some places brecciated, with calcite in crystals and botryoidal, laminated, or pisolitic forms	60
	160

Opposite Stage Barn Canyon the basal member is composed of 10 feet of hard, massive buff sandstone overlain by 25 feet of dark shale, which extends to the base of a sandstone ledge.

Section of Lakota sandstone on Boxelder Creek, S. Dak.

	Feet.
Sandstone, weathered and largely concealed	25
Sandstone, ragged, uneven; contains angular blocks and streaks of clay and many pieces of petrified wood that are not in position of growth	25
Sandstones in beds from 1 to 4 feet thick, separated by shale in beds from 1 to 6 inches thick	60
Sandstones, thin bedded, mostly concealed	50
Sandstone in 1 to 4 foot beds	40
	200

Near Rapid City the formation includes layers of slabby sandstone that exhibit ripple-marked surfaces. In cliffs 3 miles southeast of Blackhawk the basal member is made up of 20 feet of hard, coarse buff sandstone, part slabby and part cross-bedded; the middle member of 25 feet of shale, and the top member of 140 feet of massive buff sandstone with several beds of shale. In cliffs 1½ miles northwest of Rapid City, where for a short distance the formation lies directly on the eroded surface of the Unkpapa sandstone, the following beds appear:

Section of Lakota sandstone 1½ miles northwest of Rapid City, S. Dak.

	Feet.
Sandstone, buff, massive, hard	40
Shale	20
Sandstone, buff; weathers brown	5
Shale	20
Sandstone, coarse, slabby to massive, buff; weathers brown	30
	115

Some slabs from the lower sandstone beds on the north side of Elk Creek bear hopper-shaped impressions such as might have been formed by the solution of crystals of halite.

On Dry Creek the top bed is a jaspery conglomerate, a rock which appears also in the middle of the formation in the canyon of Lame Johnny Creek.

In Elk Mountains and the plateau east of Pass Creek, where the formation is 200 feet thick, the basal member, a fine hard, massive buff sandstone, 10 to 40 feet thick, forms a prominent cliff. On Pass Creek, where this basal bed is 10 feet thick, it is overlain by 10 feet of soft buff sandstone, 30 feet of purple to gray clay and shale, 10 feet of soft light-colored sandstone, 20 feet of gray shale and soft sandstone, and 40 feet of hard buff sandstone, above which a bed of softer sandstone extends to the base of the Fuson shale.

Fossils.—The upper layers of the Lakota sandstone contain much petrified wood, which weathers out extensively. At one place on Boxelder Creek and near the cycad locality southeast of Piedmont many embedded logs are exposed. The remaining part of one of these logs, 2 miles southeast of Piedmont Butte, is 25 feet long. Wood from ledges 3 or 4 miles northwest of Sturgis has been described as *Pinoxylon dacotense* by Knowlton,[8] who regards it as Cretaceous.

Many cycads have been found in the Lakota sandstone, notably in beds 90 feet below the top of the formation, half a mile south of Clemmons Spring, nearly due north of Blackhawk. They consist of a short, oval trunk showing deep scars of leaf-stem sockets. One of the finest specimens ever found, *Cycadeoidea dartoni*,[9] was obtained by N. H. Darton 4 miles northwest of Hermosa. The cycads and the fossil leaves found in the Lakota sandstone are believed to be of early Cretaceous age. Leaves obtained from basal beds 5 miles south of Sturgis have been described by Wieland as *Nilsonia nigracollensis*.[10]

In a bed 25 feet above the base of the Lakota sandstone, 3 miles north of Piedmont, C. C. O'Harra found many isopods, determined by Stanton as probably of the family Aegidae and the first isopods found fossil in America. They are similar to forms still living but are found in beds as old as the latest Jurassic (Purbeckian of Europe). In a slightly lower bed at this locality an undetermined form of *Estheria*, scales of a gar (*Lepidosteus*), and a crocodile tooth, all fresh-water forms, were found, and still lower there are remains of a small ostracode crustacean, similar to those in the underlying Morrison beds.

Bones of the type specimen of *Stegosaurus marshii* were obtained by N. H. Darton from shales that lie between the sandstones 90 feet above the base of the formation, in the small saddle between Calico Canyon and Buffalo Gap, 3 miles northwest of Buffalo Gap station. Footprints have been found by O'Harra[11] in Lakota sandstone in a quarry about 1½ miles northeast of Rapid City at a horizon about 60 feet above the base of the formation.

MINNEWASTE LIMESTONE.

In the southeastern part of the Black Hills uplift the Lakota sandstone is overlain by a thin sheet of limestone, which terminates between Buffalo Gap and Fuson Canyon. This limestone is about 12 feet thick in Buffalo Gap and 18 feet on the plateau south of Calico Canyon. It is nearly pure and of light-gray color. No fossils were found in it.

FUSON SHALE.

Outcrop.—As the Fuson formation is soft, its outcrop zone is generally marked by a depression between a low crest of Dakota sandstone on one side and a long slope of Lakota sandstone on the other, but in the region north of Sturgis it is more prominent. The formation crops out at intervals on the slopes of ridges overlooking Pass Creek. It reaches the surface also in the dome west of Bear Butte. It is covered by Tertiary deposits southwest of Fairburn and Hermosa and by talus at many places. One of its most extensive exposures is in the syncline southeast of Piedmont Butte.

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[8] Ward, L. F., and others, Status of the Mesozoic floras of the United States; The older Mesozoic: U. S. Geol. Survey Twentieth Ann. Rept., pt. 2, pp. 419–422, pl. 179, 1900.

[9] Wieland, G. R., American fossil cycads, vol. 2, Taxonomy: Carnegie Inst. Washington Pub. 34, p. 95, 1916.

[10] Ward, L. F., and others, Status of the Mesozoic floras of the United States, second paper: U S. Geol. Survey Mon. 48, pp. 319–322, 1905.

[11] O'Harra, C. C., Fossil footprints in the Black Hills: Pahasapa Quart., vol. 6, pp. 20–29, June, 1917.

Character.—The formation consists mainly of a mixture of fine sand and clay, and much of it is fire clay. Most of it is massive and weathers out in small cylindrical blocks. At some places it includes thin beds of buff sandstone. Its predominant color is white or gray, but parts of it are buff, purple, or maroon, and at some places it includes an upper member of black clay.

Thickness.—The Fuson shale ranges in thickness from a maximum of 188 feet on Squaw Creek, southwest of Hermosa, to a minimum of about 30 feet on the south side of Elkhorn Peak. West and northeast of Whitewood and near Tilford it is 70 feet thick, and on Spring Creek and near Sturgis, Blackhawk, and Rapid City it is 100 feet. West of Hermosa the thickness ranges in general from 70 to 120 feet, but locally, on Squaw Creek, it increases to 188 feet. On Dry Creek it is 50 feet; in Fuson Canyon, 100 feet; in Buffalo Gap, 150 feet; and on Pass Creek, 30 to 40 feet.

Relations.—Apparently there is no unconformity between the Fuson shale and the overlying and underlying beds, and in some of the contacts there appears to be transition. They are coextensive.

Local features.—Northwest of Whitewood the formation consists of the following beds:

Section of Fuson shale 4 miles northwest of Whitewood, S. Dak.

[By C. C. O'Harra.]

	Feet.
Shale, yellowish, sandy	18
Shale, dark gray, massive; weathers to light purple	20
Shale, dark gray to black, iron stained, massive; weathers to dark purple	10
Fine clay, sandy; contains many carbonaceous fragments	12
Beds concealed	10
	70

In the extensive exposures of Fuson shale near Spring Creek, northwest of Sturgis, most of the material is light-gray fire clay, some of it very compact, especially near the base, where it becomes a light fine-grained sandstone. The top member consists of dark clay, purple shale, and thin layers of gray sandstone. From Sturgis to Tilford the upper member is soft shale, purple, buff, and red below, underlain by black shale, and southeast of Piedmont it consists of dark-gray and black shale and a few intervening beds of soft sandstone. Near Rapid City the upper member is dark shale, the middle member is white massive shale, and the lower member consists of yellow and red fire clay and shale, about 100 feet in all. The fire clay has been utilized to some extent at Rapid City. There are excellent exposures on Rapid Creek and in some gulches farther south.

Section of Fuson shale 2 miles south of Rapid City, S. Dak.

[By C. C. O'Harra.]

	Feet.
Sandstone, thin bedded; apparently grades into Dakota sandstone	10
Shale, dark blue, sandy at base	4½
Shale, brown and gray; carries 1 to 3 inch layers of limonite	10
Sandstone, hard	1½
Fire clay; weathers into badland slopes	45
Sandstone, heavy; 6 feet; probably at top of Lakota.	
	71

In a canyon at the Reed ranch, 5 miles south of Rapid City, the formation is composed mainly of purple clay or massive shale. Six miles northwest of Hermosa it consists of an upper member of soft buff and gray sandstone, 15 feet thick; a medial member of buff massive clay, 20 feet thick, grading down into purple massive clay 35 feet thick; and a basal member of gray massive shale, 12 feet thick, which lies on Lakota sandstone. Two representative sections in the Hermosa region are as follows:

Section of Fuson shale 4 miles northwest of Hermosa, S. Dak.

	Feet.
Shale, white and dark, massive; under Dakota sandstone	20
Sandstone, buff, massive, fine	0–10
Clay, gray	3
Sandstone, light buff, thin bedded	3
Shale, sandy, light gray, massive	18
Sandstone, soft, fine, white	0–20
Clay, massive, mottled purple	30
	104

Section of Fuson shale on Squaw Creek, southwest of Hermosa, S Dak.

	Fe t.
Sandstone, soft, light colored, in 3 to 6 inch beds; under Dakota sandstone	10
Shale, gray, massive, and soft sandstone	60
Sandstone, harder, massive, buff	8
Shales and thin sandstone layers	25
Shale, buff and purple, massive; breaks into cylindrical fragments	50
Sandstone, soft, yellow; contains shale in lower part; on Lakota sandstone	35
	188

On Dry Creek northwest of Fairburn the upper member is composed of 40 feet of white very fine grained massive soft sandstone or shale and the lower member of 10 feet of buff clay. Under the clay lies a thin bed of jaspery cross-bedded sandstone, probably at the top of the Lakota sandstone.

In the extensive exposures of the formation in Fuson Canyon, its type locality, the beds differ considerably in different parts of the outcrop. The following section is representative:

Section of Fuson shale in Fuson Canyon, 6 miles northwest of Buffalo Gap, S. Dak.

	Feet.
Sandstone, moderately hard, fine grained, gray; few thin layers	60
Shale, purplish gray, massive	10
Shale, white, fine grained, massive	10
Shale, purplish	20
	100

In Buffalo Gap there is no continuous exposure of Fuson beds. Near Pass Creek the formation consists of 40 feet of purplish and gray clay or shale and thin layers of buff and brown sandstone.

Fossils and age.—The Fuson shale has yielded no fossils in the area considered in this folio, but in the Hay Creek coal field, farther north, it has yielded many plants of early Cretaceous age.

UPPER CRETACEOUS SERIES.

DAKOTA SANDSTONE.

Outcrop.—The Dakota sandstone crops out in a narrow zone along the outer slope of the Hogback Ridge. It occupies a small area on the synclinal ridge west of Whitewood and nearly encircles the Bear Butte uplift, where its continuity is interrupted by faulting. The outcrop is most prominent near Buffalo Gap, Hermosa, and Rapid City, where the sandstone slope rises high above the foothills of Graneros shale. At a few places southwest of Fairburn, Hermosa, and Rapid City, however, it is overlapped by Tertiary deposits. Farther north, from Piedmont to Whitewood, the Dakota is so thin that it forms only low ridges or knolls.

Character.—The rock is mainly gray to buff sandstone, which weathers brown and is usually more iron stained than the Lakota sandstone. It contains many small masses of iron oxide, and in places some of the sandstone is heavily impregnated with iron. Thin streaks of conglomerate occur here and there in the basal beds. The bedding ranges from massive to slabby, and the hardness is variable, although much of the rock is moderately hard, especially the portions that contain considerable iron oxide. In most sections there is an upper member of brown slabby sandstone, which contains much iron oxide, and a lower member, which is massive, weathers dark red, and in the southern part of the area crops out in cliffs presenting a rude columnar structure that is characteristic. In some areas the upper member merges into Graneros shale.

Thickness.—In most of the region from Whitewood to Hermosa the Dakota sandstone is less than 50 feet thick, but its thickness increases south of Fairburn, and at Buffalo Gap it reaches a maximum of 200 feet. In Fuson Canyon it is 140 feet; on Squaw Creek it is 38 feet; on Spring Creek, south of Rapid City, 40 feet; 2 miles south of Rapid City, 26 feet; on Rapid Creek, 45 feet; 1½ miles north of Rapid City, 40 feet; southeast of Piedmont, 20 feet; midway between Tilford and Fort Meade, 10 feet; northwest of Fort Meade, 35 feet; and northwest of Whitewood, 50 to 60 feet. On Pass Creek it is about 150 feet.

Local features.—Locally the formation consists entirely of soft massive sandstone or of slabby sandstone and sandy shale. On one side of a gulch 2 miles south of Rapid City the formation is a hard massive sandstone and forms a vertical cliff; on the other side, a hundred yards distant, it is soft and forms only a rocky slope. In the narrow gap 1½ miles north of Rapid City the upper flaggy member is underlain by a 5-foot bed of conglomerate that consists of rounded pebbles half an inch or less in diameter. At Rapid City the upper member consists of 15 feet of flaggy beds and the lower member of 30 feet of massive sandstone. On Squaw Creek, southwest of Hermosa, the top member is composed of 8 feet of slabby sandstone and the lower, massive member is 30 feet thick. In Fuson Canyon the top member consists of 80 feet of slabby sandstone and a lower member of 60 feet of massive, coarse cross-bedded sandstone, which weathers reddish brown. At the base lies 1 foot of red jaspery sandstone. In Buffalo Gap, where the formation is more than 200 feet thick, there is 50 feet of softer sandstone and shale at the base and about the same amount of thin-bedded sandstone at the top. In the Pass Creek region, on the southwestern slope of the Black Hills, the Dakota is a buff to brown sandstone, in greater part hard and massive, and some layers carry considerable ironstone.

Age.—In the region considered in this folio the Dakota sandstone has yielded no satisfactory fossils, but in other parts of the Black Hills it yields remains of dicotyledonous plants of Upper Cretaceous age.

COLORADO GROUP.

GRANEROS SHALE.

Outcrop and character.—The Graneros shale, the lowest formation of the Colorado group, is of early Benton age and is believed to be the equivalent of the Graneros shale of southeastern Colorado. The formation averages about 1,000 feet in thickness and consists mostly of dark shale but contains thin local beds of sandstone, and north of Rapid City the included Mowry member, a lighter-colored harder shale, is conspicuous. In most places there are many biscuit-shaped concretions, 1 to 2 feet in diameter, especially in the lower beds. The outcrop of the formation, 1 to 4 miles in width, extends along the eastern side of the Hogback Ridge. It occupies a small area in the extreme southwest corner of the area described in this folio. Owing to the softness of the material the outcrop zone is marked by a region of rolling plains, parts of which are overlain by Quaternary and Tertiary deposits, the Tertiary hiding the formation in a wide area extending from Lame Johnny Creek nearly to Battle Creek and also on the divide between Battle and Spring creeks. In places the lower shales of the Graneros are so dark that they have been erroneously supposed to contain coal. East of Hermosa the upper beds include a few limy layers containing fossils.

Thickness.—Near Sturgis the Graneros shale appears to be 1,100 feet or possibly 1,150 feet thick, but the thickness decreases gradually toward the south, and near Rapid City, Hermosa, and Buffalo Gap it is about 900 feet. The thickness is difficult to determine precisely, owing to the variation in the dip and the width of the outcrops.

Relations.—Apparently the formation is conformable with the Dakota sandstone and the Greenhorn limestone. Some thin sandstone beds at the base suggest transition to the Dakota, but there is an abrupt change to the Greenhorn.

Mowry shale member.—The Mowry member consists of 225 to 250 feet of dark shales and dark, hard fine-grained thin-bedded sandstones, both of which weather light gray and contain large numbers of fish scales. These features are so characteristic that they serve as a basis for correlation with the Mowry beds, which are prominent in Wyoming and Montana. The member gives rise to ridges and knolls of moderate height, most of them bearing small, scattered pines, which are conspicuous from Rapid City northward. It is much less noticeable to the south, and therefore it is not separately mapped in Custer County. The base of the Mowry beds is about 350 feet above the base of the Graneros shale near Rapid City and 225 feet above it near Sturgis. Two thin beds of bentonite occur in the upper part of the Mowry member near Spring Creek, northeast of Sturgis, one 4 inches and the other 12 inches thick. This material is a very porous white clay, which absorbs a large quantity of water. It is probably decomposed volcanic ash.

Sandstone members.—At some localities near the Black Hills the Graneros shale includes a bed of gray to buff massive sandstone from 200 to 275 feet above its base, not far below the Mowry member. Near Rapid City this sandstone forms a small but prominent ridge. At this place it is 275 feet above the Dakota sandstone, is 25 feet thick, and has been quarried to some extent. It thins out to the north but reappears in a small but prominent ridge 3 miles northeast of Tilford, where it forms a brown, hard massive bed about 12 feet thick.

West of Hermosa a local bed of sandstone occurs at a horizon about 200 feet above the base of the formation and forms a distinct ridge, which extends about 5 miles north from Battle Creek. It is a moderately fine grained light-gray rock, in part massive. It attains a thickness of 15 feet and thins out to the north and south. At a point 2 miles north of Hermosa it contains many fossil leaves.

The basal beds of the Graneros shale include layers of sandstone that may be beds of passage to the Dakota sandstone; at higher horizons the formation contains other thin layers of sandstone.

Sandstone dikes.—North of Lame Johnny Creek, 7 miles south of Buffalo Gap, the Graneros shale is cut by several small dikes of sandstone, formed of sand that has been forced up through joint cracks in the shale.

Fossils.—A few fossils of Benton age have been collected in the Graneros beds, mainly from layers of impure limestone near the top of the formation just east of Hermosa.

In the slopes west of Hermosa three thin layers of buff sandstone, which lie some distance above the 15-foot sandstone described above, contain scales, bones, and teeth of fish.

GREENHORN LIMESTONE.

Outcrop and thickness.—The Greenhorn limestone crops out continuously along the east side of the Black Hills except where it is covered by Tertiary and Quaternary deposits and interrupted for a short distance by the intrusive rock and fault at Bear Butte. The rock is mostly an impure limestone, and owing to its hardness as compared with the adjoining shales it gives rise to a ridge of moderate prominence, which at most places presents a low escarpment to the west. North of Battle Creek it is less conspicuous. The thickness of the limestone averages about 65 feet, this measure including some shaly beds in the upper part. Complete exposures are rare, however, and there may be local variations in the thickness. Some notable exposures appear in the irrigating ditch 3 miles southeast of Rapid City, just below the schoolhouse near Elk Creek, about 8 miles east-northeast of Piedmont, along the ridge 7 miles northeast of Tilford and 2½ miles northeast of Fort Meade, on Battle Creek 2 miles southeast of Hermosa, in the railroad cut just north of Fairburn, in ridges southwest of Brennan, and in slopes east of Hermosa.

Character.—In fresh exposures, such as those southeast of Rapid City and in the river bank southeast of Hermosa, the material is dark gray and consists of alternate beds of shale and limestone. The limestone is thin bedded and bears numerous impressions of the characteristic fossil *Inoceramus labiatus.* It contains considerable clay and some sand and on hardening by exposure breaks into thin pale-buff slabs, most of which show impressions of the distinctive fossil.

A section of Greenhorn limestone on the divide south of Rapid Creek follows:

Section of Greenhorn limestone 7 miles east-southeast of Rapid City, S. Dak.

[By C. C. O'Harra.]

	Feet.
Sandstone, thin bedded, limy, and shale, mostly, concealed	30
Sandstone, thin, and sandy shale; much yellow clay; weathers creamy yellow, many fossils	5
Shale, dark, limy, with fossils	3
Sandstone, light gray, with fossils	½
Shale, gray and brownish yellow, limy, with many fossils	4½
Shale, hard, yellow, with many fossils	½
Shale, light to dull gray, with fossils	5
Shale, hard, dark gray, limy, with fossils	½
Shale, soft, limy, yellow above, dark below; some sand; some fossils	16
	65

Relations.—The limestone is separated from the black shales of the Graneros formation by an abrupt change in the character of the material, but its upper part grades through a few feet of passage beds into the Carlile shale.

CARLILE SHALE.

Outcrop.—The Carlile shale crops out along the east side of the Black Hills in a zone about 2 miles wide. In the broad divides north of Lame Johnny Creek it is covered by Tertiary deposits, but small exposures appear on Dry Creek and its branches north of Fairburn. In places from Rapid Creek northward it is covered by Quaternary gravel and sand, and it is cut off by faults and intrusive rocks at Bear Butte, northeast of which it reappears.

Character.—The Carlile shale is mostly gray, but it is not so dark as the Graneros shale and is less fissile. It includes two or three thin beds of hard buff sandstone, and it contains, near the top, many oval concretions, some of them highly fossiliferous. Its thickness ranges from 500 to 750 feet but is difficult to measure precisely because of the low and ill-defined dips of the beds. Southeast of Fairburn it is 520 feet thick. The following section is typical, but the succession and character of the beds differ considerably from place to place.

Section of Carlile shale near Buffalo Gap, S. Dak.

	Feet.
Niobrara chalk.	
Shale, with large concretions; weathers buff	150
Sandstone, hard, slabby, gray	2
Shale, gray	130
Sandstone, coarse	4
Shale, gray, with large concretions at base	75
Shale, gray	40
Limestone, impure, sandy; contains fish scales and other fossils	4
Shale	180
	585

Southeast of Fairburn a thin bed of impure limestone 40 feet above the base contains many fossils, and a 4-foot bed of hard massive brown sandstone lies 70 to 80 feet higher. Concretions in the upper member are numerous and conspicuous in the railroad cuts just north of Fairburn and Ajax. The concretions in draws 2½ miles southeast of Fairburn and on slopes 15 miles southeast of Sturgis and 10 miles south of Sturgis are highly fossiliferous.

Fossils.—Fossils from the upper beds include *Prionotropis woolgari, Prionocyclus wyomingensis, Inoceramus fragilis* (some specimens a foot in diameter), *Baculites gracilis, Scaphites warreni, Fusus shumardi, Corbula* sp., *Callista?* sp., *Leda* sp., *Crassatellites* sp., *Anchura* sp., and *Cuspidaria.*

NIOBRARA FORMATION.

Outcrop.—The Niobrara formation crops out in a narrow belt along the east side of the Black Hills and is exposed at intervals in the slopes that adjoin the larger valleys, but it is largely covered by Tertiary deposits on the divides near Fairburn and Hermosa and by alluvium in the valleys. It is interrupted by faults at Bear Butte. There are prominent exposures in the ridge 6 miles south-southeast of Fairburn, on French Creek 3 miles below Fairburn, in Dry Creek valley 3 miles northeast of Fairburn, on slopes near Battle Creek east and southeast of Hermosa, on Spring Creek 6 miles northeast of Hermosa, along the railroad from Spring Creek nearly to Brennan, on the north side of the divide between Elk Creek and Alkali Creek about 10 miles east of Tilford, and on Boxelder Creek east and northeast of Rapid City.

Character.—The Niobrara formation consists of about 200 feet of soft shaly limestone or impure chalk containing more or less clay and fine sand and beds of limy shale. It includes many thin, hard layers that consist of aggregates of *Ostrea congesta,* a feature that is characteristic of the formation. The beds are light bluish gray, but they weather to tints ranging from bright yellow to dull straw color, so that their outcrops become very conspicuous. As the rock is soft it generally weathers into valleys, but in places it presents low cliffs of striking appearance.

Thickness.—The formation is between 175 and 225 feet thick, but owing to the lack of complete exposures and to low, indefinite dips no precise measurements were made.

Relations.—The Niobrara formation is conformable with adjoining formations. The limy sediments begin abruptly at the top of the Carlile shale, and the top has been placed at the summit of limy beds that weather to a light straw tint. It is not at all unlikely, however, that the basal 100 to 200 feet of the Pierre shale as here mapped belongs to the Niobrara as that formation is defined in other regions, because beds that probably lie at this horizon near Hat Creek, Wyo., contain bones of vertebrates that are presumably of Niobrara age.[12]

MONTANA GROUP.

PIERRE SHALE.

Outcrop.—A wide area of the plains east of the Black Hills is occupied by Pierre shale. Although largely covered by Tertiary and later deposits, the shale has broad areas of outcrop between Buffalo Gap and Cheyenne River and along the valleys of French, Battle, Spring, Rapid, Boxelder, Elk, and Alkali creeks and the Belle Fourche. In places along Cheyenne River and the Belle Fourche it constitutes bluffs from 30 to 60 feet high.

Thickness.—The beds that crop out in the area treated in this folio are about 1,200 feet thick, and higher beds crop out farther east and south. As most of the dips are 2° or less, it is very difficult to measure the thickness.

Character.—The formation consists of dark bluish-gray shale, which weathers light brown and is relatively uniform in composition throughout. At a horizon about 1,000 feet above its base it contains scattered lens-shaped masses of limestone filled with shells of *Lucina occidentalis.* These masses range in diameter from a few feet to 20 feet or more and are 6 to 8 feet thick. As they are hard they give rise to low conical buttes, which resemble squat tepees and have therefore been called tepee buttes. These tepee buttes are mostly from 5 to 30 feet high and are very irregularly distributed, according to the sporadic occurrences of the limestone masses. They occur in several groups north of Cheyenne River, 9 miles southeast of Fairburn; north of French Creek, at a point 6 miles east-southeast of Fairburn; south of Rapid Creek, at a point 4 miles east-southeast of Brennan; on both sides of the Belle Fourche; and from 3 to 5 miles northeast of Buffalo Gap post office. The group last indicated is possibly formed of lenses that lie at a lower horizon than the others.

Many fossil-bearing concretions of clay ironstone occur in medial and upper beds of the Pierre shale. They are mostly small, and they break into pyramidal fragments, which are scattered more or less thickly over the surface of the shale. The basal member consists of 150 to 200 feet of black shale, mostly splintery and fissile, which in places carries biscuit-shaped concretions, some of them 2 or 3 feet in diameter. Many of these concretions have an outer shell of cone-in-cone structure and are traversed by cracks filled with calcite; some contain scattered crystals of barite. Generally in the northern part of the region this basal member includes limy beds that weather light gray and that carry thin layers and flat brownish-red concretions of oxide of iron. As already explained, this lower member may represent the upper part of the Niobrara formation of Kansas and Colorado.

Fossils.—The concretions in the Pierre shale carry many distinctive fossils, including *Baculites compressus, Inoceramus sagensis, Nautilus dekayi, Placenticeras placenta, Heteroceras nebrascense,* and *Lucina occidentalis.*

TERTIARY SYSTEM.

OLIGOCENE SERIES.

WHITE RIVER GROUP.

Distribution.—The beds at the western margin of the White River group, which constitute the Big Badlands between Cheyenne and White rivers and which underlie Pine Ridge, originally extended high up the flanks of the Black Hills and far up the valleys that penetrate into their highlands. At one time these deposits formed a plain surrounding the Black Hills and extending across western South Dakota and Nebraska far into Colorado and Montana. Erosion has removed the deposits from the larger valleys near the Black Hills, but wide areas remain on the broad, tabular interstream divides between Cheyenne River and French Creek, between French and Battle creeks, and between Battle and Spring creeks. Narrower remnants cap the divide between Spring Creek and Rapid Creek. The Hogback Ridge forms the western boundary of the White River group for many miles, but the clays and sands extend farther west through several wide gaps and overlap the Algonkian rocks near Spokane Creek and the Carboniferous rocks between Squaw and Beaver creeks. Wide areas occupy the Red Valley at intervals from Fuson Canyon to the divide southeast of Rockerville, the wide valley of Boulder Creek east of Deadwood, part of the divide between Tetro and False Bottom creeks north of Maitland, and the Windy Flats ridge south of Galena. Outliers remain in many saddles between ridges all along the limestone and sandstone foothills and near Rapid City, Lead, and Deadwood, west of Whitewood, on the slopes west and east of Argyle, and in Pleasant Valley. The highest altitudes are 6,300 feet in the divide 3½ miles south of Englewood, 5,550 feet on the ridge 2 miles southeast of Citadel Rock, 5,400 feet near Lead, 5,600 feet on Windy Flats, and 5,350 feet in the head of Peedee Gulch. Some of the oldest stream and terrace deposits in the Algonkian area and along the foothills probably also represent the White River group or later Tertiary.

Thickness.—The White River deposits on the slopes of the Black Hills range from a thin remnant of scattered pebbles and sand to bodies 200 feet or more thick. The maximum thickness is in the Red Valley, on the divide south of Lame Johnny Creek, southwest of Fairburn. In the wide plateaus east of the Hogback Ridge, north and east of Hermosa, the sandstone and conglomerate averages in thickness about 30 feet and is in places covered with 10 to 50 feet of fine-grained material. The thickness of the deposits in the valley of Boulder Creek, around Lead, and in ridges east of Maitland is at least 50 feet.

Character.—One of the principal materials of the White River group is a peculiar clay of pale flesh color to light brownish buff, porous and crumbling when dry but massive, compact, and light brown when damp. This clay is a hydrosilicate of alumina and is generally mixed with more or less sand and clay. Much of it resembles fuller's earth and differs from ordinary clay in being less plastic. In the lower beds of the group this material grades into sand or into ordinary plastic clay. It alternates with irregular bodies of sand, gravel, and boulders or gives place to these bodies, which mark the courses of old channels and constitute most of the smaller outliers in the valleys and on the slopes in the higher portions of the Black Hills. For this reason it is difficult to separate some of these outliers from early Quaternary terrace deposits. In many localities the fuller's earth and finer-grained sediments are overlain by a thin mantle of coarse deposits, but the time interval between them has not been ascertained. Locally the coarse beds are consolidated into conglomerate, which constitutes extensive plateaus in the Hermosa region. Limestone occurs mostly in thin beds in the fuller's earth, but locally in the Rockerville-Fairburn region it thickens greatly and occurs at two or more horizons. The deposits also include a calcareous grit or sand cemented with calcium carbonate, which locally consists largely of limestone pebbles of contemporaneous age.

Divisions.—In the Big Badlands and on the slopes of Pine Ridge and farther south the White River group consists of three or more clearly defined divisions, of which the two lower ones are the Chadron formation or "*Titanotherium* beds" below and the Brule clay or "*Oreodon* beds" above. The Chadron formation consists of sands, sandy clays, and fuller's earth and, at most localities, a basal member of gravel or conglomerate. The Brule clay consists of sandy clays, fuller's earth, volcanic ash, and sandstone. At or near the base lies a thin bed of limestone. These formations are generally well defined, but because of local variations in character they can not be separated throughout the region considered in this folio. The Chadron formation occupies the greater area, but only in the region about Fairburn and east and northeast of Hermosa and at Lead is the Brule clay clearly recognizable. Generally the Brule clay lies on the Chadron formation, but near its western margin it overlaps the older rocks.

Local features.—In the divide between Battle and French creeks, southeast of Hermosa, there is a thick deposit of the White River group, mostly fuller's earth and other clays of light color, which in places is 150 feet thick. Outliers of this material, which extend to a point within 2½ miles of Hermosa, consist of greenish sandy clay that lies on white conglomerate. A widespread thin bed of limestone occurs at a horizon from 100 to 120 feet above the base of the group. This bed caps a prominent conical hill 7 miles north by west of Hermosa, and there are many outliers east of that town, notably near bench mark 3280, where it is 2 feet thick and contains many fresh-water shells. The same or a similar bed caps ridges 9 miles southeast of Fairburn and appears in the badlands north of French Creek, about 10 miles east of Fairburn. Below it lies 100 feet or more of fuller's earth, which rests on basal sandstone, sand, and gravel of the Chadron formation.

Around Fairburn and west of it there are extensive deposits of fuller's earth and many long channels filled with conglomerate, generally consisting of limestone pebbles and a matrix of calcium carbonate. This conglomerate extends up several of the depressions through the Hogback Ridge and either displaces the fuller's earth or is intercalated in it. Most of the limestone pebbles are of Oligocene age and were derived from slightly earlier deposits of White River time. In parts of the

[12] Loomis, F. B., Science, new ser., vol. 27, p. 256, 1908.

Red Valley between Hermosa and Rockerville the White River rocks include an extensive deposit of nearly pure limestone, in places 30 feet thick, which gives rise to a high plateau of considerable extent. (See Pl. XXVI.) It is underlain by fuller's earth. Numerous beds of limestone of different degrees of purity are intercalated in the deposits of fuller's earth that lie in depressions in the older rocks in the region west and southwest of Fairburn. North and northwest of the west end of Fuson Canyon there are two prominent beds of limestone, one of which extends southward to a point within a short distance of the west end of Fuson Canyon, where it is 25 feet thick and lies on fuller's earth. Limestone also extends nearly as far south on the high divide just north of Lame Johnny Creek, a short distance west of the Chicago & Northwestern Railway. Some beds of this limestone contain many fresh-water fossils, most of them gastropods.

Extensive exposures of the White River group occur in the railroad cuts through the divide south of Fairburn, where the materials are mainly cross-bedded coarse sands but include a large proportion of gravel, largely derived from Algonkian rocks of the Black Hills. Part of one of these cuts is shown in Plate XXV. In the outlying area just south of Wind Cave the material is a micaceous fuller's earth, well exposed in road cuts near bench mark 4160.

A thick mass of pale flesh-colored sandy clay and fuller's earth occupies the divide in the Red Valley about 10 miles southwest of Fairburn. In the long ridge between Cheyenne River and French Creek (see Pl. XXIII) the White River deposits consist of about 80 feet of light-gray to pale pinkish and greenish sandy clays and fuller's earth and a 20-foot basal member of gravelly sand, part of it red. In places remnants of the thin overlying limestone cap detached buttes. These same features appear in extensive badlands on the divides between French Creek and Spring Creek.

The wide plateaus near Hermosa are floored by coarse sandstones and conglomerates of the Chadron formation, mainly dark brown, which in the area 5 miles southeast of Hermosa occur in three heavy beds separated by clay. The Hogback Ridge southwest of Rapid City is capped by about 20 feet of coarse basal conglomerate of the Chadron formation, which there forms a mesa. (See Pl. XXIV.) At a locality $1\frac{1}{2}$ miles northeast of Blackhawk the material consists of gravel and sand, some of it having a matrix of fuller's earth. Many high-level remnants of beds of gravel that lie southwest and west of Rapid City and at intervals along the limestone slopes northwest to Sturgis probably belong to the White River group. One remnant 3 miles south of Sturgis is composed mostly of sand. Conglomerate is exposed in the central part of sec. 26, T. 1 N., R. 7 E., about 4 miles south of Rapid City; fuller's earth appears in slopes in the next section west; and a thin bed of the characteristic limestone caps a knob at an altitude of 4,027 feet in the central part of sec. 33, T. 1 N., R. 7 E. Sand and gravel that cap the Dakota sandstone on the plateau a mile west of Whitewood probably are of Tertiary age.

In the areas at Lead, on the high divide between Tetro and False Bottom creeks north of Maitland, in the region near Boulder Creek and Peedee Gulch east of Deadwood, and on the ridge north of Boulder Park the principal material is the typical compact, mostly light-buff massive sandy clay or fuller's earth. Some parts of the beds are white, pink, green, or brown. In the lower part there are a few streaks of boulders and angular rocks, comprising cherts, quartzite, several kinds of Tertiary igneous rocks, and fragments of quartz and schist. Parts of the Maitland and Boulder Creek areas are covered by a sheet of gravel, sand, and boulders, which may be later than White River. The deposit at Lead occupies most of the depression in which the city is built and extends up a saddle in the adjoining ridges south and west to an altitude of about 5,400 feet. It is exposed in a railroad cut south of the city and in other excavations, notably in a sewer trench, which yielded many fossil bones. The deposit north and east of Maitland lies at altitudes of 4,700 to 5,400 feet and consists of 40 to 200 feet of clay and fuller's earth and streaks of gravel. The greater part of it underlies a plain covered by a sheet of sand and gravel which may be of later Tertiary or early Pleistocene age.

The deposits that cap the Windy Flats ridge north of Roubaix and the divides east of Galena and extend along the Park Creek and Bear Butte Creek valleys consist of 20 to 40 feet of coarse gravel and sand underlain in places by fuller's earth and clay. Apparently these deposits are remnants of a mantle which extended from the foot of Custer Peak northeastward to the region near Sturgis and which was deposited by creeks similar to those of the present time but having different courses. Gravel caps the ridge 3 miles southeast of Citadel Rock at an altitude of 5,550 feet. The White River deposits in the divide through which the railroad passes, $3\frac{1}{2}$ miles south of Englewood, are not well exposed, but a prospect tunnel revealed 7 feet of pink sandy clay containing round pebbles of many kinds, lying on green shale at the top of the Deadwood formation.

The White River deposits southwest of Argyle consist mainly of fuller's earth and contain a 3-foot bed of volcanic ash. This ash occurs in the White River group in many other places at different horizons, either mixed with sand or clay or in bodies more or less pure. The composition of the ash near Argyle, according to an analysis made by George Steiger in the laboratory of the Geological Survey, is shown below:

Chemical composition of volcanic ash from the White River group near Argyle, S. Dak.

Silica (SiO_2)	54.47
Alumina (Al_2O_3)	14.74
Iron sesquioxide (Fe_2O_3)	2.73
Iron protoxide (FeO)	.78
Magnesia (MgO)	.29
Lime (CaO)	4.00
Soda (Na_2O)	2.55
Potash (K_2O)	3.31
Barium oxide (BaO)	.13
Titanium oxide (TiO_2)	.76
Phosphorus pentoxide (P_2O_5)	.29
Water (percentage yielded below 110° C., 0.93)	5.71
	99.76

The extent of this deposit is not apparent, owing to lack of exposures. The material consists of fine shreds of volcanic glass or pumice, mainly pure white and translucent, mixed with a few flakes of dark glassy material. It represents a rhyolitic rock. Another occurrence was noted on Fourmile Creek 8 miles southwest of Custer.

Fossils.—The White River beds contain fossil bones of animals typical of the Oligocene. Bones obtained in beds high up on the flanks of the Black Hills were determined by Dr. F. A. Lucas as follows: *Merycoidodon* (*Oreodon*) *culbertsonii*, *Poebrotherium wilsoni*, *Stylemys nebrascensis*, and *Hyracodon nebrascensis*. Bones of turtles were found in the fuller's earth southwest of Argyle. From excavations south of Lead bones of *Merycoidodon gracilis*, *Ischyromys typus*, and *Mesohippus* were obtained. All these animals are characteristic of the Brule clay. Fragments of leaves from the limestone 7 miles west-southwest of Fairburn were determined by F. H. Knowlton as *Carpinus?* sp. The basal beds yielded fragments of bones of titanotheres at several places, notably in the conglomerate on the ridge north of Spring Creek, west of the railroad, at a point $2\frac{1}{2}$ miles southwest of Brennan. These bones indicate the Chadron formation.

QUATERNARY SYSTEM.

Gravels and loams that form terraces at various heights and alluvial deposits on the bottom lands along the valleys are of Quaternary age. Some of the remnants of old gravel plains and terrace deposits at high levels, however, especially those that lack distinctive character, have been classified arbitrarily either as White River or older terrace deposits, the classification depending mainly on their physiographic relations.

PLEISTOCENE SERIES.

OLDER TERRACE DEPOSITS.

General relations.—Gravel and sand occupy terraces at different heights in many of the larger valleys, and some of the divides are capped by the same materials, evidently deposited by streams that have since deepened their valleys or changed their courses. Originally these deposits were much more extensive, but a large part of them has been removed by erosion, especially from the higher lands and from places where they were thin. A part of the deposits overlap White River beds at various altitudes. Some of the younger deposits slope down to low levels, even passing below the upper edge of the more recent alluvium.

Materials.—The older terrace deposits consist mainly of gravel and sand, but parts of them are loamy and other parts consist of boulders. The coarser materials comprise quartzite, schist, granite, limestone, and other rocks from the central area of the Black Hills, and in the northern part of the region there is also a large admixture of the younger igneous rocks. Some reddish sediments came from the Red Valley.

Distribution.—The highest terrace deposits cap all the larger divide ridges that extend eastward from the Hogback Ridge. Most of these deposits form parts of an inclined plain that presents a steep margin to the north and that slopes gently downward to the south and to the east. Their higher parts are mostly from 100 to 300 feet above the alluvium in the valleys, and in places they are more than 4 miles wide. Deposits of sand and gravel also occupy terraces at lower levels along the valleys of all the larger creeks and along both sides of the Belle Fourche and Cheyenne River. Smaller remnants of terrace deposits occur in the Red Valley from Sturgis to Buffalo Gap and in many valleys in the higher lands on the west. Some of the highest deposits of gravel and sand west of Sturgis, Rapid City, Hermosa, Fairburn, and Buffalo Gap are remnants of White River deposits, others may be of later Tertiary age, and still others may be Pleistocene.

In the ridges west of Rapid City there are terraces capped by sand and gravel at five different levels, ranging from White River on the high ridges to Pleistocene in the alluvial bottoms.

Earlier terrace deposits mantle conspicuous terraces about Sturgis, Whitewood, and Spearfish, most of them more than 150 feet above the present Red Valley and some as high as the foot of the limestone slopes. One of these terraces is known as Snake Bench. Centennial Prairie is floored with deposits of gravel, sand, and loam, most of which slope down to and in part merge into recent alluvial deposits along the creeks.

Some of the deposits of gravel and sand on slopes that cap high terraces east and west of Deadwood may be in part at least of Pleistocene or late Tertiary age, but nevertheless all have been mapped with the White River beds.

West of Hermosa and Fairburn deposits of sand, gravel, and boulders cap White River deposits and other formations on some of the divides, and they also extend far into the central area. Some of these deposits lie high above the present valleys and were laid down after the White River deposits, which they overlap in places. Doubtless some of the higher deposits date back to late Tertiary time, and originally they were much more extensive. The courses of the streams that deposited them were somewhat different from those of the present streams, although they flowed southeastward. A notable example of such an old stream course can be seen southeast of Fairburn, on the divide between French Creek and the drainage basin to the south, where a broad valley that lies 400 feet above the valley of French Creek is carved mainly in soft deposits of the White River group and is floored by a thick mantle of sand, gravel, and boulders. This valley has terraced sides that slope gradually to a central trough, now occupied in part by a small stream. One who looks westward toward the Black Hills from the edge of this deposit can see that this old valley was originally connected with narrow valleys that led out of the schist ridges at levels far above the present drainage system. This stream was a predecessor of French Creek, but its course and its branches were somewhat different. Some relations between the old and the present features are shown in Figure 39 (p. 25).

The Red Valley southwest of Fairburn contains extensive areas of gravel and sand, which to the west either merge into areas in high valleys leading out of the highlands of the central Black Hills or were formerly connected with those areas. Some of the deposits extend along the slope of the ridges adjoining both sides of the Red Valley, and in places they pass eastward through high, wide wind gaps in the Hogback Ridge. The western extension of these valleys into the region of Algonkian schist is marked by many low gravel-floored saddles.

Buffalo Gap contains several small remnants of an earlier terrace deposit, which consist of coarse gravel and boulders cemented into rock by calcium carbonate.

Many remnants of old terrace deposits lie on the slopes in the extreme southwestern corner of the area treated in this folio, indicating the former presence of a widespread sheet of stream deposits over part of the surface, probably following some old valley or series of valleys. One of the largest of these remnants caps the Spearfish formation west of Babcock's ranch, and another constitutes the top of the ridge of Sundance beds west of the West Fork of Hawkwright Creek. Sand and gravel deposits, 5 to 25 feet thick, occur on the ridges along the east side of Pleasant Valley and cap White River deposits west and northwest of Argyle. These deposits indicate the course of a fairly large stream, which was the predecessor of the creek that now flows into Red Canyon.

RECENT SERIES.

ALLUVIUM.

Alluvial deposits occupy the bottoms of all the wider valleys but are not notably present in the steeper canyons and the many small draws in the higher region, in which erosion predominates over deposition. They are most extensive in the valleys in the shale region east of the Black Hills, but the streams cross them from side to side and in places cut into the banks of shale on either side. Much of Centennial Prairie is floored with alluvium, part of which is the product of an earlier drainage system. These alluvial deposits ordinarily range from 10 to 30 feet in thickness. They consist mainly of sand, loam, and gravel from near-by localities, and they merge into the talus on the adjoining slopes. As they have been brought down and deposited by the streams they represent the rocks that the streams traverse. In the Red Valley and farther north the alluvium contains much red clay derived from the red shales of the Spearfish formation. Along Whitewood Creek the alluvium, which originally consisted mostly of gray loam, is covered with extensive deposits of gray tailings from the mills of Lead and vicinity. As the materials were transported at various stages of high and low water, they differ in composition from place to place and in different layers.

TUFA.

Along some of the watercourses in the limestone areas considerable calcareous tufa has accumulated and is still being deposited. At the mouth of Little Spearfish Creek the water falls over a ledge of limestone that was in part built up by tufa. The tufa shows the usual porous structure and contains many casts of weeds and grass. A small deposit of tufa occurs in Buffalo Gap.

TERTIARY IGNEOUS ROCKS.

By Sidney Paige.

DISTRIBUTION.

The distribution of the igneous rocks is shown on the geologic maps in this folio and their relations are described on pages 19–23. More than 80 per cent of the Tertiary igneous rocks of the northern Black Hills are rhyolites, rhyolite porphyries, monzonite, and quartz monzonite. True phonolites and grorudites each form about 6 per cent.

Although these igneous rocks show considerable diversity in texture they are all chemically related—a fact which indicates that they were intruded about the same time geologically and from a common magma.

PETROGRAPHY.

GENERAL TYPES.

The igneous rocks of the northern Black Hills are rhyolite porphyry, intrusive rhyolite, extrusive rhyolite, quartz monzonite porphyry, monzonite porphyry, grorudite, phonolite, and quartz tinguaite porphyry.

This grouping is based on mineral composition, and although it is somewhat accentuated by the fact that certain types are confined to definite areas, nevertheless there is an interrelation of types which suggests that these rocks are of common origin. Except a little rhyolite they are all intrusive.

RHYOLITE PORPHYRY.

Intrusive rocks of granitic composition in the Black Hills comprise rhyolite porphyry and rhyolite.

The rhyolite porphyries consist of orthoclase and quartz, and some of them contain ferromagnesian minerals. Three somewhat distinct types are present, distinguished by the character of the phenocrysts and by texture. One of these types has few or no quartz phenocrysts; another has abundant quartz phenocrysts; and the third, which has unusually coarse texture, contains phenocrysts of quartz and orthoclase (granite porphyry).

The first type forms the mass directly northwest of Trojan (old Portland). The rock is brownish red and contains abundant phenocrysts of orthoclase and a few of quartz, set in an aphanitic groundmass. The phenocrystic feldspars comprise orthoclase, microcline, and albite in euhedral and anhedral forms. The microgranular groundmass is composed of quartz, feldspar, and some biotite.

The rhyolite porphyry, which crosses Deadwood Creek just below the mouth of Blacktail Gulch and which forms a considerable mass on the north together with many smaller dikes, contains abundant quartz phenocrysts, some as much as a quarter of an inch in diameter. Under the microscope abundant euhedral orthoclase phenocrysts and a few of plagioclase are seen in a microgranular groundmass composed of quartz and orthoclase with some biotite.

A rhyolite porphyry of unusually coarse texture occurs in the mass that forms Anchor Hill and Bear Den Mountain. Orthoclase phenocrysts as much as 2 inches long are abundant, and many of them are twinned after the Carlsbad law. These large phenocrysts are set in a groundmass which is itself porphyritic, for it consists of abundant smaller, much resorbed phenocrysts, some of orthoclase and albite and the rest of quartz, in a microcrystalline aggregate of quartz and feldspar. Ferromagnesian minerals are rare. The rock in Anchor Hill has the smaller resorbed phenocrysts of orthoclase and quartz, and one from Bear Den Mountain has no quartz phenocrysts and the orthoclase is more perfectly crystallized.

INTRUSIVE RHYOLITE.

The rhyolites are characterized dominantly by quartz and potassic feldspars. Some soda feldspar (albite) is present, and some types contain oligoclase and approach the quartz latites in composition. Two groups are recognized—rhyolite and porphyritic rhyolite.

Rocks of the rhyolite group are fine grained to aphanitic in texture and of various shades of light gray or pink. Most of them contain a few widely scattered small phenocrysts of either quartz or feldspar and evenly distributed tiny grains of magnetite. Under a microscope they show an even, finely granular groundmass of quartz and orthoclase and also these minerals in a granophyric intergrowth as well as in subsidiary grains. The granophyric groundmass is characterized by small rounded grains of quartz filled with tiny rods of orthoclase. Scattered flakes of biotite and a small amount of reddish garnet are generally included. In rock from Custer Peak the few phenocrysts noted have nearly the composition of oligoclase, indicating affinity with the latite family, of which the porphyritic latite from the Fort Meade Timber Reservation is typical.

The porphyritic rhyolites, which in the eastern part of the field have affinities with latite, are rhyolites in which phenocrysts either of quartz or feldspar are abundant. The quartz is usually much the more prominent phenocryst, appearing both in crystal form and as resorbed grains of rounded outline. The groundmass resembles that of the rhyolites proper, being either finely granular or of granophyric texture. A little magnetite and biotite are generally present. Porphyritic quartz latite occurs in the Fort Meade Timber Reservation and consists of a gray groundmass of quartz and orthoclase, the texture of which is partly granophyric and partly composed of rods and grains, with phenocrysts of feldspar, dominantly oligoclase. The magnetite occurs in scattered grains of considerable size and evenly disseminated in tiny grains. A little biotite is present.

QUARTZ MONZONITE PORPHYRY.

Most of the quartz monzonite porphyries are medium to fine grained gray or light-greenish rocks, in places colored red by oxidation. They are composed of orthoclase, plagioclase (either oligoclase or andesine in different quantities), quartz, mica, and hornblende, and the accessory minerals magnetite, a little apatite, and zircon. The phenocrysts are dominantly feldspar, but some of them are quartz. In the rocks of the Black Hills andesine is by far the most abundant phenocryst; orthoclase is mostly in the groundmass and forms a granular or microgranular aggregate with quartz. Those quartz monzonite porphyries, however, that have been mapped with the rhyolite porphyries contain more orthoclase as phenocrysts and also more quartz and are thus closely allied to the rhyolites. The two types are discriminated by the relative abundance of plagioclase. The quartz monzonite porphyries may contain both biotite and hornblende, either of which may be the dominant ferromagnesian mineral.

MONZONITE PORPHYRY.

The monzonite porphyries are rather fine grained porphyritic rocks of gray to greenish tinge and usually show abundant slender prisms of hornblende. Phenocrysts of orthoclase and plagioclase are set in a microcrystalline trachytic groundmass of orthoclase, which in some places contains a small amount of quartz. The plagioclase ranges from albite to andesine. Hornblende is generally abundant but is much altered in the groundmass. To verify the microscopic examination the total silica was determined in a specimen from the area near Terry. The amount found, 59.10 per cent, indicates that there is little or no quartz in the groundmass and supports the other evidence that these rocks fall into the monzonite class.

GRORUDITE.

The grorudites are closely related to the rhyolite porphyries but have a higher content of soda owing to the abundant albite feldspar and the sodic pyroxene aegirite, which form a characteristic feature. They are highly siliceous, alkalic, porphyritic rocks, composed essentially of quartz and potash and soda feldspars, and contain aegirite or aegirite-augite or both. They range in color from light gray with a greenish tinge to various shades of green and in texture from aphanitic, with sparse phenocrysts, to coarse, nearly granular, with large closely set phenocrysts. Four varieties (*a* to *d*) can be distinguished under the microscope. Three of these varieties are based on the textural arrangement of the aegirite, and the fourth carries quartz phenocrysts. Variety *a* contains abundant feldspar phenocrysts set in a fine-grained granular groundmass of orthoclase, quartz, and subsidiary albite. Aegirite is also abundant and is strikingly arranged in groups of radiating fine needles or blades and in small prisms terminated by radiating needles. In one specimen from a dike on False Bottom Creek abundant phenocrysts of albite and orthoclase, some as much as 2 millimeters in length, are set in a very fine grained groundmass. The aegirite groups average 0.2 millimeter in diameter, and some of the aegirite laths are as much as 0.5 millimeter long. In a coarse variety that forms a sheet about half a square mile in extent north of Carbonate thickly set phenocrysts of microcline, albite, and orthoclase, some as much as 5 millimeters in length, are surrounded by a fine-grained groundmass of quartz, albite, and orthoclase. The aegirite in this rock is proportionately larger and the former presence of crystals as much as 0.5 millimeter in length is indicated by oxidized cavities. Groups of radiating rods are also present.

At the head of Raspberry Gulch there is a subvariety, in some of which a little albite appears as phenocrysts with very thickly set corroded phenocrysts of orthoclase.

Variety *b* differs from variety *a* in having quartz as phenocrysts. The euhedral phenocrysts, some as much as 3 millimeters long, consist of albite and orthoclase and intergrowths of these minerals. Besides the quartz phenocrysts, many of which have crystal faces, aegirite occurs as small radiating aggregates of fine blades 0.1 to 0.4 millimeter in diameter and as small individual prisms. The groundmass is orthoclase, quartz, and subsidiary albite. The texture is seriate porphyritic—that is, the phenocrysts differ greatly in size and the crystals in the groundmass also show gradation in size. Grorudites of this kind form much of Foley Mountain.

The phenocrysts in variety *c*, as in the other varieties, consist of orthoclase, the largest 5 millimeters in diameter, of albite, and of irregular intergrowths of the two minerals. No quartz appears as phenocrysts. Aegirite is present in scattered small rods and grains, 0.08 to 0.20 millimeter in length or diameter, and in abundant, evenly distributed, very fine needles, 0.01 to 0.08 millimeter in length. The larger blades poikilitically inclose grains of the groundmass, and the fine needles penetrate grains irrespective of boundaries. The texture of this variety is also seriate porphyritic. This rock is found at Carbonate, and the rock at Terry Peak is of the same character, but the crystals of aegirite are larger, 0.08 millimeter to 1.3 millimeters in length, though the needles are not so abundant nor so evenly distributed. There are a few blades of mica with blades of aegirite arranged about their edges, an association which will be discussed under the phonolites. A rock with a texture intermediate between this variety and variety *a* contains aegirite in numerous rods and grains and in small radiating aggregates.

In variety *d* aegirite appears in needles between the grains of the groundmass and rarely as a larger individual. The needles, although they penetrate all grains, are nevertheless collected characteristically in bundles or sheaves, which lie on the borders of grains. They occur much as do the impurities in a metamorphosed quartzite, outlining the individual crystals of the rock. The rock at Bald Mountain, the lower sill on Raspberry Gulch, and a part of the mass of Foley Mountain consist of this variety.

AEGIRITE PHONOLITE OR TINGUAITE.

General features.—Irving has called attention to the confusion that exists concerning the term tinguaite,[13] originally proposed for dike rocks and used by Brögger to designate the basic members of a grorudite-tinguaite series. Although the rocks here under consideration might well bear a name indicating that they are intrusives, the difficulty in consistently naming rocks according to their origin makes it advisable to use the term phonolite.

Most of the aegirite phonolites of the northern Black Hills are porphyritic, contain no quartz, and are composed of orthoclase and albite, the sodic pyroxenes aegirite-augite and aegirite, and the feldspathoids nepheline, sodalite, and analcite and include some nosean. They might be called nepheline tinguaites, for nepheline is an abundant constituent. By increase of silica these rocks grade into quartz tinguaites, such as the rock which constitutes Sheep Mountain. These rocks may be divided into those in which aegirite-augite appears as phenocrysts with feldspar and those in which it does not. Usually aegirite occurs in the groundmass.

There are two exceptional varieties—one that contains mica and the other characterized by a peculiar development of aegirite-augite—which do not fall conveniently into the broad divisions and which are described separately.

Trachytoid aegirite phonolites without aegirite-augite phenocrysts.—The group in which phenocrysts of aegirite-augite are absent comprises rocks of pronounced trachytoid texture in which tabular phenocrysts of orthoclase or orthoclase perthitically intergrown with albite are set in a trachytoid groundmass of orthoclase or orthoclase and albite, accompanied by varying amounts of sodalite, analcite, and nepheline. The nepheline is obscure but in some specimens is recognized by its square crystal outline and high refractive index. Much aegirite is present in the groundmass as fine needles or small rods and may occur between the lathlike feldspars of the groundmass or oriented in all directions. The needles rarely occur within phenocrysts. Sodalite may occur within feldspar crystals or between them. The particles are commonly of irregular shape and seldom in crystals. Some of the feldspars are replaced by zeolites.

Two rocks without aegirite-augite phenocrysts are characterized by an unusual amount of sodalite. One of these rocks, from Spearfish Canyon below Long Valley, has phenocrysts of orthoclase, many of which are perthitically intergrown with albite and notably replaced by sodalite and zeolites. The groundmass is composed of orthoclase, sodalite, and a myriad of aegirite needles. Nepheline was not recognized with certainty. The other rock, which contains more albite, occurs at Crown Hill.

Trachytoid aegirite phonolites with aegirite-augite phenocrysts.—In the group of phonolites that carry phenocrysts of aegirite-augite these phenocrysts are 1.5 millimeters in length or smaller and accompany the feldspar phenocrysts, which may be either albite or orthoclase. The feldspars range in size downward from 3 millimeters, are not so generally tabular as in the other group, and in some specimens are replaced by zeolites. The groundmass, which is invariably trachytoid, contains both albite and orthoclase in abundance though in varying proportions. It also contains as a rule numerous rods or grains of aegirite and varying amounts of sodalite and obscure nepheline and in some specimens titanite. The large igneous mass north of Tetro Rock carries a notable amount of sodalite in the groundmass, and the phenocrysts of aegirite-augite are all surrounded by shells of aegirite.

In Spearfish Canyon below the mouth of Squaw Creek a sill of phonolite carries biotite and contains aegirite in nests of microlites. This rock, broadly classified, would fall in the sodalite group described above. It contains abundant phenocrysts, some of them 2.0 millimeters in length, of light-green aegirite-augite, rimmed and terminated by darker-green aegirite; phenocrysts of matted aggregates of aegirite microlites of the same order of magnitude; and biotite centers, surrounded by a mat of aegirite microlites, which grade outward into aegirite needles of larger size. Phenocrysts of feldspar are absent. The groundmass is mainly orthoclase and albite and contains also sodalite, analcite, fine blades or needles of aegirite, and rarely apatite. Where albite is especially abundant the groundmass is trachytoid. The notable feature is the acicular nestlike habit of the aegirite, which occurs in radiating acicular groups scattered through the groundmass, in acicular aggregates that replace aegirite-augite phenocrysts, in acicular aggregates that surround apatite, and in nests that surround biotite, which appears to have been resorbed.

The rock of Spearfish Peak is unusual in having large crystals, some of them 5 millimeters in length, of aegirite-augite, which inclose the minerals of the groundmass; also in the great abundance of nepheline in tiny square or oblong crystals, closely set throughout the groundmass. A few orthoclase phenocrysts, some of them 3 millimeters in diameter, are present. The groundmass is trachytoid, predominantly of orthoclase, and albite is subsidiary. Sodalite and nephelite are abundant, and much nosean occurs in cloudy crystals, the largest 0.8 millimeter in diameter.

QUARTZ TINGUAITE PORPHYRY.

The rock in Sheep Mountain is closely allied to those described above but differs from them in containing free quartz. Orthoclase phenocrysts are set in a trachytoid groundmass dominantly of albite and containing orthoclase and a little clear quartz, generally filled with needles of aegirite. Needles of aegirite are abundant and tend to segregate between the laths of the groundmass, and sodalite is present. Parts of the feldspar phenocrysts are replaced by zeolites. By an increase of quartz this rock would grade into the grorudite type.

CHEMICAL COMPOSITION.

The following analyses of rocks from the Black Hills,[14] when considered in connection with the mineral composition of the rocks, indicate some of their chemical interrelations. Their most striking feature is that they are dominantly potash-soda rocks, not lime-soda rocks. They range from rocks of the monzonitic group, characterized by orthoclase and andesine feldspar, to rocks of the phonolite group, characterized by orthoclase and the soda-bearing minerals albite, aegirite-augite, aegirite, nephelite, analcite, and others. The rhyolite and quartz monzonite porphyries and the grorudites are intermediate. The grorudites are related to the phonolites through their content of considerable soda but differ from them in having a higher content of silica, by which they are allied to the rhyolites.

With increase of silica the monzonites pass into quartz monzonites, and these in turn are related to the rhyolite porphyries, from which they differ only in containing a little more lime, which appears in the andesine feldspars; and in turn the monzonite porphyries, by increase of soda and decrease of potash, pass into the phonolites. Although not all these intergradations have been noted in the field, some of them are strongly suggested in the rocks collected, and possibly detailed studies would reveal more clearly their relations.

Analysis 1 in the following table represents an average of 20 analyses of phonolites described by Irving. The high content of soda shown in analysis 3, which represents one of the rhyolite porphyries, suggests the relations between the rhyolites and the grorudite-phonolite group. These relations may be summarized by regarding the rhyolite porphyries as a datum type from which the other types diverge by progressive increase in soda and decrease in silica to the grorudites and the phonolites or by progressive increase in lime and decrease in silica to the quartz monzonites and the monzonite porphyries.

A partial analysis of a grorudite from Elk Mountain shows 72.25 per cent of silica, about 15 per cent of alumina, 2 per cent of ferric oxide, and 2 per cent of lime. The high silica content of the rock indicates its affiliation with the rhyolites.

Analyses of phonolites and porphyry from the Black Hills.

	1	2	3
SiO_2	57.89	69.78	67.77
Al_2O_3	19.58	16.07	17.57
FeO	4.75	----	1.59
CaO	1.67	1.17	.51
MgO	.50	----	.49
K_2O	4.88	----	4.56
Na_2O	8.33	----	6.20
H_2O	.26	.65	.73
Loss	2.16	.10	1.47

1. Average of 20 analyses of phonolites.
2. Specimen of rhyolite porphyry from area north of Trojan.
3. Specimen of rhyolite porphyry from dike in Ulster mine.

SEQUENCE AND SOURCE OF INTRUSIONS OF PORPHYRY.

Dikes of phonolite cut the other intrusive rocks of the region, but there is no evidence as to the relative age of the grorudite and the rhyolite porphyry series. There is evidence that the monzonites were the earliest intrusive rocks and that they were followed by the rhyolite and quartz monzonite porphyries and these in turn by the phonolites. The presence of extrusive rhyolite near Brownsville, however, proves that this type is really the most recent, and Jaggar[15] found rhyolite cutting phonolite. The dikes and stocks of rhyolite porphyry appear to occupy the former conduits for the sheets of fine-grained rhyolite, which, nevertheless, they cut in places. There is nothing unusual, however, in this relation, for intrusion along the dike channels may have continued after parts of the sheet had solidified.

The chemical affinities of these rocks seem to indicate that the grorudites followed the rhyolite porphyries and in turn

[13] Irving, J. D., A contribution to the geology of the northern Black Hills: New York Acad. Sci. Annals, vol. 12, pp. 187–340, 1899.

[14] Irving, J. D., op. cit., pp. 272, 277.

[15] Jaggar, T. A., jr., The laccoliths of the Black Hills: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 3, p. 185, 1901.

were followed by the phonolites, thus making a series that grows progressively richer in soda and poorer in silica.

These intrusions took place while there was great igneous activity elsewhere. Many great batholiths came into place about this time and produced domes in the beds which they invaded. It is believed that an extensive batholith underlies the Black Hills, and the monzonitic character of the intruded rock supports this belief, as this period of igneous activity more than all others was characterized by intrusions of magma of the quartz monzonitic type. The phonolites and grorudites may well be regarded as representing an alkaline phase of the same magma that produced the quartz monzonite.

QUATERNARY (?) IGNEOUS ROCKS.

RHYOLITIC EXTRUSIVE ROCKS.

The extrusive rocks discovered by Darton[16] are gray and aphanitic and closely resemble the intrusive rhyolites already described, but they are filled with débris derived from the underlying pre-Cambrian schist. At a place $1\frac{1}{4}$ miles northwest of Roubaix a band of black obsidian resting on flow breccia and tuff is unmistakably extrusive. Rhyolite lava (black obsidian) and breccia also cover about half a square mile just north of Brownsville, about 7 miles south of Deadwood. Two small areas of similar rock are found about 7 miles east of this occurrence, one on Meadow Creek, the other at the head of Little Elk Creek.

STRUCTURAL GEOLOGY.

STRUCTURE IN ALGONKIAN ROCKS.

By Sidney Paige.

The thick series of slates and schists that forms the greater part of the pre-Cambrian nucleus of the Black Hills strikes northwest and dips to the east, generally at steep angles, except in the extreme southwestern part of the area. Granite intrusions break the strata to the south, and schistosity parallel with the contact is developed around the granite mass of Harney Peak. The schistosity is in general parallel with the bedding, and the strata are compressed into a number of great folds, upon which are imposed innumerable minor isoclinal folds. By tracing individual beds the position and nature of the greater axes of folding have been located and the presence of two extensive faults revealed.

FOLDING.

A notable feature in the pre-Cambrian area is the association of amphibolites, quartzites, metamorphic limestone, and replacement veins at four widely separated places—at Lead and Deadwood, between Roubaix and Rapid Creek, at Rochford and north of it, and west of Hill City. At no two of these places are the rocks precisely alike, and the intrusive amphibolites differ considerably in their relations to the formations which they intrude. On the eastern border the order from east to west is thin limestone, beds of quartzite interbedded with slate and amphibolite, and a prominent replacement vein. In the area near Lead and Deadwood the rocks include, from west to east, calcareous slate, narrow bands of metamorphic limestone, slate with beds of quartzite, narrow bodies of amphibolite, and small replacement veins. In the Rochford area amphibolite is interbedded with metamorphic limestone on two sides of a fold, and to the north, along the strike of these rocks, a replacement vein is associated with a thin bed of limestone. West of Hill City the succession from west to east is siliceous schists, metamorphic limestones, and amphibolite, with vein quartz of the replacement type. These successions, when considered in connection with the structural features described below, indicate the general structure in the entire field. Perhaps the most useful key to the structure is a well-defined synclinal axis west of Hill City, which trends northwestward from a point a mile west of Oreville to a point $1\frac{1}{2}$ miles west of Dwyers ranch. It is in one of the very few areas where opposing dips may be observed over an extensive territory. West of this axis a granite mass forms the nucleus of a partly exposed domelike uplift, around which curve the metamorphic limestone and amphibolite. To the northeast lies the Rochford fold, which is a closely compressed isocline that has steep dips to the east on both sides and a southward pitch. A synclinal axis lies between the Rochford fold and the beds near the eastern border of the pre-Cambrian area. To the north these beds disappear beneath Paleozoic beds, but the strike of the schists that lie west of them curves to the west in the vicinity of Galena, and they dip to the south into the syncline, the axis of which pitches southward. If this axis extends southward near Mountain Meadows and southeastward through Silver City it accounts for the presence and the significant outline of the extensive succession of graywackes and quartzites interbedded with slates, a succession which crops out in a northward-pointing triangular area whose base extends across the front of the intrusive granite of Harney Peak. If the outcrop of these rocks is involved in a large synclinal overturn that pitches southward it would naturally become narrow to the north and widen to the south. Three other well-marked folds enter into this broad structural outline, and some intruded schists in the southern part of the area are also included in it. The first of these folds appears to involve the conglomerates and grits on the extreme eastern border of the area of pre-Cambrian rocks. The presence of a southward-pitching anticline is suggested by the heart-shaped outline of the area of conglomerate, which points to the south, by the flanking groups of limestone west and east of this conglomerate, and by the southward-pointing angle in the boundary of the amphibolite mass north of it. The beds south of the conglomerate, too, are finer grained than those north of it, a fact which suggests that the fold involves higher beds. This fold is separated from the syncline on the west by a fault.

The next notable fold is just southwest of the anticline described above, but it lies across and west of the fault. Here a series of graywackes interbedded with some slate occurs in an area that narrows to the north and is finally represented by a narrow outcrop that extends northward for several miles and probably terminates against the fault. The widening of this quartzite to the south probably indicates an anticline that pitches to the north, and the next flexure to the west is synclinal. According to this interpretation, the contorted series of quartzites south of Bogus Jim Creek, at the edge of the Paleozoic strata, is correlated with the great northward-trending series of quartzites that extends from Rapid Creek to the area beyond Boxelder Creek. This series is mapped as a single bed, but it consists of a succession of closely spaced beds like those seen farther east.

In the Lead and Deadwood region a series of beds that are in many respects similar to those in the eastern region lies on the east flank of an anticline that is exposed on Deadwood Creek at Central City. The western limb of this anticline is masked by Tertiary igneous rocks and Paleozoic beds, which hide the corresponding beds on that side of the axis. This anticline, which pitches southward, is cut off on the south by the Lead shear zone. In the area west of this fault similar beds appear to be flexed in a closely compressed syncline, though Tertiary intrusive rocks and Paleozoic strata hide their relations.

Prominent structural features in the pre-Cambrian area are connected with the granite intrusions, particularly with the great mass in the Harney Peak area which caused profound deformation of the sedimentary rocks. Here the general northwesterly trend prevalent elsewhere gives place to a series of concentric folds that extend around the periphery of the granite mass. These folds are peculiar in that their axial planes lie at low angles and are approximately parallel with the intrusive contact of the granite. The granite was probably intruded during or near the end of a period of compression, and the advancing mass of igneous rocks probably caused the folding of the schists. The heat that accompanied the intrusion, the pressure that it caused, and the aqueous solutions associated with the granite all aided in producing plasticity in the sedimentary rocks, so that they gave place to the advancing magma and were compressed by it. The effects of these influences would be greatest close to the granite and would diminish gradually as the distance from it increased, a condition clearly apparent in the field. The folds, which are very closely appressed and recumbent and which are accompanied by perfectly developed schistosity near the granite, merge farther away into the general northwestward-trending folds.

The structure in the area that lies south and southeast of the large mass of granite at Harney Peak is complicated by intricate intrusions of granite. About 5 miles southeast of Custer a roughly domical structure, the center of which is about a mile northwest of the old sawmill, is clearly seen. Farther northeast, in the region around Otis, the quartzites have low dips. In this region the intricate intrusion of the granite obscures the structural relations, but apparently a syncline that includes many minor folds, some of them sharp, extends along the borders of low domes. The dips and strikes shown on the map give a clue to the lines of trend. Probably the area is underlain by a granite batholith, from which arise the many dikes and lateral branches that are exposed.

FAULTING.

Two notable faults or shear zones have been recognized in the area of Algonkian rocks. The first of these, a shear zone, passes through Lead in a northwesterly direction. West of this fault the schists strike northwestward, practically parallel with it, and dip steeply eastward. East of it the schists strike northeastward and dip eastward, though not so steeply. The fault cuts obliquely along the west side of the low southward-pitching anticline that is fairly well exposed on Deadwood Gulch from Central City to the mouth of Blacktail Gulch. The dolomitic rocks involved in this fold are the beds which have been replaced by the ore-bearing solutions that formed the Homestake ore body. West of the fault there seems to be a closely appressed southward-pitching syncline that involves beds similar to those east of the fault.

The second notable fault, for which the evidence is not so clear, extends from a point on Bogus Jim Creek near the boundary of the Paleozoic formations to a point beyond Estes Creek. Its presence is inferred from the discontinuity of the outcrop of certain beds, but distinctive beds are few and of such character that their absence possibly may not be caused by faulting. Moreover, the plane of the supposed fault is nearly parallel with the strike of the beds displaced. Outcrops of a thin limestone and of a series of quartzite beds appear to be cut off at their northern ends in a manner that suggests crumpling along a compression fault at a low angle. (See the geologic map.) To the north the interrupted limestone that is interbedded in slates approaches nearer and nearer to a second limestone interbedded in grit beds east of it. As these limestones apparently are entirely separate and not the same bed involved in an anticline or syncline, they are most probably separated by a fault. The quartzites that seem to have been cut off by this fault comprise five beds, which end very abruptly along a zone into which much secondary silica has been introduced. On the opposite side of the supposed fault only one bed of the quartzite occurs, and it is turned back so that its corner crosses the general trend of the other beds at a very sharp angle. The compression of these quartzites—that is, the direction of their shortening and thickening—seems to be due largely to movement along a plane trending north and south, which is the direction of the supposed fault. Another quartzite on the west seems to have been shortened, though to a less degree, which is further indication that this region has been subjected to compressive stresses extending northward and southward. This fault or shear would therefore seem to have been produced by stress exerted in a northwesterly direction, comparable in a way to that which produced the Homestake fault.

STRUCTURE IN CAMBRIAN TO CRETACEOUS BEDS.

By N. H. Darton.

STRUCTURE OF THE BLACK HILLS UPLIFT.

The Black Hills uplift is an irregular dome at the north end of the anticlinal axis that extends northward from the Laramie Range of the Rocky Mountains. (See fig. 5.) The dome is

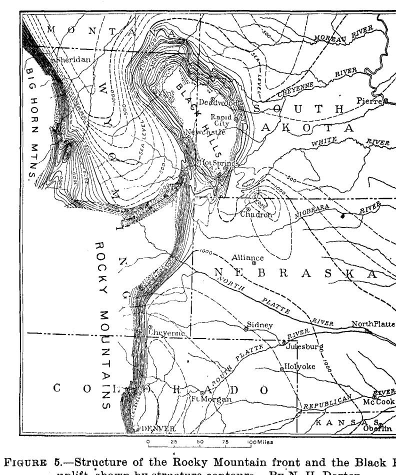

FIGURE 5.—Structure of the Rocky Mountain front and the Black Hills uplift, shown by structure contours. By N. H. Darton.

Contours are drawn on the Dakota sandstone and are not shown where that formation has been eroded. Broken lines are hypothetical. Contour interval, 250 feet.

elongated to the south and northwest, has steep slopes on the sides, and is nearly flat on top. The greatest vertical displacement of the Paleozoic beds, as indicated by the present height of the granite floor, amounts to about 9,000 feet. (See fig. 6.) Subordinate flexures occur mainly along the eastern side of the uplift, the most notable ones being at Whitewood, northeast of Aladdin, in the ridges of Minnekahta limestone just west of Hot Springs, and at localities northwest of Rapid City and in the Hogback Ridge northeast of Piedmont. Several small anticlines also occur. Most of the subordinate flexures, which are characterized by steeper dips on their western sides, merge into the general dome in one direction and run out with a declining pitch in the other direction. On the western side of the main uplift there is a marked local steepening of dips and at the north an abrupt deflection of the dome to the northwest, which is one of its most notable irregularities. In the northern Black Hills there are numerous local domes and flexures, due mainly to laccolithic igneous intrusions, of which the most prominent is that of the Bear Lodge Range. (See fig. 6.)

Faults are rare except in areas where the igneous masses have dislocated the beds and elevated them unevenly. The principal faults observed in the areas of Paleozoic and Mesozoic

[16] Darton, N. H., Volcanic action in the Black Hills of South Dakota: Science, new ser., vol. 36, pp. 602–603, 1912.

rocks are near Jewel Cave, on Whitewood Creek below Deadwood, in Deadman Gulch, north of Roubaix, about Bear Butte, and in Nevada Gulch.

GENERAL FEATURES.

The principal structural features of the region are illustrated by the structure sections on the structure-section sheet, which represent the beds as they would appear in the sides of a deep trench cut across the country. The position of each section is shown by the line at the upper edge of the blank space above it on the map. In general the beds from the Cambrian to the Cretaceous on the sides of the Black Hills dip away from the central area, mostly at angles less than 20°, and in the plains east of the Black Hills the rate diminishes to less than 5°. The monoclinal structure of the slopes of the uplift is interrupted by the few local flexures or faults above mentioned, some of them caused by the intrusion of igneous masses, such as those in Bear Butte and the laccoliths south of Sturgis, Deadwood, and Spearfish.

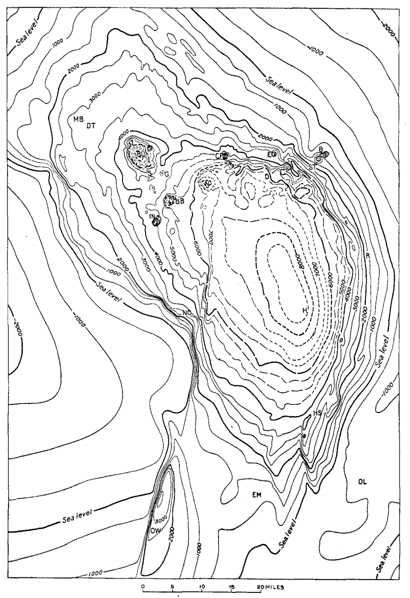

FIGURE 6.—Black Hills uplift shown by contours drawn on the surface of the Minnekahta limestone. By N. H. Darton.

The calculated position of the contours in places where the Minnekahta limestone has been removed by erosion is represented by broken lines. Long dashes indicate areas from which Minnekahta and overlying formations have been eroded; short dashes areas from which all sedimentary rocks have been removed. Contour interval, 500 feet. B, Bear Butte; BB, Black Butte; BL, Bear Lodge Range; C, Crook Mountain; CP, Crow Peak; D Deadwood; DT, Devils Tower; E, Elkhorn Ridge; EM, Edgemont; G, Green Mountain; H Harney Peak; HS, Hot Springs; IN, Inyankara Mountain; MB, Missouri Buttes; N, Nigger Hill; NC, Newcastle; OL, Oelrichs; OW, Old Woman Creek; R, Rapid City; S, Sundance; ST, Sturgis.

LOCAL STRUCTURE.

Lead-Deadwood dome.—The mountain region that extends from Bear Butte Creek to Spearfish Creek is developed on a low, wide structural dome that rises on the north end of the general uplift. In this dome there are pre-Cambrian schists and many laccoliths, sills, dikes, and stocks of igneous rocks. At most places the strata on the slopes of this dome are traversed by several local anticlines, notably those formed by the intrusion of the laccoliths of Spearfish Peak, Polo Peak, and Dome Mountain. The northern side of the dome is corrugated by transverse flexures that pitch northward and northeastward. The valley of Whitewood Creek is cut deeply across the center of the Lead-Deadwood dome, exposing the schists from a point near Englewood to a point below Deadwood. The Deadwood formation circles around the eastern side of the dome and caps the high ridge that divides the drainage basins of Bear Butte and Whitewood creeks. Its basal contact, well exposed along the railroad in the lower part of Deadwood, shows a smooth plane that dips N. 20° E. at a low angle.

West and south of Deadwood the pre-Cambrian surface rises steeply and schist constitutes a hilly district of considerable size. The schist is cut by many porphyry dikes, most of which extend into the overlying Deadwood beds, where the porphyry spreads out as sills. The lower quartzite of the Deadwood formation extends to the crest of Strawberry Ridge, south of Deadwood, where for some distance it forms a wall. At many points this wall is broken by porphyry dikes, which were feeders for a cap of porphyry that covers most of the northeastern dip slope of the ridge, though in most places the porphyry has been eroded away from its crest. In the higher part of the escarpment, near the head of West Strawberry Creek, the Deadwood strata are broken across obliquely by the porphyry, and the basal beds have been uplifted to a level somewhat higher than their position on the southwest side of the valley. Here, as in other places, the trend of the dislocation is northwestward and southeastward, or along the general strike of the strata. At one place in the slope a lower bench of basal massive white quartzite is capped by red shale, which is repeated higher up above a talus of porphyry fragments, a relation due either to faulting or intrusion or both. At most places the quartzite on this ridge dips to the northeast at a low angle, but locally the amount is increased or direction changed by the presence of the intrusive rocks. In railroad cuts a few miles south of Englewood the Englewood limestone shows several small faults with downthrow of 1 to 3 feet on the north side. Along the escarpment east of West Strawberry Creek and around Butcher Gulch the dip is 10° to 11° NE. Near Strawberry Creek and Moll the beds have been tilted by laccolithic intrusions so that they dip east, southwest, and southeast at low angles. From Strawberry Ridge a wide ridge of nearly horizontal lower Deadwood strata, capped in part by rhyolite, extends westward some distance beyond Custer Peak.

Northeast of Custer Peak the Deadwood sandstone dips gently northeastward, but northwest of the peak for some distance there is a down-curving dip toward the northwest that increases gradually from 5° to 45°. On this slope rests an outlier of Pahasapa and associated limestones—a small remnant of strata uplifted by the Custer Peak laccolith.

Lead occupies a basin in schists, which is rimmed on the north and south by rounded hills that consist of conglomerate, sandstone, dolomite, and shale of the Deadwood formation. These beds, about 200 feet thick, lie nearly horizontal and inclose sills or eroded laccoliths of porphyry or are capped by porphyry. The high walls of the Homestake open cut near Lead expose a cliff of the mineralized schist overlain by nearly horizontal sandy shale. The basal conglomerate is here absent, because the ore body formed a ridge when Deadwood deposition began. Several parallel sheets of porphyry have been intruded into the Deadwood beds a short distance above their base, and conduit dikes rise through the schist. The main hill is capped by remains of a thick laccolithic mass, which is especially well exposed in the southern open cut of the Deadwood-Terra workings at the head of Bobtail Gulch. Some relations of the rocks in this vicinity are shown in Figure 7.

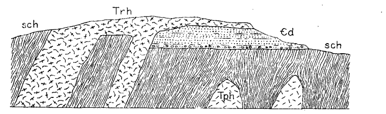

FIGURE 7.—Section showing intrusions in Algonkian schist and Deadwood formation in railroad cut on north side of hill just south of the western part of Lead.

sch, Pre-Cambrian schist; Ꞓd, Deadwood formation; Trh, intrusive rhyolite; Tph, intrusive phonolite.

Terry district.—Porphyry is intruded into or under the lower members of the Deadwood formation at most places about Terry. In Nevada Gulch, south of Bald Mountain, there are several faults, most of the relations of which are revealed in underground workings between Bald Mountain and Sugarloaf Mountain, notably in the Tornado mine. The faults trend northward, and with one exception the upthrow is on the west side and the planes are inclined at high angles toward the east. One of the two largest faults—the westernmost — crosses the gulch northwest of Terry. It has been traced 4,000 feet and has a throw of 300 feet. The other, which has been traced 2,000 feet, has a throw of 72 feet. The southernmost fault in the Mogul mine has a downthrow of 100 feet on its west side. Six small faults in the Tornado mine appear to be branches of the large displacement and resemble a succession of steps rising from east to west; their aggregate throw is 115 feet. Farther south these displacements merge into a single fault, which is indicated by the recurrence of schist on the west side of an area of porphyry and Deadwood sandstone in the bottom of Nevada Gulch, at a point where the Chicago & Northwestern Railway makes a horseshoe bend, about half a mile southeast of the summit of Bald Mountain. High on the north side of this gulch the upper beds of the Deadwood formation abut against the schist, whereas on the south side of the gulch the fault cuts the west side of a sheet of porphyry from which, however, it diverges toward the south. Somewhat similar relations doubtless exist in the bottom of Fantail Gulch, almost due south of the point at which the fault crosses Nevada Gulch, but igneous rocks cover the surface. In Nevada Gulch the schist continues to crop out to a point half a mile above the fault, where it passes beneath the Deadwood beds. These beds and the schist are also cut by many masses of porphyry. To the north the fault disappears in Bald Mountain and to the south it is lost among sills and dikes of porphyry that penetrate the Deadwood formation in the eastern spurs of Terry Peak. Most of the productive mines in the refractory siliceous ores in the Ruby Basin district are near this fault. As some of the ore bodies are closely related to vertical fissures, the presence of this fault is highly significant. There is a notable coincidence in the general north-northwest trend of the vertical fissures of the mines and the lamination planes of the schist. Apparently in the schist the faulting was effected by movement along lamination planes, but the overlying Deadwood strata were partly bent and irregularly fractured. The dislocation was clearly much later than the intrusion of the porphyry.

Between Englewood and Nevada Gulch the contact between the schist and the Deadwood rises 400 feet in a northwesterly direction, an uplift probably effected in large part by slipping on lamination planes of the schists, without notable fracturing of the overlying strata. The faults in Nevada Gulch are doubtless the results of local increases in the amount of such slipping.

Limestone plateau.—In the limestone plateau that extends across the west-central part of the Black Hills the beds lie so nearly horizontal that their dip is hardly perceptible. However, there is a general inclination of the beds westward in the monocline that constitutes the western slope of the Black Hills uplift.

The fault that passes near Jewel and Jasper caves follows a nearly eastward course part way across the plateau near the south line of T. 3 S. and makes a prominent offset in the escarpment about 8 miles southwest of Custer, where the schist and the lower beds of the Pahasapa limestone are in contact. Some relations near the caves are shown in the two sketch sections in Figure 8. Near Jewel Cave the displacement is about 120 feet, and near Jasper Cave, where the fault branches and the limestones are slightly up-arched, the total displacement is about 100 feet.

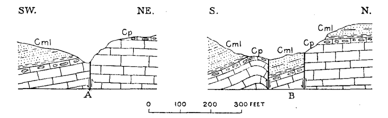

FIGURE 8.—Sections across east-west fault in Jewel Cave National Monument.

A, 1 mile west of Jewel Cave; B, at Jasper Cave. Cp, Pahasapa limestone with cherty top member; Cml, Minnelusa sandstone.

A somewhat similar fault extends eastward for a few miles a short distance north of the Richardson ranch. Its maximum displacement is about 130 feet, and the drop is on the north side, bringing Spearfish red beds and upper sandstone of the Minnelusa in contact.

South of the latitude of Custer the strike swings gradually from south to southeast, and as the southwestward dips steepen slightly the area of the outcrop of the limestone narrows. Southwest of Spearfish also the monocline gradually swings around, so that the strata finally dip gently northward. The general uniformity of structure is sharply interrupted by the dome-shaped uplifts of the Crow Peak and Citadel Rock laccoliths, which, however, affect only small areas, and by the irregular uplifts caused by the intrusive masses on Deer Creek. Spearfish Canyon is cut deeply into the plateau and exhibits the monoclinal structure in its walls.

The deeper parts of the canyons of Spearfish and East Spearfish creeks trench nearly to and finally into the pre-Cambrian schistose quartzite, which is exposed in small outcrops near the mouth of Sweet Betsey Creek and at Hanna. The difference in altitude of these outcrops indicates a gentle slope northward of the contact between the schist and the Deadwood, closely accordant with the attitude of the overlying sedimentary beds. The Deadwood formation, which constitutes the lower slopes of Spearfish Canyon and its branches, dips 3°–6° N. At the mouth of Iron Creek, however, its top sags somewhat, and for a few rods the floor of the canyon consists of Whitewood limestone. A mile above its mouth Little Spearfish Creek flows on Pahasapa limestone, but above the mouth of Dry Creek a low arch brings to view the Englewood limestone and finally the upper and medial members of the Deadwood formation. The high cliffs of these canyons are of Pahasapa limestone, which is 600 feet thick. Its dip is 1°–6° N. At the mouth of Spearfish Canyon, near Spearfish Peak, the Minnelusa and Minnekahta beds dip 5°–18° NNE. The tilting is caused mainly by intrusive masses near by. The limestone lies nearly horizontal about the heads of Timber and Hellgate gulches but shows several low undulations. The structure between Ragged Top and Tollgate Flat is that of a shallow syncline.

Limestone ridges from Spearfish Canyon to Whitewood Creek.—In the limestone front ridge at Little Crow Peak and south of Carbonate, on the east side of Spearfish Canyon, the dips are mostly low and slightly east of north, except locally, where there are slight disturbances. Near Spearfish Peak the dip averages 10°, but it diminishes somewhat to the east, finally to less than 8° in the ridge that culminates in Tetro Rock. East of Tetro Creek the beds have been more steeply upturned by the great laccoliths that extend to Green Mountain and Polo Peak, and consequently the outcrop has decreased greatly in width. This narrowing is largely due also to an upward extension of the igneous rock across the Deadwood formation and the Whitewood, Englewood, and Pahasapa limestones for some distance, and to the local thinning of the Pahasapa. In the vicinity of Polo Creek the beds all come up again in regular order and have average dips of 18° NE. in the lower formations and 8° N. or NNE. in the Minnekahta limestone. On the divide east of Polo Creek, where the dip diminishes, the direction is more nearly north, and the ridge widens so that its southern escarpment is only a mile south of Deadwood. On Whitewood Creek the limestone slope is interrupted by the Whitewood Peak uplift. This uplift is cut by a fault with upthrow on the north side. The fault dies out to the east and west and doubtless was caused by uplift due to an extension of the Whitewood laccolith. The relations of this fault and uplift are shown in section C–C′ on the structure-section sheet.

Limestone ridges from Whitewood Creek to Elk Creek.—In the limestone region from Whitewood Creek to Elk Creek the general structure is monoclinal, sloping northeastward, but it is interrupted by several laccolithic domes and by the anticline and syncline of Boulder Park. (See Pl. XXII.) The steep dip shown by the strata along the narrow part of this park is due to crowding by the laccolith of the Crook Mountain dome. Between this dome and the Whitewood Peak laccolith there is an irregular shallow syncline, which extends far to the southeast, passing between Galena and Kirk Hill. The anticline east of the Boulder Park syncline extends northward through Whitewood and southeastward to the laccolithic uplifts about Deadman Gulch. On Bear Butte Creek the anticline has the form of a steep fold with its steeper limb toward the southwest. The area of Cretaceous beds west of Whitewood lies in the widened northern prolongation of the Boulder Park syncline. Toward the south, in the region of Deadman Mountain and Park Creek, this syncline bifurcates into two broad synclines, both of which separate intrusive masses.

In the Elk Creek region the Deadwood beds lie nearly flat, and for this reason they spread out into a wide area about the headwaters of Little Elk Creek. Farther east they dip at moderate angles down the east slope of the general Black Hills uplift.

The detached mass of Pahasapa limestone on Meadow Creek 2 miles southeast of Elk Creek post office is an anomalous structural feature. It lies on lower beds of the Deadwood formation, about 250 feet lower than its normal position, and is evidently the remains of a landslide from ledges that originally capped the ridges to the east and west.

Limestone ridge from Piedmont to Wind Cave.—From Little Elk Creek to Beaver Creek the limestone ridge on the eastern slope of the Black Hills is remarkably uniform in structure. The strata lie in a general monocline that dips gently to the east, the direction being slightly north of east to Rapid Creek, due east from Rapid Creek to Battle Creek, and farther south swinging gradually to a few degrees south of east. The rate of dip is mostly from 8° to 12°, but there are small local variations, which include a slight general steepening in the region between Squaw and Lame Johnny creeks. The following dips are representative: In the Deadwood formation, on Spring Creek, 12° E.; on Rapid Creek, 7° E.; in Dark Canyon, 12° NE.; on Bogus Jim Creek, 3° to 8° E.; and 1 mile southeast of Robbers Roost, 5° SE.; in the Pahasapa limestone, on Rapid Creek, 8° E.; 2 miles east of Spokane and 2 miles southeast of Bakerville, 12° E.; in the Minnelusa sandstone, on Boxelder Creek, 8° E.; southeast of Bakerville and southeast of Spokane, 12° SE.; in the Minnekahta limestone, on Rapid Creek and in Mill Gulch, 10° E. For a short distance west of Piedmont the Minnelusa sandstone dips 45° and the Deadwood formation 57° where it passes beneath the Englewood and Pahasapa limestones in Little Elk Canyon, as shown in Plate XXVIII, but a short distance to the east the beds are again nearly horizontal.

Limestone ridge in the region southeast and south of Pringle.—Southwest of Wind Cave the dips flatten, and the limestone ridge widens greatly where it passes over the southern part of the Black Hills dome. The direction of dip also gradually changes from southeast to south on Coldbrook Canyon and to southwest in the region between Pringle and Argyle. By this broadening of the ridge it finally develops into the wide plateau that constitutes the higher part of the western slope of the Black Hills.

Red Valley and Hogback Ridge from Spearfish to Sturgis.—The Red Valley and Hogback Ridge, which extend from Spearfish nearly to Sturgis, are developed on the regular monocline on the northeastern slope of the uplift, and the dips are mostly to the northeast at a low angle. The anticline near Whitewood and the syncline west of that place cause a marked deflection in the course of the Red Valley and the Hogback Ridge. The Hogback Ridge consists largely of Lakota sandstone, which extends for some distance down its northeastern side, but some of the canyons in this ridge are sufficiently deep to reveal the underlying Morrison and Sundance formations. North of Sturgis the Dakota and Fuson beds extend to the crest of the Hogback Ridge for a short distance. The syncline west of Whitewood widens the Hogback Ridge into a plateau with wide areas of Lakota and Dakota sandstones, and in its northern extension it holds a shallow basin of lower members

of the Graneros shale. In the center of this syncline the dips are very low, but along the eastern, western, and southern margins they are steep, notably from Whitewood northward, where they range from 20° to 45° for a few miles and then greatly diminish. The dips are also exceptionally steep for a short distance east of Elkhorn Peak and south of Whitewood. They become very low in the Centennial Prairie region and beyond Spearfish, except that a low anticline passes just east of Lookout Peak and dies out in the Spearfish area a short distance to the south.

Red Valley and Hogback Ridge from Sturgis to Buffalo Gap.—The eastward-dipping monocline from Sturgis to the vicinity of Rapid City is corrugated by a small anticline in the Red Valley south of Blackhawk and by a local anticline and syncline on the Hogback Ridge near Elk Creek, southeast of Piedmont, the relations of which are shown in Figure 9.

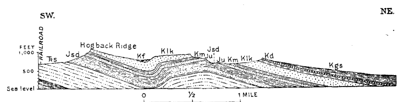

FIGURE 9.—Section across flexure 3 miles southeast of Piedmont.
Ꞧs, Spearfish formation; Jsd, Sundance formation; Ju, Unkpapa sandstone; Km, Morrison shale; Klk, Lakota sandstone; Kf, Fuson shale; Kd, Dakota sandstone; Kgs, Graneros shale.

The dip in the general monocline differs considerably at different places, but in general it diminishes to the east, so that it is very low in the Pierre shale. The dips along the foot of the limestone ridge in most places range from 8° to 10°, except for a short distance west of Piedmont, where they are steeper. Along the Hogback Ridge the dips are steepest near Sturgis, where they are 12° to 15°, and they diminish to the south and in the shale area on the east. At Piedmont Butte the Dakota sandstone dips 4°, on Elk Creek 8°, and on Rapid Creek 22°. On the west side of the anticline southeast of Piedmont, as shown in Figure 9, the dip in one place is 60°.

From Spring Creek southward past Hermosa there is a uniform monocline with dips of 5° to 12° E. On Squaw Creek the Dakota sandstone dips 9½°, and 5 miles northwest of Hermosa it dips 10°. The Graneros shale half a mile west of Hermosa dips 12° to 14°.

In the southeast corner of T. 3 S., R. 7 E., 8 miles southwest of Hermosa, a small syncline and anticline bring up the Dakota sandstone in the midst of the White River beds. These flexures may extend to Fairburn, where a small anticline and syncline produce a double ridge in the Greenhorn limestone just south of the village. There is also a small domelike anticline on Dry Creek 7 miles northwest of Fairburn, which brings up the Minnekahta limestone.

An anticline of considerable prominence west of Buffalo Gap brings up Minnekahta limestone for a mile and a half on the east side of Martin Valley. This anticline pitches up considerably to the south, where it increases the width of the Hogback Ridge. It also continues northward for several miles and passes the west end of Fuson Canyon, a mile northwest of which two small areas of Minnekahta limestone mark its crest. Here the dip is 12° NE., but in the Hogback Ridge it is 35° for a short distance, and it diminishes to 12° in the upper Lakota beds.

A small flat anticline extends southward out of the Hogback Ridge near Lame Johnny Creek and is marked by outcrops of supposed Dakota sandstone near the railroad, but the rocks in this vicinity are mostly covered by Tertiary deposits, so that the relations are not well exposed. The eastward extension of the Niobrara formation in Battle Creek valley beyond the west line of Range 9 is due to a low anticline or partial dome on the general monocline, although all the dips are eastward.

Just west of the village of Buffalo Gap the eastern slope of the Black Hills uplift is locally steepened, a feature that gives increased prominence and steepness to the Hogback Ridge of Dakota sandstone. Here the maximum dip is 50° along a narrow zone, east and west of which it diminishes markedly, being only 10° in the Greenhorn limestone ridge. In Calico Canyon, in this vicinity, the Unkpapa sandstone has yielded excellent specimens showing minute block faults that traverse the bright-colored layers or bands of the rock. Some features of these faults are shown in Plate XXIX. The displacement is very slight, and it appears to be entirely within the Unkpapa sandstone, taken up in part by cross faulting and in part by diagonal shearing. In the gap of Dry Creek, northwest of Fairburn, the Lakota sandstone is displaced about 8 feet by a fault that is very well exposed. (See Pl. XXX.)

Red Valley and Hogback Ridge in the Pass Creek (Elk Mountain) region.—On the southwestern slope of the Black Hills uplift the beds dip to the southwest at very low angles. Near the junction of Hell Canyon and the valley of Pass Creek a low irregular dome in the Red Valley widens the outcrop of Spearfish red shale and exposes Minnekahta limestone, and in Schenck and Hell canyons the top of the Minnelusa sandstone is revealed. A small minor dome also brings up the Minnekahta limestone in a knoll near the mouth of Hell Canyon. Partly because of this doming the Hogback Ridge has a crescentic course on both sides of Pass Creek canyon. In the Elk Mountains the beds dip 10°–25° W., and in the ridge east of Pass Creek, where the dips are low, a wide cuesta of Lakota and Dakota sandstones has been formed.

Plains east of the Black Hills.—In the plains east of the Black Hills the general eastward slope of the strata continues for some distance from the Hogback Ridge, but the dips are low and in general gradually diminish to the east. The structure of this region, as shown in the cross sections and as indicated on the ground-water maps by the depth to the Dakota sandstone, is deduced mainly from the relations and distribution of the Greenhorn limestone, the Niobrara formation, and the tepee buttes in the Pierre shale. The principal horizon of the limestone concretions that cause the formation of these tepee buttes is about 1,000 feet above the base of the Pierre shale.

In the outcrop zone of the Graneros shale and the Greenhorn limestone the beds dip 5°–10°; in the Niobrara area the dip rarely is as much as 5°, and it is less than 2° in the area southeast of Hermosa. East of Rapid City the Greenhorn limestone dips 10° E., but the dip is considerably less than this in the regions on the north and south. Along the outcrop of the Carlile formation the dips are in general 2° to 3°, but at some places they increase to 5° or 6°. In the weathered outcrops of the Pierre shale the dip is difficult to discern, but on the assumption that the main horizon of the tepee buttes is constant, the beds appear to be nearly horizontal a few miles east of Buffalo Gap and to be flexed into a shallow syncline on Cheyenne River southeast of Fairburn. On Battle Creek the dip is eastward at the rate of about 250 feet to the mile, and the rate gradually increases to about 400 feet in the northeast corner of the quadrangle, east of Brennan. To the north the rate decreases to about 125 feet to the mile around Bend post office. In the region 10 to 20 miles east of Sturgis and Piedmont the beds are nearly horizontal, but along the Belle Fourche there is a long low syncline, and probably there is a faint anticline northeast of that stream.

STRUCTURAL FEATURES FORMED BY TERTIARY IGNEOUS INTRUSION.

By N. H. Darton and Sidney Paige.

General relations.—The intrusion of igneous masses into the sedimentary strata of the northern Black Hills in early Tertiary time caused marked deformation of the invaded rocks, notably in the areas occupied by the larger laccoliths and igneous plugs. The resulting features were independent of and superimposed upon the great Black Hills dome, a fact which is well shown in Figure 6. It is also notable that they are confined to a belt 15 to 20 miles wide, which extends westward across the northern part of the uplift from Bear Butte to Missouri Buttes.

The relations of the laccolithic rocks of the Black Hills have been described in considerable detail by T. A. Jaggar.[17] Although the present study has not greatly modified his general conclusions, those relations have been completely reexamined in the field, and many additional facts have been observed, some of which do not agree with the older descriptions. The interpretations and conclusions here set forth are based on this later field work.

Bear Butte.—The very prominent Bear Butte is a large plug of rhyolite, which was forced up through the sedimentary strata and which now projects about 1,400 feet above the adjoining plains. (See Pl. XXVII.) It has upturned and faulted the strata, revealing beds as low as the Pahasapa limestone, and it has also broken across them for hundreds of feet in a very irregular manner. The principal features are shown in Figures 10 and 11.

The structural dome west of Bear Butte is probably due to a laccolith, doubtless an unexposed branch of the main mass, as suggested in section A–A′ in Figure 11, but a recent boring shows that if the dome includes igneous rock it lies lower than the Minnelusa sandstone. The contact relations of the igneous mass of Bear Butte are hidden by heavy talus along the southern side and at places on the northern and western slopes of the butte. On the east side 300 feet of the uplifted Pahasapa limestone crops out in a prominent ridge. (See Pl. XXVII.) On the east this limestone dips steeply under a succession of Minnelusa, Opeche, and overlying beds, but on the south it bends around into a steep anticline, and the plane of intrusion rises to or into the Minnelusa sandstone, in a position that it probably maintains under the talus on the southern slope. The great fault that circles around on the east, south, and west of the butte bounds a block that is uplifted on its inner side. At the south end of the limestone ridge the fault brings Niobrara and Minnekahta limestone into contact. It turns abruptly northward around the southeast corner of the butte, and in extending northward it brings the Sundance formation into contact with the Pierre shale along the eastern slope of the uplift. The relations of this part of the fault are well shown in the northwest corner of sec. 21, where the fault trends due north.

[17] Jaggar, T. A., jr., The laccoliths of the Black Hills, with a chapter on experiments illustrating intrusion and erosion, by Ernest Howe: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 3, pp. 163–303, 1901.

At the northeast corner of Bear Butte the strike of the Pahasapa and overlying formations gradually swings to the west-northwest, and the beds dip away from the intrusive mass. For some distance along the northern slope the igneous contact is with the Pahasapa limestone, and possibly it may continue at this horizon as far as the northwest corner of the butte, but the relations are hidden by the talus that extends to the ledges of the Minnelusa and overlying beds. At the northwest corner of the butte the Spearfish and overlying beds are exposed near the igneous mass and dip northwestward, but the contact is covered by talus. Here a thin sill of igneous rock is intruded between the Sundance and Morrison formations for more than half a mile.

On the western side of the butte there is an extensive exposure of the contact of the main igneous mass with the upper

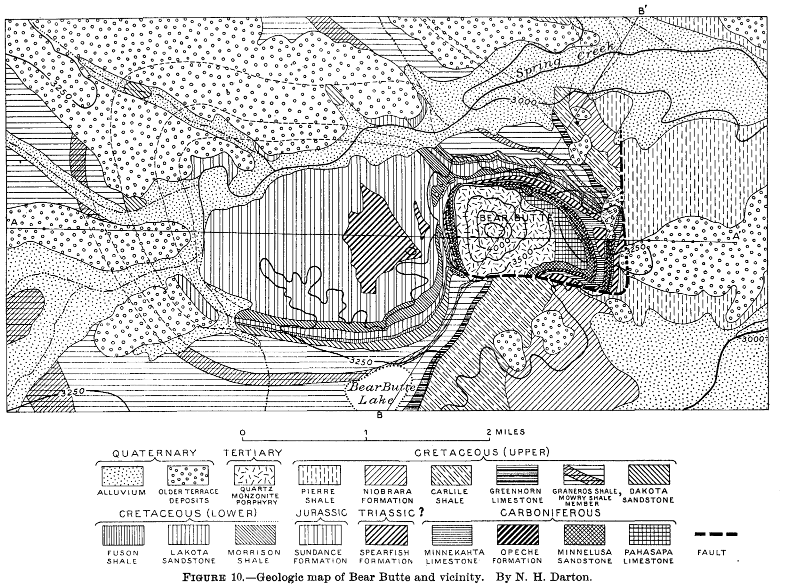

FIGURE 10.—Geologic map of Bear Butte and vicinity. By N. H. Darton.
Shows details of porphyry intrusion and resulting doming and faulting. For sections along lines A-A′ and B-B′ see Figure 11.

sandstone of the Minnelusa, which is mostly changed to a quartzite and is in part reddened by iron oxide. This relation continues southward along the western slope to the southwest corner of the butte and to the talus which covers the contact for some distance along the southern side of the butte. Below this talus the Graneros, Greenhorn, and Carlile beds strike directly into the butte but are doubtless cut off by the fault described above. This fault appears to turn northward from the southwest corner of the butte, where Lakota and Spearfish beds are in contact but are in places separated by a dike. A short distance north of the turn the throw of the fault diminishes, and it dislocates red shale, either Opeche or Spearfish and Minnelusa, which is greatly squeezed and

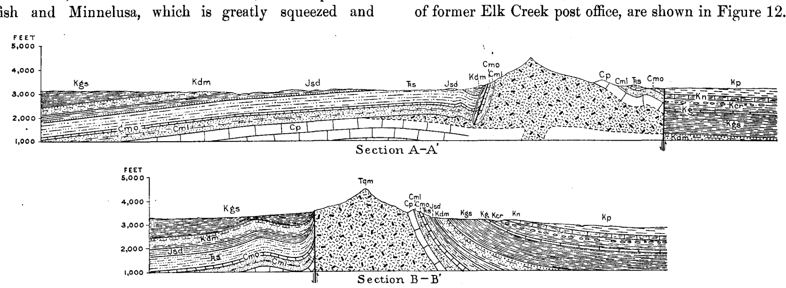

FIGURE 11.—Sections through Bear Butte along lines A-A′ and B-B′ on map forming Figure 10, showing nature of porphyry intrusion and faulting.
Cp, Pahasapa limestone; Cml, Minnelusa sandstone; Cmo, Minnekahta limestone and Opeche formation; ₹s, Spearfish formation; Jsd, Sundance formation; Kdm, Dakota sandstone to Morrison shale; Kgs, Graneros shale; Kg, Greenhorn limestone; Kcr, Carlile shale; Kn, Niobrara formation; Kp, Pierre shale; Tqm, intrusive quartz monzonite porphyry.

crushed. Along the western slope of the butte extends a southward-pitching syncline, which separates the Bear Butte uplift from the dome just to the west. This syncline contains Sundance beds near Spring Creek, but as it pitches down toward the south higher and higher beds appear in it, until near the southwest corner of Bear Butte it is strongly outlined by a ridge of Lakota and overlying sandstones.

The dome west of Bear Butte lifts the beds nearly 1,000 feet higher than they are north and south of it. As above described, its eastern side is crowded steeply against Bear Butte, from which it is separated by a shallow, irregular syncline, a zone of crushing, and a fault. In the center of the dome about 200 feet of the red beds of the Spearfish formation are exposed, dipping away in all directions. An artesian well in the center of the dome penetrates Minnelusa sandstone. The outcrops of the overlying formations to the lower Graneros follow successively in concentric rings, but terrace deposits and alluvium cover all but a few small outcrops in the valley of Spring Creek. There is a ledge of Lakota sandstone in sec. 19, T. 6 N., R. 6 E., and smaller outcrops of brown sandstone, apparently Dakota, are exposed a short distance to the northwest.

Vanocker laccolith.—The extensive irregular igneous mass in the limestone front range between Vanocker Creek and Elk Creek, called the Vanocker laccolith, may comprise intrusions from more than one vent. In its vicinity the general monocline of the Black Hills uplift dips northward and northeastward at low angles. The strata uplifted on the sides of the laccolith dip away from it in all directions at angles of 5° to 15°, and they are mostly removed from its top. The central part of the laccolith consists of coarse quartz monzonite porphyry, but most of the outer part is finer-grained porphyry, and large masses of rhyolite occur on its northwestern slope. The igneous rock attains a thickness of 700 feet, as beds on top of the laccolith have been uplifted to that extent. On the southwest and north the upper contact of the igneous mass is at or near the contact between the Deadwood and the Whitewood, but at several places it rises into the Englewood or the Pahasapa limestone. The relations of part of the rim of the Vanocker laccolith, visible three-fourths of a mile northeast of former Elk Creek post office, are shown in Figure 12.

In the immediate vicinity of Runkel the massive Pahasapa limestone is crossed irregularly by the porphyry, notably in the slope north of the village, where the contact cuts obliquely across the strata on a plane inclined to the east. This mass of porphyry is probably a dike, and if so it occupies the only conduit exposed. Much crosscutting is exposed in the slopes east of this place.

Along the eastern side of the laccolith, where the overlying strata dip eastward at moderate angles, the horizon of intrusion ranges from Deadwood to Minnelusa. On Alkali Creek the contact descends abruptly from lower Pahasapa beds on the west side of the valley to upper beds of the Deadwood formation on the east side. A short distance farther east it rises to the base of the Englewood and then descends deep into the Deadwood formation, a position which it holds for a mile. The strata here dip 12°–15° NNW. The plane of intrusion follows lower beds of the Pahasapa limestone southward to a point 2 miles west of Tilford, where it rises abruptly into the Minnelusa beds. The southeastern part of the igneous rock in this vicinity is an irregular branch laccolith with dikelike offshoots rising high in Pahasapa limestone and Minnelusa sandstone. Somewhat similar relations exist at the northwest corner of the laccolith, near the upper part of Deadman Gulch, where a great sheetlike offshoot of igneous rock cuts upward across the strata and finally reaches a horizon near the middle of the Minnelusa sandstone.

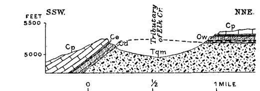

FIGURE 12.—Section across southwestern part of Vanocker laccolith, three-fourths of a mile northeast of former Elk Creek post office.
Cd, Upper shale member of Deadwood formation; Ow, Whitewood limestone; Ce, Englewood limestone; Cp, Pahasapa limestone; Tqm, intrusive quartz monzonite porphyry.

Several porphyry dikes, from 30 to 80 feet wide, cut both porphyry and sedimentary rocks in this area. Four of these dikes, which trend S. 60° W., traverse the porphyry on the ridge west of Alkali Creek, south of the head of Vanocker Gulch. In the saddle southeast of the head of Alkali Creek a 30-foot dike, which has hornblende phenocrysts in a light-gray groundmass, cuts the main porphyry mass along a course that trends N. 60° W.

Kirk Hill laccolith.—Kirk Hill is a symmetrical dome on an expansion of a western limb of the Vanocker laccolith, which is separated on the surface from the main intrusive body by sedimentary rocks. Limestones and sandstones of the Deadwood formation cover most of the top and slopes of the hill, but the porphyry core is revealed in canyons, in one of which well-formed columnar structure normal to the contact is exposed. Ridges of the upper sandstone member of the Deadwood formation revet the west and south bases of the hill. Some relations of the laccolith are shown in Figure 13.

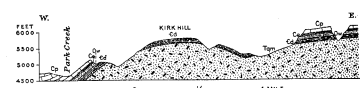

FIGURE 13.—Section through Kirk Hill, showing relations of laccolith.
Cd, Deadwood formation; Ow, Whitewood limestone; Ce, Englewood limestone; Cp, Pahasapa limestone; Tqm, intrusive quartz monzonite porphyry.

Deadman Mountain laccolith.—In the lower part of Deadman Gulch and on the northern slope of Deadman Mountain appears the top of a mass of quartz monzonite porphyry, possibly a branch of the Vanocker laccolith, which uplifts the upper part of the Deadwood formation and the overlying strata.

The strata that dip northward from the main Vanocker laccolith form a syncline in Deadman Mountain. They rise again to the north on the slopes of the Deadman laccolith and form a low dome, in which the deep gulch reveals a high cliff of the underlying porphyry. On the northern side of the dome there is a fault that trends S. 80° W. At this fault, on the west side of Deadman Gulch, the igneous rock rises a few hundred feet to a plane low in the Minnelusa sandstone, apparently in the form of a dike, as it follows the fault fissure for a short distance. The ragged vertical contact shows that the beds were dislocated at the time of the intrusion. In the canyon a short distance to the south the porphyry cuts across

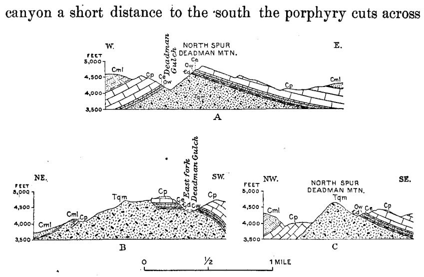

FIGURE 14.—Sections across laccolith at north foot of Deadman Mountain.
A, Section across Deadman Gulch, south of fault; B, section along east side of Deadman Gulch; C, section just north of fault.
Cd, Deadwood formation; Ow, Whitewood limestone; Ce, Englewood limestone; Cp, Pahasapa limestone; Cml, Minnelusa sandstone; Tqm, intrusive quartz monzonite porphyry.

Englewood and Whitewood limestones and the top shales of the Deadwood formation. North of the fault the east wall of this canyon reveals a very instructive cross section of the upper part of the laccolith in the northern spur of Deadman Mountain. Here the porphyry cuts across Pahasapa beds and finally spreads out in the lower part of the Minnelusa sandstone. At one point a small remnant of Pahasapa limestone and the overlying basal bed of Minnelusa sandstone remain on the outer margin of the laccolith. Some of the relations exposed near the gulch are shown in Figure 14.

Bear Den Mountain laccolith.—The mass of quartz monzonite porphyry that constitutes Bear Den Mountain cuts across the edge of strata from basal Pahasapa at its southwest end to the Opeche at its north end. These beds dip northeastward at angles that average about 20°, and the basal igneous contact descends in altitude about 700 feet in the same direction. The overlying strata and some of the porphyry have been removed, and the thickness of the remainder of the igneous mass ranges from about 200 to 300 feet, but it is obviously a laccolith. At the south end of the mountain several dikes of the porphyry extend into the Pahasapa limestone, one of which cuts off a mass of Whitewood limestone and adjoining beds. In the slopes north of Galena there are dikes and irregular masses of porphyry, which follow fractures in the limestone and are probably conduits of the Bear Den Mountain laccolith. The section given in Figure 15, which extends north-northeastward from the mouth of Butcher Gulch at Galena, shows some of the features.

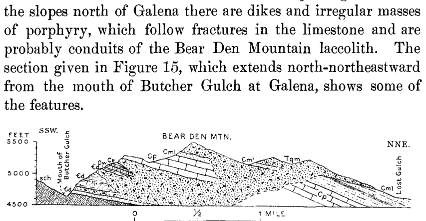

FIGURE 15.—Section through Bear Den Mountain laccolith from Bear Butte Creek near Galena to Lost Gulch.

sch, Pre-Cambrian schist; Ꞓd, Deadwood formation; Ow, Whitewood limestone; Ce, Englewood limestone; Cp, Pahasapa limestone; Cml, Minnelusa sandstone; Tqm, intrusive quartz monzonite porphyry.

Laccolith of Anchor Hill, Dome Mountain, and Pillar Peak.—The large mass of quartz monzonite porphyry that extends from Strawberry Creek to Pillar Peak and farther east is part of one huge laccolith, possibly fed from more than one vent. On the east it is connected with the Bear Den Mountain laccolith, and a branch dike and sill extend to Galena. On the southern side the plane of intrusion is at the base of the Deadwood, but it rises toward the north, follows the shale at the base of the Whitewood limestone on the western side of Dome Mountain, cuts the Englewood and Pahasapa limestones north and east of the mountain, and finally extends into the lower Minnelusa beds on the east end of the Pillar Peak mass. Originally it may have extended into higher beds that have been removed by erosion. The general dip of the strata in this region is northeastward at a moderate angle, but many irregularities and some local doming occur where the igneous mass thickens. This feature is illustrated in Dome Mountain, on the northern side of which quartzite and shales in the upper part of the Deadwood formation dip 22° N., whereas shales on the summit and quartzite on the southwestern edge dip 5°–14° SW. On the northeastern flank of Dome Mountain, along the saddle leading to Pillar Peak, the Pahasapa limestone dips away from the intrusive mass at an angle of 40° and is infolded in a small pinched syncline that plunges northeastward between two lobes of the laccolith. The strata are contorted at the contact. The southeastern border of the Dome Mountain mass shows a ragged contact crossing the Pahasapa limestone and cross sections of probable main conduits. Contact relations can be seen along the road in the divide at the head of Lost Gulch, where northward-dipping Pahasapa limestone overlies massive coarse columnar porphyry, the columns of which are perpendicular to the limestone contact. A dike of finer-grained rock, which trends eastward and northeastward and connects the Dome Mountain and Bear Den Mountain laccoliths, makes a short but conspicuous ridge, which crosses this saddle at the head of Lost Gulch. Pahasapa limestone bounds the mass on the east, the plane of intrusion being at or near the base of that formation, the moderate northward dip of which it follows down to Lost Gulch at a point a mile southeast of Pillar Peak. Lower limestones may possibly be present in places under the talus. North of Lost Gulch and in the vicinity of Pillar Peak the contact ascends rather steeply across Pahasapa beds into the Minnelusa beds at the eastern edge of the igneous mass as mentioned above.

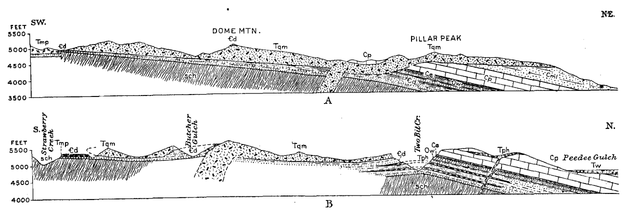

FIGURE 16.—Sections through Anchor Hill–Pillar Peak laccolith.

A, Section from north slope of Anchor Hill through Dome Mountain and Pillar Peak; B, section from Strawberry Gulch over east slope of Anchor Hill and across Two Bit Creek.

sch, Pre-Cambrian schist; Ꞓd, Deadwood formation; Ow, Whitewood limestone; Ce, Englewood limestone; Cp, Pahasapa limestone; Cml, Minnelusa sandstone; Tw, deposits of White River group; Tqm, intrusive quartz monzonite porphyry; Tmp, intrusive sheet of monzonite porphyry; Tph, intrusive phonolite.

An outlier of the Deadwood formation caps the porphyry on the summit of Dome Mountain. On the southeastern slope of this mountain the quartz monzonite porphyry passes beneath the rhyolite that caps the ridge west of Galena and along Butcher Gulch. West of Anchor Hill it is nearly everywhere in contact with the large mass of fine-grained monzonite porphyry; but in places these two rocks are separated by small masses of the Deadwood formation, which is also seen at the head of Butcher Gulch, in Lost Gulch, and in the valley of Two Bit Creek. In the valley northwest of Dome Mountain these underlying strata contain several sills of monzonite porphyry and dip northwestward under Whitewood, Englewood, and Pahasapa limestones with the relations shown at the left end of section B in Figure 16.

In Bear Butte Canyon near Galena there are several very instructive exposures that show the structure of beds intruded by porphyry. Four of these exposures, which are described by Jaggar, are shown in Figure 17.

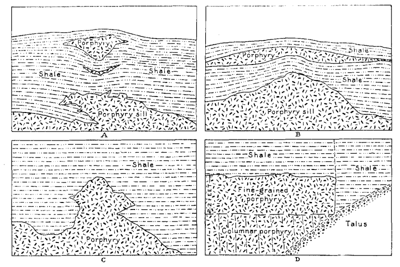

FIGURE 17.—Sketches showing detailed relations of intrusive porphyry to Deadwood formation east of Galena.

A, Miniature laccolith exposed on slope below Sitting Bull mine, opposite the smelter at Galena; B and C, upper contact of a porphyry sill exposed in slopes east of Galena; D, abrupt end of a porphyry sill at a joint plane, exposed in slope above Hayes mine, Galena. Sketches by T. A. Jaggar, jr.

Laccolith of Strawberry Ridge and Spruce Gulch.—The long, irregular intrusive mass which extends southward from the vicinity of Deadwood to the western slope of Anchor Hill and Strawberry Ridge consists mainly of dark fine-grained monzonite porphyry. The plane of intrusion is in the lower part of the Deadwood formation, fragments of which are included in the porphyry, and the Deadwood beds are penetrated by several porphyry sills. The eastern edge of the mass is in contact with the coarse quartz monzonite of Dome Mountain and on the western side of Strawberry Ridge with rhyolite, which it appears to overlie.

In the upper part of the valley of Two Bit Creek and in the hills adjoining Spruce Gulch the flagstones and shales of the Deadwood formation alternate with so many sills of the intrusive rock that only the larger masses can be shown on the areal-geology map. Some of the features are shown in Figure 18. The porphyry predominates in the center of the area, for here it thickens into a laccolith, probably 400 feet thick. The shaft at the Monarch mine, at the head of Spruce Gulch, was sunk through 50 feet of porphyry, 8 feet of shale, 54 feet of white quartzite at the base of the Deadwood formation, and 30 feet of coarse hornblende porphyry that rests on black schist. The beds dip 4° S. Some striking exposures in the long escarpment on the ridge east of Pluma and West Strawberry Creek show masses that rise through conduits in schist and quartzite and spread out as sills in the overlying strata. Several of these conduits connect with the sheet of porphyry that caps the ridge. One dike of the porphyry 40 feet wide cuts northward obliquely across the quartzite, and a conspicuous break in the quartzite ledge is occupied by a composite dike that consists of 100 feet of coarse-grained porphyry flanked on each side by 75 feet of fine-grained porphyry. The schist in the slopes and gulches adjacent to West Strawberry Creek is capped with porphyry, which is in places connected with vertical dikes.

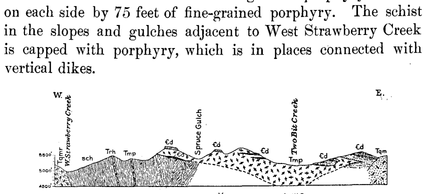

FIGURE 18.—Section across Spruce Gulch laccolith, from West Strawberry Creek near Pluma to a point beyond Two Bit Creek.

sch, Pre-Cambrian schist; Ꞓd, Deadwood formation; Tmp, intrusive monzonite porphyry; Tqm, intrusive quartz monzonite porphyry; Trh, rhyolite; Tqmr, quartz monzonite and rhyolite porphyries.

In the ridge southwest of West Strawberry Creek coarse-grained quartz monzonite is bordered on the southeast by fine-grained white rhyolite, which also occupies the whole divide. A 70-foot shaft cuts through the quartz monzonite to the Deadwood formation at a sharp contact trending N. 25° E. At one point there is an inclusion of the monzonite in the rhyolite, which indicates that here the rhyolite is younger. On the escarpment of Strawberry Ridge the rhyolite breaks across and locally tilts the basal conglomerate of the Deadwood formation. At the mouth of the east fork of West Strawberry Creek the southern slope is formed on schist and the northern slope is formed on porphyry, some of it full of small fragments of schist. The contact trends N. 80° E.

Whitewood Peak laccolith.—The rhyolite porphyry exposed west of Whitewood Peak is part of an irregular laccolith that probably underlies the dome-shaped uplift about that peak. It extends southward to a fault with upthrow on the north side, which was doubtless caused by the intrusion and which afforded a channel through which the porphyry ascended. The plane of intrusion is mostly low in the Deadwood formation, where the strata are bent back sharply at the contact. A small mass of Algonkian granite lies against the porphyry at a locality half a mile southwest of Whitewood Peak. On the north side of the laccolith the beds are also upturned and locally shattered. The overlying beds on Whitewood Creek dip 11° N. Small dikes of phonolite in Pahasapa limestone 1½ miles southwest of Whitewood Peak appear to be later intrusions. The principal structural features of this laccolith are shown in section C–C′ on the structure-section sheet.

Sheep Mountain laccolith.—Sheep Mountain is a small mass of green grorudite that rises above slopes of quartz monzonite and rhyolite. This mass appears to be an irregular laccolith, but its contact relations are largely masked. On the southwestern spur of the mountain the top sandstone of the Deadwood formation dips S. 20° W. at an angle of 50°, and a few feet higher on the slope the basal conglomeratic sandstone is exposed and is overlain by 15 feet of rhyolite. This relation probably indicates the presence of a fault conduit on the south side of the intrusive mass, through which the rhyolite of the adjoining laccolith of Polo Peak and Green Mountain ascended, bending back the formation on the south and lifting all the strata on the north. The grorudite was intruded later above the upper contact of the rhyolite. On the eastern slope of Sheep Mountain there are eastward-dipping outliers of the upper sandstone and shale members, the shale cut by coarse quartz monzonite. On the west slope of the mountain the medial member of the Deadwood formation dips southwestward and shows brecciation and bending, and a shaft on the south slope passes through 40 feet of grorudite to the basal Deadwood sandstone. The gulch northeast of the mountain reveals the contact of rhyolite with a small mass of flat-pebble limestone conglomerate and flags of the Deadwood formation, which are bent up about 5 feet at the contact. This contact trends N. 44° E. and dips steeply southeastward; quartz monzonite lies on the east side. On the northwestern slope of the mountain a tunnel reveals the edge of the rhyolite of the large body north of Sheep Mountain and a 35-foot rhyolite dike. The dike dips eastward and rests on quartzite and glauconitic sandstone of the Deadwood formation, which dip 5° SW. Lower down the slope there is a small outcrop of nearly horizontal red sandy flagstones, limy flags, and flat-pebble conglomerate.

Laccolith of Polo Peak and Green Mountain.—The area of rhyolite that extends from a point 2 miles northwest of Deadwood to Tetro Creek is a great sheet or irregular laccolith intruded in Deadwood and overlying strata. Along its southern side lie masses of quartz monzonite and quartz monzonite porphyry, and in Sheep Mountain it appears to be penetrated by grorudite.

On the southwestern flank of Polo Peak there are remnants of sandstone and limestone breccia of the Deadwood formation, which dip 65° SW., and on the ridge a mile farther west there are large remnants of Whitewood limestone, all of which have been lifted by the intrusion. Underlying Deadwood rocks are exposed along Miller, Polo, and Spring creeks. These relations indicate that although the plane of intrusion was mainly in the upper part of the Deadwood formation its course was irregular, and north of Green Mountain and Tetro Creek it ascended across the limestone and finally reached the lower beds of the Minnelusa sandstone. This gradual transgression northward from lower to higher beds is a common characteristic of these laccolithic intrusions.

Laccoliths between Spearfish Peak and Tetro Rock.—Spearfish Peak consists of an eroded mass of phonolite, from 300 to 400 feet thick, which lies on a northward-sloping platform of Minnelusa sandstone. There is no trace of the fissure of intrusion and apparently no branches or sills, but in places the base of the mass cuts across the strata at a very low angle. The general relations are shown in Figure 19.

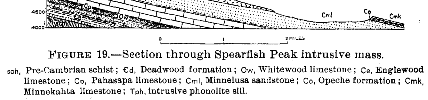

FIGURE 19.—Section through Spearfish Peak intrusive mass.

sch, Pre-Cambrian schist; Ꞓd, Deadwood formation; Ow, Whitewood limestone; Ce, Englewood limestone; Cp, Pahasapa limestone; Cml, Minnelusa sandstone; Co, Opeche formation; Cmk, Minnekahta limestone; Tph, intrusive phonolite sill.

A similar but smaller mass of phonolite caps Pahasapa limestone on the next ridge to the southeast and bears on its northern slope a small remnant of the Pahasapa limestone and a thin overlying sheet of phonolite, as shown in Figure 20.

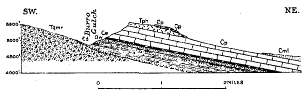

FIGURE 20.—Section through Burro Gulch laccolith and phonolite sill on ridge 1 mile southeast of Spearfish Peak.

€d, Deadwood formation; Ow, Whitewood limestone; Ce, Englewood limestone; Cp, Pahasapa limestone; Cml, Minnelusa sandstone; Tph, intrusive phonolite sill; Tqmr, intrusive quartz monzonite and rhyolite porphyries.

Another mass, about 400 feet thick, caps the ridge of Tetro Rock. It is similar in character and structure to the mass of Spearfish Peak but lies on the northward-sloping surface of the Pahasapa limestone. The plane of intrusion rises somewhat near the north end of the mass and then descends and is represented by a dike that extends through Tetro Rock.

Bald Mountain.—Bald Mountain consists of a thick mass of grorudite similar in structure to that which forms Terry Peak, but the plane of intrusion is much lower in the Deadwood formation. The strata on its southern side have been shattered and penetrated in every direction by igneous rock. Some features that are exposed in railroad cuts are shown in Figures 21 and 22.

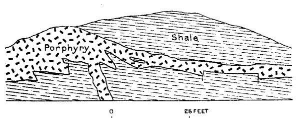

FIGURE 21.—Sketch of porphyry intrusive in Deadwood formation in cut of Chicago & Northwestern Railway on south slope of Bald Mountain.

Showing irregular sill and dike in shale. Sketch by J. M. Boutwell.

Another thick dike, with eastward-dipping walls and rough columnar joints, unites above with a smaller dike that arches through shaly limestone.

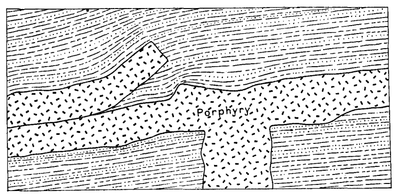

FIGURE 22.—Sketch of detail of a porphyry dike and sill in Deadwood formation exposed in cut of Chicago & Northwestern Railway on southwest slope of Bald Mountain.

Showing relation of intrusive mass to the bedding of the formation.

In the gap northwest of Green Mountain a thin sill of porphyry is intruded in flaggy beds and upper quartzite of the Deadwood formation, which dip 15°–50° S. In the Chicago & Northwestern Railway cut at Trojan flaggy beds of Deadwood formation are underlain by a sill that shows a sinuous contact line, and all dip toward Green Mountain. On the southern side of this mountain massive glauconite flags dip 33° S. 10° E. under calcareous sandstone and shale.

Elk Mountain.—Elk Mountain is a mass of grorudite about 170 feet thick, which caps a high mound of Pahasapa limestone. Its relations are shown in Figures 23 and 24. It is a remnant of a laccolith intruded high in the Pahasapa, and possibly its conduit is under the mountain. On its southern side, along McKinley Creek, the limestone dips in different directions and is indurated and slickensided adjacent to the porphyry. Prospect holes 170 feet below the top revealed the limestone on two sides of the mountain. Tunnels on the eastern slope, 300 feet below the top, are driven in limestone that dips 20° NE., but elsewhere the strata are nearly horizontal. A 75-foot shaft on the northern slope penetrated limestone parted by two somewhat irregular sills of porphyry.

Ragged Top laccolith.—Ragged Top Mountain is the top of a laccolith of phonolite, much of which shows columnar structure. On the southwestern, southern, and northern slopes of the mountain the Pahasapa limestone and underlying strata are upturned, and their dip increases in steepness toward the igneous contact. At the foot of the southwestern slope the strata dip 51° WNW., and near the porphyry on the southeastern face of the mountain they are vertical. In a tunnel on the eastern slope the limestone dips 20° NE., but on the surface near by it dips 80° E. and on the southwestern slopes it dips 16° W. but in places is much steeper. On the southeastern slope the strata are but little tilted, and a small remnant of shale on the summit is horizontal. Along part of the southern and northern slopes the plane of intrusion descends to the base of the upper member of the Deadwood formation, which is exposed in Calamity Creek. A drill hole at the head of this creek was entirely in phonolite, but the Badger shaft, at the foot of the northern slope of the mountain, penetrated Deadwood strata for 316 feet along a vertical wall of phonolite, and then the slope of the contact diminished to about 45° and the shaft was continued in the igneous rock. A section through Ragged Top Mountain is given in Figure 23.

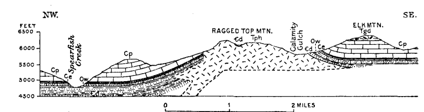

FIGURE 23.—Section from Spearfish Creek through Ragged Top laccolith to Elk Mountain.

€d, Deadwood formation; Ow, Whitewood limestone; Ce, Englewood limestone; Cp, Pahasapa limestone; Tph, intrusive phonolite; Tgd, intrusive grorudite sill.

War Eagle Hill laccolith.—In the ridges at the head of the south fork of Squaw Creek, northwest of Trojan, a thick mass of quartz monzonite and rhyolite porphyry occupies an area of about 2 square miles. As shown in Figure 24, the plane of intrusion is mainly in the lower part of the Deadwood formation, but east of Cyanide it rises into the Pahasapa limestone.

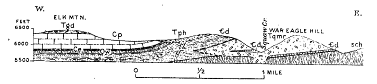

FIGURE 24.—Section from Elk Mountain through War Eagle Hill laccolith to War Eagle Hill.

sch, Pre-Cambrian schist; €d, Deadwood formation; Ow, Whitewood limestone; Ce, Englewood limestone; Cp, Pahasapa limestone; Tph, intrusive phonolite; Tgd, intrusive grorudite sill; Tqmr, laccolith of quartz monzonite and rhyolite porphyries.

On the hill half a mile north of Trojan a capping of shale dips 25° W. On the southern side of the ridge, on the northeastern and western slopes of War Eagle Hill, on the southern side of Squaw Creek, and on Labrador Gulch there are inclusions of nearly horizontal Deadwood strata. Along nearly all of its eastern side this laccolith is separated from the schist by a thin body of lower Deadwood strata that dips southwestward at a low angle. In railroad cuts between Crown Hill and Trojan the Deadwood strata are penetrated by irregular tongues and sills from the top of the laccolith.

Twin Peaks laccolith.—The Twin Peaks are composed of coarse rhyolite, which penetrates or overlies a large, thick mass of monzonite porphyry intruded into the Deadwood formation and Pahasapa limestone, with the relations shown in Figure 25.

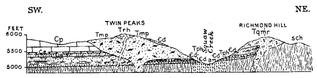

FIGURE 25.—Section across Twin Peaks and Richmond Hill laccoliths.

sch, Pre-Cambrian schist; am, pre-Cambrian amphibolite; €d, Deadwood formation; Ow, Whitewood limestone; Ce, Englewood limestone; Cp, Pahasapa limestone; Tph, intrusive phonolite; Tqmr, laccolith of quartz monzonite and rhyolite porphyries; Tmp, monzonite porphyry laccolith; Trh, rhyolite.

The surrounding strata are not greatly disturbed. Pahasapa limestone crops out south and west of Twin Peaks, but on the east the plane of intrusion descends, so that in Squaw Creek Canyon it is near the bottom of the Deadwood formation. In an exposure on the west side of Redpath Creek, half a mile above its mouth, the porphyry cuts across northward-dipping basal Pahasapa, Englewood, and Whitewood limestones. At the south end of this exposure the monzonite porphyry abuts against or underlies rhyolite porphyry of the large mass that extends to the foot of Green Mountain. Small remnants of overlying Deadwood formation occur on the ridge between Redpath and Squaw creeks.

Region between Terry Peak and Green Mountain.—Terry Peak consists of a conical mass of sills and thick lenses of grorudite, about 300 feet thick, which lies on Deadwood strata and is the remnant of an extensive laccolith. The general structure is that of an irregular shaped dome. A small mass of Pahasapa limestone at the head of Raspberry Gulch is all that remains of the overlying beds, and it lies low on the flanks of a subordinate sill. It dips 80° SSW. Masses of flags and sandstones of the Deadwood formation are included in the igneous body; some of them are horizontal, but those on the southeast side dip eastward and those on the northeast side dip 22°–25° E. and NE. North of the summit the beds dip northeastward; on the northwest side they lie horizontal, and on the southwest spur they dip 18° SW. In a railway cut at Trojan intrusive masses of grorudite of irregular form penetrate the green shales. Some of these masses are elliptical or circular in cross section and were evidently forced through the shale in long, slender curving fingers. In another cut the shales were crumpled by the intrusion, as shown in Figure 26. At some places the igneous contact follows the curves in the deformed beds of shale and at others it cuts across them irregularly, as shown in the center of Figure 26. Along the railroad west of Trojan the upper sandstone member of the Deadwood formation is cut across and shattered by the igneous rock, which also includes fragments of it. Some features in this vicinity are shown in Figure 27.

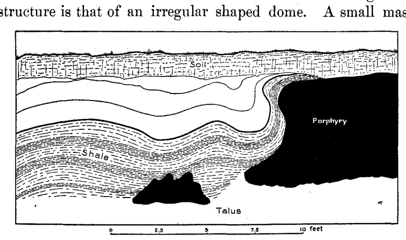

FIGURE 26.—Shale in Deadwood formation deformed by intrusion of porphyry, in north side of cut of Chicago, Burlington & Quincy Railroad east of Whitetail Gulch.

Sketch by T. A. Jaggar, jr.

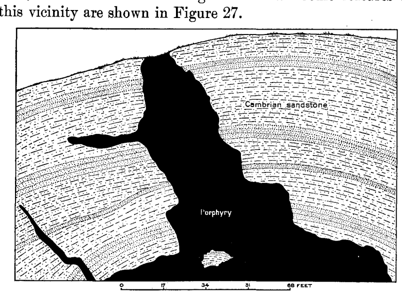

FIGURE 27.—Porphyry cutting across the bedding of the Deadwood formation in cut of Chicago, Burlington & Quincy Railroad west of Trojan.

Sketch by T. A. Jaggar, jr.

At the Snowstorm mine, about halfway between the top of Terry Peak and Green Mountain, a 374-foot shaft penetrated 124 feet of porphyry, 217 feet of alternating shale and porphyry, and 33 feet of shale and sandstone.

Sugarloaf Mountain laccolith.—Sugarloaf Mountain is an eroded laccolith about 250 feet thick, the nearly level base of which lies on shale about 50 feet above the base of the Deadwood formation. It presents cliffs of columnar dove-colored trachytoid phonolite on its western and northern sides. The cliffs on the western side show horizontal platy jointing transverse to the columnar structure, which somewhat resembles bedding. The phonolite appears to cease abruptly on the northern side. It is overlain by Deadwood sandy shale north of Aztec, and lower Deadwood beds form a terrace above schist slopes in Whitewood Creek valley. On the northeast spur of the mountain the strata are nearly horizontal, but in places the contact is very irregular. Dikes are abundant in the schist in the vicinity, and among them is a large one that consists of very coarse quartz porphyry. In the Union mine, north of bench mark 5864, dikes and sheets of phonolite ramify through the shales that underlie the laccolith. There is little contact metamorphism along the irregular lower contact, and the widespread silicification of the beds was probably caused by hot solutions.

Deer Mountain laccolith.—Deer Mountain consists of a thick mass of grorudite, probably an extension of the Terry Peak laccolith, overlain by 100 to 200 feet of flagstones and sandstones of the Deadwood formation, which on the western and southern slopes of the mountain dip away from the igneous body. These beds at the summit are penetrated by two small masses of phonolite. Some structural features of the mountain are shown in Figure 28.

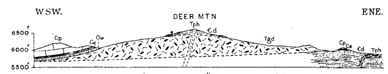

FIGURE 28.—Section through Deer Mountain laccolith.

€d, Deadwood formation; Ow, Whitewood limestone; Ce, Englewood limestone; Cp, Pahasapa limestone; Tph, intrusive phonolite; Tgd, grorudite laccolith.

The intrusion is mostly in the middle of the Deadwood formation, but the contact gradually rises on the southern and western flanks of the laccolith, so that near Raspberry Gulch it reaches the lower beds of the Pahasapa formation. Here the Pahasapa beds dip 15° SSW., whereas the Deadwood beds on the north side near the summit dip 20° NNE. On the west, however, the Deadwood sandstone bends downward on the western slope of the laccolith through angles that range from 5° to 27°. A small outlying mass of Pahasapa and Englewood limestones on the knob 1 mile east-northeast of the mountain lies nearly horizontal, but in the ridge a mile southeast of the mountain these limestones dip 12° SSE.

Woodville Hills and ridge east of Woodville.—The Woodville Hills, east of Englewood, consist of a large residual mass of rhyolite about 400 feet thick, having the general relations shown in Figure 29. The overlying strata are gone, but the bottom contact extends obliquely across the Deadwood formation from the basal member on the north to the top beds on the south.

A broad sheet of the same kind of rhyolite caps the divide in the region northeast of Woodville. It lies on the lower sandstone member of the Deadwood formation, and at a point 2 miles northeast of Woodville it is overlain by a small cap of this formation. The northeastern edge of the rhyolite either abuts against or passes under the monzonite porphyry of Strawberry Ridge. It is cut by phonolite 2½ miles northeast of Woodville and by dikes of coarse quartz monzonite 3 miles southeast of Kirk Ridge.

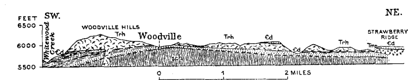

FIGURE 29.—Section along the divide from Woodville Hills to Strawberry Ridge, showing relation of intrusive sill.

sch, Pre-Cambrian schist; Ꞓd, Deadwood formation; Tmp, intrusive monzonite porphyry; Trh, intrusive rhyolite sill.

Custer Peak laccolith.—Custer Peak, the southernmost of the large Tertiary igneous masses of the Black Hills, consists of a thick mass of rhyolite that lies on a platform of Deadwood formation. It is evidently the remains of an old laccolith from which the overlying beds have been entirely removed. The plane of intrusion crosses the Deadwood strata for short distances. The fine-grained light-gray rhyolite has a strong vertical cleavage, which follows the general trend of the ridge, N. 35° W. On the southwestern slope the rhyolite cuts across the Deadwood beds to the lower part of the Pahasapa limestone, a feature probably indicating the location of the vent. A remnant of this limestone is preserved in a shallow syncline northwest of the mountain, and limestone caps the ridge that extends west and south from the saddle at the southwest corner of the intrusive mass. The Deadwood beds south and west of the peak are nearly horizontal, but the shale along its northeastern slope is steeply tilted. The section given in Figure 30 shows the general relations on a line which runs from the North Fork of Rapid Creek north-northeastward to Custer Peak and thence northwestward to Elk Creek.

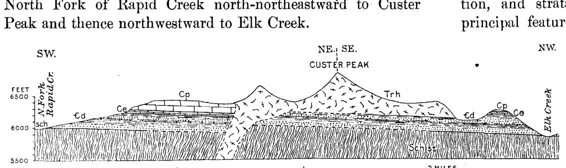

FIGURE 30.—Section through Custer Peak laccolith.

sch, Pre-Cambrian schist; Ꞓd, Deadwood formation; Ce, Englewood limestone; Cp, Pahasapa limestone; Trh, rhyolite laccolith.

Nigger Hill laccolith.—The eastern side of the Nigger Hill laccolith, in the Sundance quadrangle, is exposed in the valleys of Deer and Iron creeks. The rock is quartz monzonite porphyry, and it is intruded mainly in beds high in the Deadwood formation. The intrusion has produced an elongated dome of irregular form, which pitches eastward. On its southeastern side the strata dip southeastward at low angles, and on its northern side they dip north-northwestward. Just north of the mouth of Deer Creek there is a subordinate fold, which trends northward and has steep dips on its eastern side. On the divide between Deer and Iron creeks the porphyry is overlain by an outlier of beds from upper Deadwood to lower Pahasapa, which dip gently eastward, and across these beds the plane of intrusion rises gradually from east to west. The margin of the plane also rises toward the south and finally reaches the basal member of the Minnelusa sandstone.

Crow Peak laccolith.—Crow Peak is an irregular laccolith of quartz monzonite porphyry, which is intruded mainly near the base of the Whitewood limestone but which rises to the base

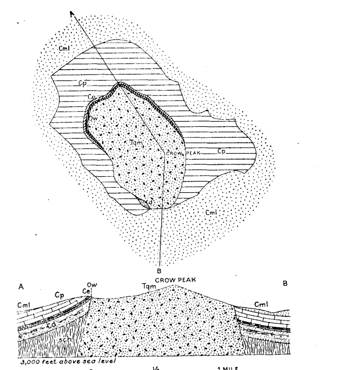

FIGURE 31.—Geologic map of Crow Peak laccolith and section through the laccolith.

sch, Pre-Cambrian schist; Ꞓd, Deadwood formation; Ow, Whitewood limestone; Ce, Englewood limestone; Cp, Pahasapa limestone; Cml, Minnelusa sandstone; Tqm, quartz monzonite porphyry intrusive plug.

of the Minnelusa sandstone toward the south. The strata were sharply upthrust, as shown in Figure 31.

Near its southern edge a small wedge-shaped mass of Deadwood sandstone is brought up by the intrusion. The lower sedimentary rocks form a low but sharp ridge, in which the beds dip at angles that are steep near the igneous rock but that diminish outward in a short distance, where the uplift merges into the general northward-sloping monocline on the north side of the Black Hills uplift. The area of marked disturbance is about 2½ miles in diameter, but a low anticline extends several miles farther north. High on the eastern slope of the peak the limestone dips 51° E. and shows many small faults with upthrow on the west side. On the southwest side there is an abrupt change from dips of 60° near the contact to a nearly horizontal position in the Opeche formation. At the north end of the intrusion the dips are 27°, 40°, 65°, and 89° in beds from Minnelusa to Whitewood, and a tunnel into the peak passes through 105 feet of igneous rock into 5 feet of Deadwood sandstone that dips 12° N. 20° W. The contact here is ragged and trends north-northwestward. The beds tilted by the intrusion comprise about 400 feet of the Deadwood formation, 80 feet of the Whitewood limestone, 30 feet of the Englewood limestone, 550 feet of the Pahasapa limestone, and about 400 feet of the Minnelusa sandstone.

Citadel Rock laccolith.—The igneous rock of the Citadel Rock laccolith crops out in an irregular amphitheater surrounded by a higher rim of upturned sedimentary rocks.

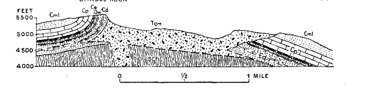

FIGURE 32.—Section through Citadel Rock laccolith.

sch, Pre-Cambrian schist; Ꞓd, Deadwood formation; Ow, Whitewood limestone; Ce, Englewood limestone; Cp, Pahasapa limestone; Cml, Minnelusa sandstone; Tqm, quartz monzonite porphyry laccolith.

The plane of intrusion is mostly low in the Deadwood formation, and strata up to the Minnelusa are upturned. The principal features are shown in section A–A′ on the structure-section sheet and in Figure 32. The dips are moderate, the highest observed near the igneous rock being 42° to 50°, in the Pahasapa limestone. At its north end the igneous mass crosses the Pahasapa limestone to the lower part of the Minnelusa sandstone, and on the northeastern side branch sills extend into the Deadwood formation.

Crook Mountain.—The dome-shaped uplift of Crook Mountain is doubtless underlain by a laccolith. It consists, as shown in section C–C′ on the structure-section sheet, mainly of Minnelusa sandstone and Pahasapa limestone, which dip away from the center at angles between 15° and 20°. The Minnekahta limestone encircles the dome and occupies a small syncline on the south side. The Pahasapa limestone is revealed on the western, northern, and southern sides.

Elkhorn Peak.—Elkhorn Peak consists of Minnelusa sandstone with revetments of Minnekahta limestone on its lower slopes. It is a nearly symmetrical dome, but the dips are greater on the southeastern and eastern sides than on the western and northwestern sides. It probably contains a laccolith. Its structure and relations are shown in section B–B′ on the structure-section sheet.

THE MECHANICS OF INTRUSION OF THE TERTIARY IGNEOUS ROCKS.

By SIDNEY PAIGE.

The deep erosion in the Black Hills region makes it possible to observe the relations of the igneous masses at many horizons, so that the mode of their intrusion may be readily inferred.

The shapes of the intrusive masses have been greatly influenced by the structure of the invaded rocks. In the steeply inclined Algonkian schists these masses are either dikes that generally follow planes of schistosity or stocks of irregular outline that partly cut schistosity and partly follow it, with their longer diameters generally in the direction of the schistosity. In the Paleozoic rocks also the intrusive masses followed the lines of least resistance, so that in large part they spread laterally as sills and laccoliths of different shapes and sizes, lifting the strata in some places into domes of considerable height and size. They also followed certain horizons more readily than others: First in order from below upward, the unconformity at the base of the Deadwood formation; second, the black soft shale, if it is present, between the upper sandstone member of the Deadwood formation and the tough Whitewood limestone; third, the Englewood limestone, where it is underlain by the Whitewood limestone; and fourth, the Opeche formation, a thin, soft deposit which lies between the Minnelusa sandstone below and the resistant Minnekahta limestone above. Other horizons of intrusion are just above the basal quartzite or just beneath the top quartzite of the Deadwood formation, but in some places other beds and overlying formations were invaded. Although the intrusive masses are generally sill-like or laccolithic the contact in many places cuts across the strata for long distances. A notable example is the upper contact of the large Kirk Hill laccolith south of Sturgis, which follows the top shale member of the Deadwood formation for several miles and then cuts upward through the Pahasapa limestone, in which it follows several horizons. The Deadman Mountain laccolith, probably a branch of the Kirk Hill mass, has cut successively across Deadwood, Pahasapa, and Minnelusa formations. The contact of the great igneous mass at Pillar Peak cuts across beds that range from pre-Cambrian schists to Minnelusa sandstones, and similar features exist in Deer Mountain, Ragged Top, Citadel Rock, Crow Peak and other laccoliths.

The strong influence of bedding planes on the form of intrusive masses, however, is shown at many places. The large sheet northeast of Woodville is notably regular, and its base is everywhere low in the Deadwood formation. It is a remnant of a sheet that probably once extended from Sugarloaf Mountain to the rhyolite-covered hills around Lead. The Deer Mountain mass also is remarkably uniform, notably along its southern edge, where the upper contact follows the base of the Englewood limestone.

The intrusion of these great bodies of molten rock between the Paleozoic strata folded and displaced them, or the flexing and displacement immediately preceded the intrusion; it is not possible to distinguish between cause and effect in this relation. Locally, at least, the entrance of the magma was the immediate cause of deformation. The formation of dikes and stocks in the schists caused an increase of bulk which, together with the intrusion of sheets and laccoliths into the Paleozoic rocks, lifted the overlying strata, producing domes of different shapes, some very low and broad, others higher and more steep-sided. As this deformation caused very little faulting the arched beds must have been stretched.

The shape which the igneous masses assumed within the Paleozoic strata was dependent on several factors, the respective importance of which can not be determined. Among these factors are the viscosity of the magma at the time of injection, its rate of cooling, the speed and duration of its injection, the weight of the overlying strata, and the structure of the invaded beds with respect to planes of easy passage. Variations in any of these factors would correspondingly affect the shape and size of the intrusion.

In the Crow Peak igneous mass, the structural relations of which are described on page 24, the intrusion has resulted in the steep uplifting and faulting of about 1,460 feet of beds, from the Deadwood to the Minnelusa, in an area about 2½ miles in diameter, or about twice the longer diameter of the igneous outcrop. Possibly the low anticline that projects northward from Crow Peak was formed by an underground extension of the laccolith. A conception of the mechanics of this intrusion must be largely theoretical, for the form of the laccolith is not fully exposed. At its north end, as shown in Figure 31, the igneous rock is intruded at the base of the Whitewood limestone, but on the south the plane of intrusion rises until it enters the lower part of the Minnelusa sandstone, thus crossing about 700 feet of strata. The small mass of Deadwood sandstone that lies against the porphyry at the south end of the area and the rise of the plane of intrusion toward the south appear to indicate that the magma forced its way violently through the overlying strata at this place, much as a punch might perforate plastic material. Features of this character probably led Russell to call these masses igneous plugs.

The general structural relations of many other intrusive bodies in this region are similar to those in the Crow Peak uplift, but the cause of the evidently violent rupture of beds at the summit of the uplift and the particular curve that the magma followed as indicated by the dips of the inclosing strata deserves consideration.[18] A fundamental difference may be noted here between the curve on the upper surface or flanks of the laccoliths of the Henry Mountains of Utah and the curve on many laccoliths of the Judith Mountains of Montana, as observed by Pirsson.[19] A comparison of Gilbert's section

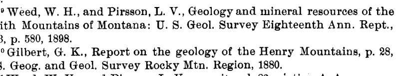

FIGURE 33.—Ideal cross section of the laccoliths of Mount Holmes. (After Gilbert.)

of the laccoliths of Mount Holmes[20] (see fig. 33) with Pirsson's section of the Judith Mountains[21] (see fig. 34) shows that the upper surfaces of the laccoliths of Mount Holmes are everywhere *convex* upward, whereas the surfaces of those of the Judith Mountains are locally almost level or slightly *concave* upward.

After seeking an explanation of the condition at Crow Peak by considering the result of one of Howe's experiments in

[18] See Paige, Sidney, The bearing of progressive increase of viscosity during intrusion on the forms of laccoliths: Jour. Geology, vol. 21, pp. 41-49, 1913.

[19] Weed, W. H., and Pirsson, L. V., Geology and mineral resources of the Judith Mountains of Montana: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 3, p. 580, 1898.

[20] Gilbert, G. K., Report on the geology of the Henry Mountains, p. 28, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1880.

[21] Weed, W. H., and Pirsson, L. V., op. cit., pl. 82, section A–A.

artificial laccolith building,[22] the writer concluded that the form of the upper surface of a laccolith might be materially affected by the progressive increase in viscosity of the magma during injection. The fluid magma, if driven by pressure from

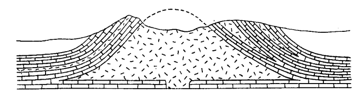

FIGURE 34.—Section of laccolith in Judith Mountains. (After Pirsson.)

beneath, would probably insinuate itself along the basal contact of a subhorizontal sedimentary series and form a thin sill or sheet of roughly circular outline. Such a sheet while fluid would transmit hydrostatic pressure from beneath, and if this was sufficiently great to overcome the weight of the overlying strata a dome would be formed. If this magma were introduced violently the body might take the form of the Shonkin Sag laccolith[23] (see fig. 35), described by Pirsson. The form of

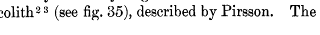

FIGURE 35.—Cross section of Shonkin Sag laccolith. (After Pirsson.)

this mass suggests that the magma was impelled by a pressure from beneath sufficiently great to lift suddenly the cylindrical mass of rock above it. Pirsson reaches this conclusion from other considerations. He says: "The occurrence of ball-like masses in the upper crust of the laccolith seems to show that the filling took place with considerable rapidity." Now if this magma was introduced slowly or if there was increasing viscosity due to marginal cooling, the effect of the increased viscosity becomes noteworthy. For by just so much as hydrostatic pressure is overcome or impeded, by just so much will there be unequal distribution of pressure upward. The greatest pressure will be exerted directly over the source of supply, where the magma is most fluid, and from this region outward decreasing pressure will be exerted on the roof. The series of five diagrams (fig. 36) illustrates possible results during intrusion under these conditions. The outer part would congeal first, and as the area in which pressure was transmitted

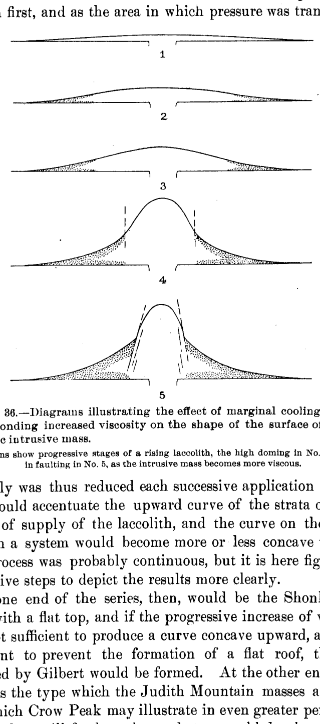

FIGURE 36.—Diagrams illustrating the effect of marginal cooling and corresponding increased viscosity on the shape of the surface of a laccolithic intrusive mass.

The sections show progressive stages of a rising laccolith, the high doming in No. 4 resulting in faulting in No. 5, as the intrusive mass becomes more viscous.

perfectly was thus reduced each successive application of pressure would accentuate the upward curve of the strata over the source of supply of the laccolith, and the curve on the flanks of such a system would become more or less concave upward. The process was probably continuous, but it is here figured by successive steps to depict the results more clearly.

At one end of the series, then, would be the Shonkin Sag type, with a flat top, and if the progressive increase of viscosity was not sufficient to produce a curve concave upward, although sufficient to prevent the formation of a flat roof, the type depicted by Gilbert would be formed. At the other end of the series is the type which the Judith Mountain masses approach and which Crow Peak may illustrate in even greater perfection. Obviously a still further advanced stage could develop.

Thus where the dips of the overlying strata approach the vertical, and the central part of the igneous mass is still competent to transmit pressure either by hydrostatic action or by direct thrust through a central core, now very viscous, it is possible that breaks would occur and that the configuration of the mass would become roughly cylindrical and the fault surface more or less circular. This last result was probably reached at Crow Peak, where much of the intrusive mass now rests against soft shale of the Deadwood formation, and where a small fragment of sandstone of the Deadwood formation is faulted against Minnelusa sandstone at the south end of the intrusive mass. The shale of the Deadwood formation would form an ideal locus for such a break after the beds had been steeply bent upward. The block of sandstone of the Deadwood formation would naturally have been dragged up along the fault plane.

There are many excellent exposures that show different stages of laccolithic intrusion. The symmetrical dome at Elkhorn Peak, 8 miles east of Spearfish, undoubtedly has an igneous core, which in time will be exposed by erosion. The great rhyolite sheet northeast of Woodville is completely bared, and its base is exposed for several miles. In these two examples two extremes are represented—the domelike top and the relatively flat top; and there are many intermediate stages. Kirk Hill is perhaps the best example of a partly denuded laccolith, and another good one is the Iron Creek area (Nigger Hill laccolith), where a thin veneer of the top quartzite of the Deadwood formation remains on the curved surface of the porphyry.

A plane of intrusion crossing the bedding laterally appears to be well shown at Pillar Peak. Here the porphyry west of the peak cuts eastward from the Deadwood formation to the Pahasapa limestone, which it follows east of the peak. The intricate sill type of intrusion is illustrated southeast of Deadwood, where the intrusive rock includes many thin wedges of sedimentary beds. At Whitewood Peak and just northwest of Deadman Mountain the pressure of the magma broke the sedimentary beds on the west side of the dome. At Crow Peak, Citadel Rock, and Ragged Top Mountain crosscutting intrusive rocks are well exposed. The complex of sills and crosscutting laccoliths in Deer Mountain, Terry Peak, and Foley Mountain shows large masses wedging out along bedding planes. Lowest of all, the pre-Cambrian schists are cut by the dikes that were conduits for sills or laccoliths in overlying Paleozoic strata. Although the local deformation which accompanied the intrusion of the sills and laccoliths was in the main probably a consequence of the intrusion, the relations of this deformation to the general uplift of the Black Hills dome may well be considered.

All the Tertiary intrusive masses lie within a crescent-shaped area that extends eastward across the northern part of the principal axis of the Black Hills uplift, a relation which is doubtless highly significant. Zones of igneous intrusion are generally associated with lines of weakness in the earth's crust, and as the igneous rocks above described ascended through the pre-Cambrian schists, they probably followed lines of weakness in these old formations. In the study of this region it is therefore important to determine whether or not there is any structural feature in the pre-Cambrian schist that tended to restrict the intrusion to the zone it occupies. The dikes and stocks that occur in the schist area generally follow the schistosity, which trends northward. The principal axis of the Black Hills uplift extends from its south end northeastward for a short distance but turns northwestward near the center of the uplift—that is, the uplift is crescentic in form, its north end being bent to the northwest. (See fig. 6, p. 18.) This westward bending may have produced lines of weakness that crossed the trend of the schistosity. That this result might be expected is illustrated by the behavior of a number of sheets of paper held firmly together at the ends and bent as shown in Figure 37. A bulge is formed on the inside of the bend, due to compression on that side. Perhaps no

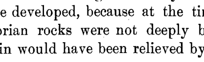

FIGURE 37.—Diagram illustrating the bulging and spreading of layers of a sheaf of paper held firmly at each end and bent in the middle.

Suggests an analogous mechanical effect within the vertical Algonkian schists and offers a possible explanation for the line of weakness along which the Tertiary intrusions entered.

openings in the schist were thus caused, but the tendency to open probably existed and sufficed to permit the magma to force its way upward. Most of the individual feeding dikes trend northward, whereas the zone in which they occur trends eastward. From this relation it would appear that the ascending magma followed planes of schistosity along which the bending had developed a tendency to form openings. These openings were formed en échelon across the inner side of a great bend in the dome, where a zone of weakness had been established as the schist bulged laterally. Such a tendency to open could be developed, because at the time of the doming the pre-Cambrian rocks were not deeply buried. In deeper zones the strain would have been relieved by plastic flow.

GEOLOGIC HISTORY.

ALGONKIAN PERIOD.

By Sidney Paige.

The earliest records of geologic history in the Black Hills are found in conglomerates, grits, graywackes, slates, and schists of pre-Cambrian age. The materials of these rocks were derived from a land mass of unknown location and extent and were deposited on the floor of a bordering sea. The material of the conglomerates and coarse arkoses doubtless accumulated rapidly along a rugged coast line, and the irregularities in the distribution and the thickness of the deposits point to the existence of stream channels of rather high gradient. The associated calcareous beds suggest deposition in quiet water, protected from the influx of coarse material. In fact, the beds on the eastern border of the pre-Cambrian area seem to have been deposited on a fairly abrupt coast line, the material of the conglomerates having been laid down in stream channels and the coarse arkosic material having been swept along the shore by currents. Farther out from the shore limestone and possibly iron carbonate accumulated.

During a slow encroachment of the sea over the land finer sediments were laid down upon the coarser. Slight changes in the relative levels of land and sea, or changes in the amount of rainfall, which might produce changes in the character of the débris, would account for the intercalation of coarse sediments with finer ones in the later deposits and for the accumulation of the associated limestones.

The deposition of this sedimentary series was followed by a period of igneous activity, at a time not precisely indicated except that it was prior to the main folding of the beds. Dioritic and diabasic magmas were injected into the sedimentary beds, mainly along planes of stratification but in part also across those planes. The folding and metamorphism that followed were doubtless connected with the intrusion of the granite. While still buried deeply the entire series was subjected to compressive stresses, in general from northeast to southwest, which produced a series of major folds, and upon these folds were imposed many minor wrinkles. There is evidence that before this compression had ended, and perhaps owing to a continuation of the same forces, granite was intruded, and thus the northwestward trend of the folds was modified by a doming of the sedimentary beds in the vicinity of the intruded mass. The actual differential movement of bed past bed during this folding developed schistosity. The softer beds were completely recrystallized, the harder beds were partly recrystallized, and much cleavage was developed. In many beds new minerals were produced, notably by the alteration of impure limestones to quartz-amphibole rocks, and diorites were changed to amphibolites.

The further course of pre-Cambrian events is not indicated. The rocks were uplifted, and the uplift was doubtless in progress during their compression. Subsequently they were planed down and submerged by the advance of the Cambrian sea.

CAMBRIAN TO QUATERNARY PERIODS.

By N. H. Darton.

General sedimentary record.—The materials of the sandstone, shale, sand, loam, and gravel exposed in the Black Hills uplift were originally derived by erosion from the older rocks and deposited in water, and the limestone and gypsum were chemical precipitates from salty water. Igneous rocks were intruded in a molten state, and volcanic ash, lava, and tuff were ejected from volcanic orifices.

The character and relations of these sedimentary rocks indicate the conditions under which they were deposited. Sandstones ripple marked by water and cross-bedded by currents and shales, afterward cracked by drying on mud flats, were deposited in shallow water; pure limestones suggest clear open seas and scarcity of land-derived sediment. The fossils contained in the beds belong to species known to inhabit waters that are fresh, brackish, or salt, warm or cold, muddy or clear. The character of the adjacent land is shown by the character of the sediments derived from its waste. The quartz sand and pebbles of sandstones and conglomerate, such as those in the Deadwood, Minnelusa, Lakota, and Dakota formations, were derived from the crystalline rocks, but some of this material has been repeatedly distributed by streams and concentrated by wave action on beaches. Red shales and sandstones such as make up the "Red Beds" are commonly the products of a revival of erosion on a land surface that has been long exposed to decay and oxidation, which has developed a deep residual soil, generally red. Limestones that were formed near the shore indicate that the land was low and that its streams were too sluggish to bring down coarse material, the sea receiving only fine sediment and substances in solution.

The older formations exposed by the Black Hills uplift were laid down in a sea that covered a large part of the west-central United States, for many of the beds are continuous over a vast area. The land areas were large islands in an archipelago that was in general coextensive with parts of the present Rocky Mountain province, but the shores of that archipelago have not been even approximately determined for any one epoch, and the relations of land and sea varied greatly from time to time.

Cambrian submergence.—The interior sea submerged the Rocky Mountain province in later Cambrian time, although for a while the rocks of the central part of the Black Hills formed an island or a peninsula in that sea. From the surface of the ancient crystalline rocks streams and waves gathered sand and pebbles and deposited them in widespread sheets. As their altitudes were reduced by erosion and their areas

[22] Jaggar, T. A., jr., The laccoliths of the Black Hills, with a chapter on experiments illustrating intrusion and erosion, by Ernest Howe: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 3, Experiment 3, p. 297, 1901.

[23] Weed, W. H., and Pirsson, L. V., Geology of the Shonkin Sag and Palisade Butte laccoliths in the Highwood Mountains of Montana: Am. Jour. Sci., 4th ser., vol. 12, pp. 1-17, 1901.

were lessened by submergence this land yielded the finer-grained muds now represented by the shales that occur in the upper beds of the Cambrian. Finally, in many regions the earlier land surface of the crystalline rocks was buried beneath the sediments.

Ordovician-Devonian time.—The very long time from the end of Cambrian to the beginning of Carboniferous time is represented in the Black Hills only by the Whitewood limestone, of late Ordovician age, which attains a thickness of 80 feet in the area to the north but is absent in that to the south. The scantiness of this record is probably due to the fact either that the area was long occupied by a large but shallow sea or that the land was so low that no evidence of erosion remains. Possibly, however, sediments were deposited and later removed by erosion.

Carboniferous sea.—Early in Carboniferous time most of the Rocky Mountain province was submerged, and in these early Mississippian seas were laid down calcareous sediments that are now represented by several hundred feet of Englewood and Pahasapa limestones. As the sediments of that time include no coarse deposits probably no crystalline rocks were then exposed above water in this region. The conditions during the long hiatus in late Mississippian or middle Carboniferous time are not indicated, but there was evidently no deformation, and if sediments were laid down they were planed off by erosion in later uplifts.

In later Carboniferous (Pennsylvanian) time much fine sand was deposited in thick but regular beds, together with considerable calcium carbonate and more or less iron oxide. The presence of iron oxide is indicated by the color of many beds of the Minnelusa sandstone. The next stage was marked by uplift and by the accumulation of the bright-red sands and sandy muds of the Opeche formation, of probable Permian (latest Carboniferous) age. The thin Minnekahta limestone was deposited from sea water, and its general uniformity indicates widespread submergence. Its fossils do not show with certainty whether it is of Permian or of Triassic age.

Red gypsiferous sedimentation (Triassic?).—After the Minnekahta limestone had been laid down there was a resumption of "Red Beds" deposition, which resulted in the accumulation of the 700 feet of red sandy clay that forms the Spearfish formation, which is supposed to be of Triassic age. It was laid down in shallow salty lakes, upon wide flood plains, and in bayous bordering sluggish streams, which were formed by extensive uplift and aridity. Its uniform deep-red tint is undoubtedly its original color, for it is red through its entire thickness, as is shown by deep borings, and its color is therefore not due to later or surface oxidation. At many times the accumulation of clay gave place to the precipitation of gypsum in beds that range in thickness from a few inches to 30 feet and are mostly free from mechanical sediment. This gypsum is probably the product of evaporation in extensive basins during an epoch of little rainfall and consequently of temporarily suspended erosion; otherwise it is difficult to understand its purity. This epoch appears to have been followed by extensive uplift with some planation and channeling, which represents a portion of Triassic and Jurassic time of unknown duration. It was succeeded by the deposition of late Jurassic sediments.

Jurassic sea.—In late Jurassic time the region was covered by shallow and moderately deep marine water alternately. In the southeastern part of the region the earliest deposit was moderately fine sand, doubtless laid down on a shore, but at some places shale lies directly on the Spearfish red beds. Upon this shale lies a fine-grained ripple-marked sandstone that was laid down in shallow water in which there were no strong currents. The red color of part of the medial sandy series suggests a transient recurrence of an arid climate. An extensive marine fauna and the limestone layers in the upper shale of the Sundance formation indicate that deeper water followed. After this stage widespread uplift gave rise to bodies of fresh water in which the first sediments formed consisted of the thick deposit of fine sand of the Unkpapa sandstone, which is conspicuous along the eastern side of the Black Hills.

Cretaceous seas.—During the Cretaceous period deposits of various kinds, but generally uniform over wide areas, were laid down in a great series, beginning with those that are characteristic of shallow seas and estuaries along a coastal plain, passing into sediments laid down in deep marine waters, and changing toward the end to fresh-water sands and clays that carry remains of marsh vegetation. The earliest of these deposits, beginning, however, possibly in late Jurassic time, is the sandy clay of the Morrison shale. The absence of this formation in the southeastern part of the Black Hills is probably due to local uplift of that region and degradation of unknown extent and duration, which is further marked by erosional unconformity between the Unkpapa sandstone and the Lakota sandstone. In the Morrison-Lakota contact, however, there is no evidence of hiatus, and sedimentation may have been continuous. The materials of the Lakota sandstone consist mainly of coarse sands spread by strong currents, in beds 30 to 40 feet thick, but include several thin deposits of clay and local accumulations of vegetal material which constitute the coal of the Cambria, Aladdin, Sundance, and Edgemont areas. The thin Minnewaste limestone apparently was deposited only in a local basin in the southern part of the Black Hills. The next deposit in early Cretaceous time was a widely extended sheet of clay that formed the Fuson shale, laid down in quiet water. This time of quiet water was followed by one in which the waters had strong currents, as in Lakota time, which transported the coarse sands of the Dakota sandstone.

At the beginning of the Graneros epoch there was a very rapid change of sediment from sand to clay. In the great Upper Cretaceous submergence, which prevailed throughout the Colorado and Pierre epochs, several thousand feet of clay were deposited. In early Colorado or Benton time several thin deposits of sand were laid down. Two of the later ones were widespread, and an earlier one produced the local sandstone members which now underlie the Mowry member at some localities. The presence of beds of bentonite indicates that volcanoes were active in the general province. The middle of Benton time was marked by the widespread deposition in characteristic alternation of the clay and limy sediments of the thin Greenhorn limestone. After the clay of Benton time had been laid down several hundred feet of impure chalk, constituting the Niobrara formation, followed, and this in turn was succeeded by clay, now represented by more than 1,500 feet of Pierre shale, deposited under very uniform conditions. At some places, especially in areas to the north of that here considered, thin but widespread deposits of sand were laid down, their deposition interrupting that of clay. The Cretaceous sea retreated during the Fox Hills epoch, in which sands were spread in an extensive sheet over the clay beds, causing the development of large bodies of brackish or fresh water, which received the sands, clays, and marsh deposits of the Lance and later formations, some of which extended into early Tertiary time. Whether the Fox Hills and the immediately succeeding sediments were deposited over any of the area now occupied by the Black Hills is not definitely known, but possibly they were so deposited, as they are upturned around two sides of the uplift.

Early Tertiary mountain growth.—The Black Hills dome was uplifted to a moderate height early in Tertiary time by a movement that may have begun in latest Cretaceous time. The larger topographic outlines of the region were established before the Oligocene epoch, the dome having been truncated and most of the larger valleys excavated, in part to their present depths. This relation is indicated by the occurrence in the valleys of White River (Oligocene) deposits, even in some of their deeper parts. Some idea of the extent of this degradation is shown by Figure 38, which represents a profile across the highest part of the dome and indicates approximately the position of the surface of the Pierre shale if this formation covered the Black Hills region. Where the great mass of eroded material was carried is not known, for in the lower lands on the east and southeast no early Eocene deposits have been found nearer than those on the Gulf coast and in the Mississippi embayment and the Denver Basin.

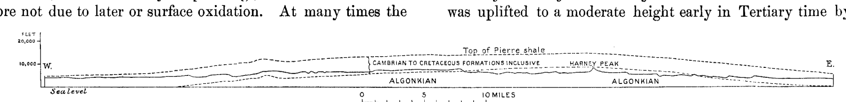

FIGURE 38.—Outline section across the center of the Black Hills to suggest extent of degradation.
The beds shown above the surface profile were removed by erosion.

The igneous intrusions probably occurred during early Tertiary time and in connection with the general uplift. In parts of the area the igneous rocks cut or uplifted Cretaceous formations as young as the Benton, and the fine-grained deposits of the Niobrara and Pierre in the region indicate that there was no interruption in the sedimentation until the later part of Cretaceous time. As fragments of all the igneous rocks occur in the early Oligocene deposits, they were evidently intruded prior to the Oligocene.

Oligocene fresh-water deposits.—Clays and sands of the White River group were laid down by streams, most of them very sluggish, and in local shallow lakes and bayous and finally covered the country to a level now high up the flanks of the Black Hills. That there was volcanic activity at this time is shown by the occurrence of a large amount of volcanic ash in some of the deposits, but the location of the volcanic vents is an enigma. Erosion has removed the White River deposits from most of the higher parts of the Black Hills, especially along their western side, but in the vicinity of Lead and Deadwood outliers remain at an altitude of more than 5,400 feet, and on the north end of the Bear Lodge Mountains the White River beds lie 800 feet higher. In many places on the slopes of the uplift there is clear evidence of superimposition of drainage, owing to a former capping of White River deposits.

Middle Tertiary mountain growth.—After the Oligocene epoch the dome was raised somewhat higher, and the uplift was followed by extensive erosion. No representatives of the Arikaree (Miocene) and Ogalalla (Miocene and Pliocene) formations have been recognized in the immediate vicinity of the Black Hills, but they constitute Pine Ridge, farther south, and small remnants cap high buttes in the northwest corner of South Dakota. Probably slow uplift continued, and much

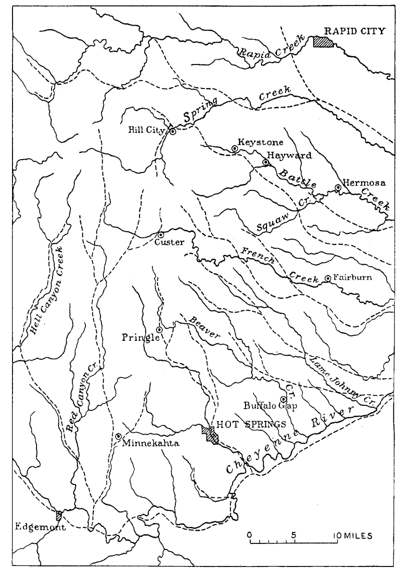

FIGURE 39.—Drainage map of the southern part of the Black Hills, showing the courses of some early Pleistocene streams. By N. H. Darton.
Broken lines show approximate courses of the older streams.

material was eroded from the higher slopes of the Black Hills, but most if not all of the detritus was carried far away, or if it was deposited in this region it was removed by erosion.

Quaternary uplift and erosion.—During the early part of the Quaternary period there was widespread erosion of the preceding deposits, and although many streams were revived in old valleys there was rearrangement of some of the drainage on the eastern side of the Black Hills, caused mainly by increased tilting to the northeast. In this rearrangement several streams that flowed on Oligocene deposits cut across old divides, and in some places connected a valley with its neighbor on the north. Such streams now flow southeastward for some distance in pre-Oligocene valleys and then turn abruptly northeastward into canyons of post-Oligocene age, leaving elevated saddles which mark the continuation of the old valleys

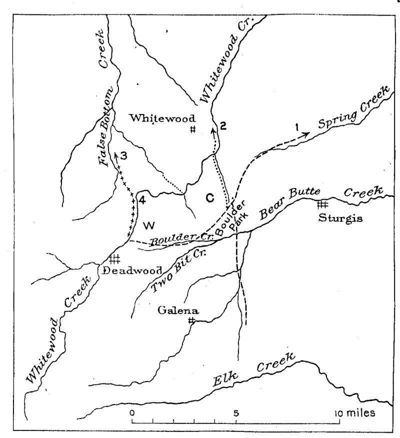

FIGURE 40.—Drainage map of a portion of the northern Black Hills, showing the courses of some early Pleistocene streams. By N. H. Darton.
C, Crook Mountain; W, Whitewood Peak. Lines 1, 2, 3, and 4 show progressive courses in the order given of parts of Whitewood Creek.

to the southeast. (See fig. 39.) Some of the offsetting in the present drainage has been largely increased by early Quaternary erosion and the recent capture by one stream of the tributaries of another. (See fig. 40.) Mansfield[24] has given some

[24] Mansfield, G. R., Post-Pleistocene drainage modifications in the Black Hills and Big Horn Mountains: Harvard Coll. Mus. Comp. Zool. Bull., vol. 49 (Geol. ser., vol. 8), pp. 61-76, 1906.

interesting information concerning the older drainage lines in the region northeast of Deadwood.

Apparently there was slight additional uplift in late Quaternary time, for the present valleys, which are below the level of the earlier Quaternary high-level deposits, seem to be cut more deeply than they would be in grading their profiles to the level of Missouri and Cheyenne rivers. Wide, shallow valleys have been formed in the soft deposits and canyons of moderate extent and depth in the harder rocks. Later erosion progressed with but little local deposition, but in some places the shifting of channels has caused accumulations of local deposits on small terraces at different levels.

ECONOMIC GEOLOGY.

The following account of the metalliferous mineral resources of the Black Hills is based in part on work done by J. D. Irving and S. F. Emmons in 1899,[25] and in part on observations made by Sidney Paige in his areal mapping in 1913 and 1914. A detailed study of the Algonkian rocks and special investigations of the Homestake mine in 1920 and 1922 by Mr. Paige have afforded data for the new conclusions here set forth regarding the structure and origin of the Homestake ore body. Information regarding deposits of tin, mica, tungsten, and lithia has been obtained mostly from published reports by Hess and Zeigler.

METALLIFEROUS DEPOSITS.

By Sidney Paige.

The metalliferous deposits of the Black Hills are classified as follows:

- Gold ores:
  - Deposits in Algonkian rocks:
    - Homestake ore body.
    - Quartz veins.
    - Mineralized shear zones.
    - Mineralized replacement lodes.
  - Deposits in Paleozoic rocks:
    - Refractory siliceous replacements:
      - Deposits in dolomites of Deadwood formation.
      - Deposits in Pahasapa limestone.
    - Fossil placers.
  - Deposits in Tertiary porphyry.
  - Recent placers.
- Lead-silver ores:
  - Deadwood formation.
  - Pahasapa limestone.
- Tungsten ores.
- Tin ores.
- Copper ores.

GOLD ORES.

DEPOSITS IN ALGONKIAN ROCKS.

The gold ores in the Algonkian rocks of the northern Black Hills for a long time yielded about 90 per cent of the metal produced in the region, but since 1890 the output of gold from the Deadwood formation has increased considerably.

HOMESTAKE ORE BODY.

HISTORICAL SKETCH.

The Homestake ore body was discovered in 1876. The outcrops consisted of ledges of iron-stained metamorphic rocks, which in places carried as much as $16 in gold to the ton but were generally of much lower grade. The outcrop zone, about 2,000 feet wide and about a mile long, extends from Lead a mile northwestward across Bobtail and Deadwood gulches to Sawpit Gulch, beyond which it passes beneath the Deadwood formation. In 1877 a number of companies were formed to work the ground, among them the Homestake, Highland, Deadwood-Terra, and Father de Smet. All these companies finally came under the control of the Homestake Mining Co., which has operated the property with great success.

Development.—The first workings were open cuts on the sides of Bobtail and Deadwood gulches and great pits or "glory holes" on the Caledonia claim and on the north branch of Gold Run Gulch between the Homestake and the Highland shafts.

The general ore zone strikes about N. 30° W. and dips eastward, but the ore body pitches southeastward, so that its bottom was first reached in the northernmost claims. Work in the Columbus mine, on Sawpit Gulch, was stopped so long ago that the only fact now ascertainable concerning the ore bodies is that they had the same dip and strike as those of the Homestake. The Father de Smet mine was worked only to about the 300-foot level, whereas the Homestake mine, at the south end of the belt, has been developed to a depth of 2,000 feet, and the Ellison shaft has been sunk on the south side of Gold Run Gulch, considerably south of the last outcrop of ore. Owing to the large size of the ore body, the output of the mine has steadily increased, and the capacity of the mill has been enlarged from 180 stamps in 1878 to more than 1,000 stamps in 1924. The ore has been of low grade, yielding less than $10 a ton in the first years and barely half that amount with increase of depth and with the adoption of the practice of breaking down large faces without sorting. Most of it has been free-milling and the total cost of mining and extraction has been less than $2 a ton. About 70 per cent of the gold was caught by amalgamation and the remainder extracted by cyaniding. The total recovery was about 95 per cent. The fineness of the bullion averages about 0.76. Formerly, when more surface ore was mined, it was a little more than 0.80. The impurity is largely silver (18 per cent).

Production.—According to the published reports the cost of operations and plant, except an original stock assessment of $200,000, has been paid out of the earnings. The 5,685,771 tons of ore that was milled from 1878 to June 1, 1900, yielded $31,190,083 in bullion, of which $8,668,750 was paid in dividends.

From June 1, 1900, to December 31, 1922, the mine value of the ore milled was $182,019,256, and the dividends amounted to $43,802,724.

GEOLOGY.[26]

General features.—The Homestake ore body is a replacement deposit in closely folded pre-Cambrian carbonate-bearing schists, and its form is due in large measure to this fact. The ore body conforms in the main to a group of beds whose principal structural features comprise a major anticline and a major syncline, which are separated by a zone of intense shearing. Many minor folds are superimposed on both the major flexures. The great ore body, so far as developed, lies within the major anticline east of the shear zone. These relations are shown on the accompanying geologic map. (See also fig. 41.)

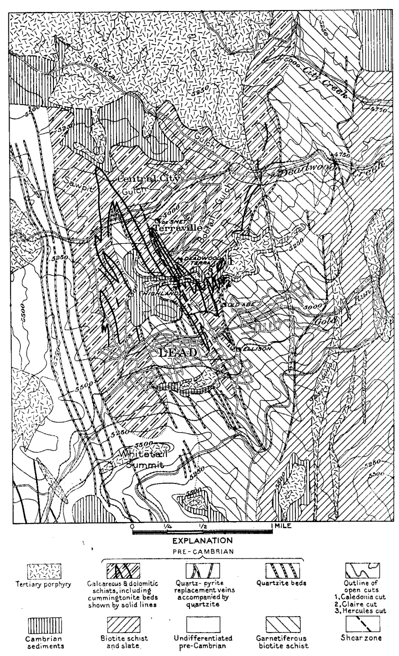

Figure 41.—Detailed geologic map of the vicinity of Lead. By Sidney Paige.

This map differs somewhat from the colored areal-geology map in the folio because it embodies new data obtained since that map was printed.

The rocks.—The pre-Cambrian schists near the mine have been divided into three main members and several minor beds, which are defined on the map showing the areal geology of the Lead quadrangle. The highest member stratigraphically, which is the one that lies farthest east, is composed of biotite slates and schists. Beneath this lies a second member containing more abundant garnet. These two members are separated by a thin bed of quartzite, which is accompanied by graphitic slate, pyrite, and much secondary quartz, forming what is locally termed "the iron dike," which is indicated on the areal-geology maps and on Figure 41 as a quartz-pyrite replacement vein. It weathers to a siliceous limonitic gossan. Beneath the garnetiferous schist member and separated from it by a number of beds of quartzite lies the third member, the schists of which contain large amounts of carbonate. These carbonate schists are of many varieties and in addition to different amounts of iron, magnesium, and calcium carbonates contain biotite, sericite, phlogopite, chlorite, amphibole, garnet, quartz, sulphides, and gold. These rocks are well exposed in the railroad cut opposite the mouth of Blacktail Gulch, on Deadwood Creek, and they appear also in Bobtail Gulch at Terraville and in Deadwood Gulch in the vicinity of Central.

A highly metamorphosed bed, which crops out in Deadwood Creek a short distance below the mouth of Blacktail Gulch and which can be traced, though interrupted along its strike, to the Homestake open cut and thence into the mine, is peculiar in that it contains many small flat lenses and bands of sugar-grained quartz set in a compact matrix of amphibole and garnet. This rock is the principal ore bearer of the Homestake lode system. The amphibole is the iron-magnesium variety, cummingtonite, and the garnet is a lime-iron-aluminum garnet. This bed is the metamorphic equivalent of a sideritic dolomite. The rocks involved in the ore zone belong to the carbonate series. A second similar bed occurs a short distance lower stratigraphically. It can not be traced so far as the first, but in the upper workings of the mine and on some lower levels there are two or more of these beds. Many specimens of ore and wall rock were collected, and some were examined with a microscope and analyzed. Some features of a few typical specimens are noted below.

At the extreme north end of the ore body, on the surface in the De Smet open cut, some ore remained unmined in the trough of a minor synclinal fold. This rock is dark green to black and rather massive and micaceous. With the microscope abundant carbonate can be seen as cloudy patches set in a groundmass of quartz and green mica. The border of many of these patches has altered to a brownish-red mineral (limonite?). On analysis this carbonate proves to be magnesium and iron carbonate. The matter soluble in acid consisted of MgO, 2.6 per cent; Fe_2O_3, 23.9 per cent; and CO_2, 7.2 per cent, which would form $MgCO_3$, 5.4 per cent; $FeCO_3$, 11.5 per cent; and Fe_2O_3, 16.0 per cent (as limonite). No calcium or manganese carbonate was found. No doubt this magnesium-iron carbonate is an integral and original part of the rock, which before its metamorphism was a dolomitic or sideritic sandstone. It is the ore carrier of the De Smet ore body of the Homestake mine.

A bluish-banded calcareous schist on the 300-foot level at the B. & M. (Old Abe) shaft is made up dominantly of carbonates and abundant chlorite, some mica, some amphibole, and subsidiary quartz. It contains $CaCO_3$, 5.5 per cent; $MgCO_3$, 9.6 per cent; $FeCO_3$, 4.7 per cent; and Fe_2O_3, 28.3 per cent (as limonite). In this specimen, as in many others, the mica and amphibole clearly replace carbonate in a bed that was originally a dolomitic iron-bearing carbonate rock. Another specimen, collected at the edge of the ore body on the 300-foot level, is a siliceous schist but contains layers of carbonate.

The more highly metamorphic varieties of these carbonate rocks are typified by the "80-foot" ledge on the 400-foot level, a bed that lies west of the main ore body and west of the footwall shear zone but that is typical also of the highly metamorphic beds found east of the shear zone. This bed shows an abundant development of cummingtonite and green mica enmeshed in a groundmass of quartz and subsidiary feldspar. Residual carbonate can be seen with the microscope and also well-developed characteristic fan-shaped growths of cummingtonite. It is significant that at some places the carbonates contain no calcium.

Another specimen, from the small Independence ledge on the 300-foot level, illustrates the growth of cummingtonite even more clearly than the specimen last described. At this locality the Independence ledge plunges southeastward as if it formed the nose of an anticlinal fold. In a specimen collected near the western wall rather scant patches of carbonate are interspersed with the quartz between blades of cummingtonite. At other localities the cummingtonite occurs as bands in carbonate-bearing schists. Thus there is no reason to doubt that this almost complete replacement differs from other replacement only in degree. The cummingtonite has replaced not only the carbonate but also much quartz.

Many similar examples were found, which, together with the results of other partial analyses of carbonate rocks either from the ore bodies or near them, prove that abundant carbonate forms an integral part of the ore-bearing series.

Structure.—The Homestake ore bodies lie entirely within metamorphosed sedimentary rocks; they are not associated with pre-Cambrian igneous rocks. They are no doubt underlain by granite, for they contain much quartz in veinlets and masses. To explain the structure of the Homestake ore bodies it is therefore necessary to rely wholly on the principles that govern the metamorphism, folding, faulting, and mineralization of a series of sedimentary rocks. A study of the field relations here and in other regions proves conclusively that where deeply buried rocks are highly compressed a system of folds is developed which has certain well-known characteristics; the major folds carry secondary folds upon their flanks, the secondary folds carry a third system, and the third system carries a fourth. In their larger as well as in their minor features all these folds show notable resemblances. They are generally thicker at their crests and troughs than along their flanks. They develop cleavage across the bedding of the strata

[25] Irving, J. D., Emmons, S. F., and Jaggar, T. A., jr., Economic resources of the northern Black Hills: U. S. Geol. Survey Prof. Paper 26, 1904.

[26] For detailed description see Paige, Sidney, The geology of the Homestake mine: Econ. Geology, vol. 18, pp. 205-237, 1923; Geology of the region around Lead, S. Dak., and its bearing on the Homestake ore body: U. S. Geol. Survey Bull. 765, 1924.

at the turns of the folds nearly at right angles to the axial plane of the fold. Soft beds are more likely to fold than hard beds, which may rupture and be pulled apart for long distances. All these features may be studied on the small folds, some of them may be observed on the intermediate folds, and others may be inferred with respect to the major folds after field study.

To decipher the intricacies of the folds near Lead it was necessary to trace on the surface a number of definite beds and to follow the folds of these beds underground in the mine. Although the pre-Cambrian rocks are invaded by Tertiary porphyry and their outcrops are concealed in places by Cambrian beds, the position of the major folds and of many of the minor folds could be ascertained. The axis of a major anticline was thus found to pass southward through Central City and to swing southeastward near Lead. West of this anticline lies a major syncline, which has a southeasterly trending axis, and west of this syncline are other major folds, the details of which have not been mapped. The lowest rocks stratigraphically that are exposed in the major anticline are the impure calcareous and dolomitic schists and slates in Deadwood Gulch. There the westward dips on the west limb of the anticline may be observed, but these dips give way to the prevailing steep easterly dips opposite the De Smet cut, on the northernmost extension of the Homestake ore body. The relative position of the open cuts of the Homestake system of ore bodies (see fig. 41) is suggestive of the structure that determines their position. For example, the Caledonia ore body (No. 1, fig. 41) is formed by a tightly compressed double fold, which involves massive beds of cummingtonite schist. The beds involved in the Caledonia open cut are the same as those that may be observed in Deadwood Gulch, and they may be traced, though interrupted, beyond the Caledonia cut to the Claire cut (No. 2, fig. 41), from which they pass by folding to the Hercules cut (No. 3, fig. 41). From the Hercules cut a prominent layer of cummingtonite schist can be traced directly into the great open cut, where it becomes involved in a number of anticlinal and synclinal folds, which determine the shape and position of the several remaining ore bodies. The separate ore bodies are the Old Abe ore body (unimportant except for the light it throws on the structure), the Incline ledge, the Pierce ledge, the Main ledge, and the De Smet ledge, which is really an integral part of the Main ledge. The structure on the 300-foot mine level is shown in Figure 42.

If the disturbance produced by the Tertiary porphyry and faulting is disregarded and the fact that the dolomitic schists do not everywhere contain ore is considered, the major features of the structure become clear. From the Old Abe ore body the cummingtonite-bearing beds pass by way of a double fold, first synclinal and then anticlinal, into the synclinal fold that forms the Incline ore body. From this ore body the beds pass to the Pierce ore body, a tightly compressed anticlinal fold, and farther on they pass to the main ore body, consisting of a number of closely compressed synclinal and anticlinal folds, which on their western side are involved in a shear zone. West of this zone these beds again appear in the major syncline and at a number of places are mineralized. If the ore bodies are viewed as mineralized portions of a series of folded beds of definite stratigraphic position and known chemical composition most of their characteristics may be readily explained.

The ore is invariably found either at a horizon immediately under that of the quartzite or a short distance below it. The beds above the quartzite, chiefly garnetiferous schists, are everywhere barren of ore. The carbonate beds beneath the quartzites, however, particularly the cummingtonite rock, almost invariably accompany the ore; in fact, at most places they form the so-called ore-bearing ledges. Chlorite schists and slates associated with the more highly carbonate rocks carry gold and are mineralized in places, but the series of metamorphic rocks that contains calcium, magnesium, and iron is the series that bears the ore.

The typical structure of a mine level is illustrated in Figure 42, which shows in a general way the position of the several ore bodies on the 300-foot level and the folds in which they are involved. On this level all the ore bodies appear, and if they are plotted as connected the plot shows that the ore-bearing beds are folded. For example, the suggested connection of the Old Abe ledge northwestward and northward with the Caledonia is very clear. The Caledonia terminates to the north in a very sharp synclinal fold. This feature is more clearly shown on other levels.

The main portion of the ore body shows an alternation of barren horses and connecting ore-bearing beds, as is indicated by the dotted lines. The upper line (stratigraphically) represents approximately the position of the base of the barren quartzite series; the lower line (stratigraphically) represents the approximate base of the cummingtonite series—that is, the beds that make ore. The Incline ledge is much broken by porphyry. The De Smet ledge is formed by the single limb of a closely appressed syncline cut on the west by a shear zone. The Independence ledge, before shearing occurred, was probably connected with the De Smet ledge. The connecting bed is now drawn out and pulled apart. There is evidence that the Independence ledge is anticlinal. Thus the ore body, in plan, takes on distinctly the appearance of a group of connected synclinal and anticlinal folds.

The ore.—The ore of the Homestake lode invariably carries sulphides, which are generally abundant in the best ore. The sulphides, named in the order of their introduction, are arsenopyrite, pyrrhotite, and pyrite. Gold is associated with each of these minerals—that is, it occurs in them or in gangue minerals near by. The sulphides have replaced portions of the carbonate schist series so that the deposit is not a vein nor a series of sheeted veins but is distinctly a replacement lode. The distribution of the sulphides conforms, in the main, to the schistose structure of the rock, and in many places the sulphides have replaced original carbonate minerals. They follow bedding planes and lines of schistosity. Their general appearance might suggest that they had been intensely compressed and folded with the gangue minerals, and this is partly true, though the evidence suggests that they were introduced before the final stages of the metamorphism. Arsenopyrite characteristically develops with crystal faces and replaces the body of the rock irrespective of the rock-forming minerals. Subsequent compression and movement have broken these crystals, and pyrite has been deposited on their edges, rounded by attrition, and in cracks in the crystals. Nowhere was arsenopyrite observed cutting pyrite or pyrrhotite, which shows that arsenopyrite is the oldest. Evidently it was introduced at a late stage of the metamorphism of the schists and was partly deformed. Soon afterward pyrrhotite and pyrite were introduced. Pyrite is later than pyrrhotite because it replaces pyrrhotite, occurs as veinlets cutting pyrrhotite, and fills angles in groups of crystals of pyrrhotite. Of special interest in this connection is the discovery that there are two generations of pyrite, as indicated by veinlets of pyrite of the second generation cutting pyrite grains of the first generation.

Age of the ore.—The Homestake ore is of pre-Cambrian age, though it was probably enriched in Tertiary time, when gold was deposited in the overlying Cambrian beds.

The pre-Cambrian age of the Homestake ores is shown by the mineralogy of the ores and the association of the gold, by the character of the gold, by the pre-Cambrian shearing of the ore bodies, by the presence of Cambrian placers, and by the relation of Tertiary porphyry to the Homestake ore. These features are epitomized below but are more fully considered in recent publications by the author.[27]

The principal sulphides of the Homestake ore, named in the order of their introduction, are arsenopyrite, pyrrhotite, and pyrite. Gold is associated with all these sulphides. Pyrrhotite, which is abundant in the Homestake ore, is absent in the Tertiary ores, and there is evidence that much gold was introduced with pyrrhotite.

The gold of the Homestake ore is relatively coarse as compared with the gold of the Tertiary ores, and 70 per cent of it is caught by amalgamation. The gold of the Tertiary ores occurs principally as telluride, and these ores must be treated by cyaniding. There are practically no tellurides in the Homestake ores.

The Homestake ores within the principal shear zone that limits the main ore bodies on the west are folded and sheared. The shearing was undoubtedly the result of compression during pre-Cambrian time. The sulphides and gold that suffered this disturbance must be pre-Cambrian.

It seems evident that the placer deposits in the conglomerate of the Deadwood formation were formed from the outcrops of the Homestake lode as the Cambrian seas advanced.

Tertiary porphyry has invaded the Homestake ores, has broken the continuity of the ore beds, and cuts across all pre-Cambrian structural features. After this porphyry had been injected, still in Tertiary time, solutions no doubt brought some gold to the Homestake ore, but the amount so introduced was probably very small as compared with that introduced in pre-Cambrian time.

[27] Paige, Sidney, The geology of the Homestake mine: Econ. Geology, vol. 18, pp. 205–237, 1923; Geology of the region around Lead, S. Dak., and its bearing on the Homestake ore body: U. S. Geol. Survey Bull. 765, 1924.

The origin of the ore.—The mineralization of the Homestake ore body is believed to have been an effect of the granitic invasion of the schists and to have occurred at a late stage in the metamorphism of the schists. Great quantities of quartz that is clearly of granitic origin are associated with the ores.

QUARTZ VEINS.

Characteristics.—Quartz veins cut the metamorphic rocks at many places, particularly in the region bordering the Harney Peak mass of granite and near Keystone. Most of the mines on quartz veins are now idle and inaccessible.

The Clover Leaf mine at Roubaix was examined by Irving, who found that the ore body is a large saddle-shaped mass of quartz in mica schist. Its crest strikes N. 64° W. and pitches to the southeast at an angle of 40°. At the 250-foot level it has the form of the letter U, with slightly flaring arms, which converge abruptly. The northern arm, which is 20 feet in average width, strikes N. 40° W., and the southern arm, which is 10 to 12 feet wide, strikes S. 75° W. This quartz body is thickest at its crest, and the lamination of the inclosing schist is parallel to its surface, curving around so that the body resembles a folded lens at the crest of a southeastward-pitching anticlinal fold. The quartz and schist carry much pyrite, which is completely oxidized at the surface. The gold in the quartz was free and most of it was associated with galena. Ore from the pay streak, which occurred in the southeastern or thickest part of the quartz body, consisted of a matrix of milk-white quartz carrying streaks and patches of galena that completely surrounded small nuggets or grains of gold, some of which showed crystal faces. The ore was amalgamated and was said to have yielded from $40 to $400 a ton. The silver content was very small.

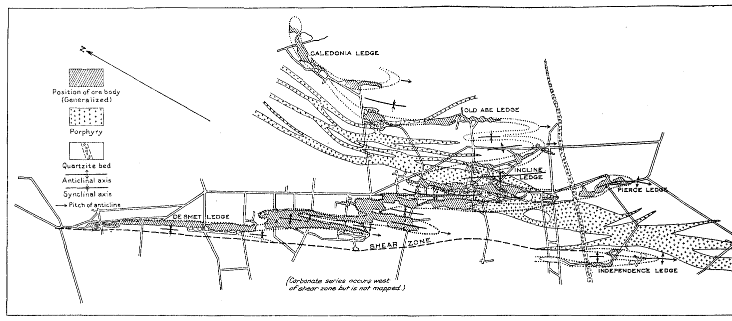

FIGURE 42.—Generalized plan of the 300-foot level of the Homestake mine, showing structure of the ore body.

At the Summit mine, 2½ miles east of Hill City, a quartz vein cutting biotite schist crops out for about 300 feet along an eastward-trending course and dips about 45°. Underground it is flexed in a syncline, which trends northwestward and pitches 12° SW. The ore body is said to have been 600 feet long, 40 feet high, and from 6 inches to 6 feet thick. Free gold was irregularly distributed through it, but in places the ore was very rich. At the Forest City mine, 4 miles east of Hill City, a similar vein, which ranges in size from a stringer to a body 6 feet thick, strikes north and south and dips 50° W. but is cut off by a fault at its north end. A pegmatite dike cuts the vein and also follows it.

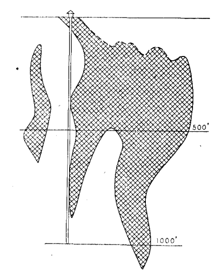

FIGURE 43.—Section of ore shoots in Holy Terror mine, near Keystone.

Several quartz veins have been worked at Keystone, but none of the mines is now accessible. The Holy Terror mine at Keystone, which was opened in 1894 and worked for about 10 years, was the principal producer; its output was valued at about $200,000. The vein cropped out for about 70 feet from north to south and was 4 to 28 inches wide. The most profitable mining was done at a depth of 200 to 700 feet, below which the vein narrowed to the 1,000-foot level, where, according to reports, an accident and excessive water discouraged further mining. A section by L. D. Huntoon, given in Figure 43, shows that there are two ore shoots—a small one, which was not mined below the fifth level, and a much larger one, which descended to the seventh level. Many assays of ore mined above the sixth level showed an average of $40 a ton, but as the total average was said to have been $20 the ore must have decreased greatly in value below the fifth level. East of the Holy Terror vein are the Keystone and the Bullion veins. The Bullion is apparently a quartz filling that carries sulphides and follows a diorite dike. It was explored by a tunnel 1,100 feet long, which yielded only two carloads of ore. Several other veins have been worked in the vicinity, among them the Bismarck and the Egyptian.

At Keystone some prospecting has been done on a northwestward-trending shear zone that is associated with a metadiorite dike, which carries quartz and gold. At Glendale, 2½ miles southeast of Keystone, a little silver-bearing galena has been found in narrow, irregular quartz veins. A group of narrow quartz veins that cut the schist in the hills between Kelly and Sunnyside gulches, about 2 miles N. 35° W. of Silver City, has been prospected by a shaft and tunnel. One vein in the tunnel ranges in width from 2 to 30 inches and carries irregular bunches and streaks of a lead-antimony sulphide (probably jamesonite), arsenopyrite, pyrite, a little sphalerite, and free gold in a gangue of quartz. Other similar veins to the east have been prospected, but they thicken and thin irregularly. Except where rich ore is in sight such veins offer little or no encouragement for development.

Origin of the veins.—In the description of the relations of the granite mass at Harney Peak the intergradation between quartz veins and pegmatite dikes was pointed out, and this relation has been observed in other regions. It is therefore believed that most of the quartz veins in the Black Hills are genetically connected with the granite and that their form and relations indicate approximately the time and manner of their formation. Some quartz veins follow the schistosity of the metamorphic rocks, but most of those which cut across the schistosity are nevertheless folded. This relation indicates that schistosity existed, in places at least, before the veins were formed and that they were subsequently deformed. Such veins as the one at the Clover Leaf mine at Roubaix filled open spaces on the crests of minor folds. Probably these spaces were formed slowly and could not remain open through a long period of deformation when silica-bearing solutions were also present and ready to deposit quartz. The swelling and pinching of the veins indicate that they were formed while the inclosing rocks were in an unstable condition, probably during the period of intense deformation when the schistosity of the sediments was being developed and when granite was being forced into the schist body. The intrusion of the main mass of igneous rock was doubtless preceded by the infiltration of weak solutions of silica. Where cracks were made or distended by the advancing magma, quartz veins were formed, which were later pulled apart or folded by continued or subsequent deformation. The differential movement of beds during folding caused bulging along the crests of the minor anticlines, and saddle-shaped quartz veins were deposited in these slowly opening spaces. The continued encroachment of the magma resulted finally in the intrusion of pegmatite dikes, which cut the quartz veins.

MINERALIZED SHEAR ZONES CUTTING PLANES OF SCHISTOSITY.

A mineralized shear zone, 4 to 16 feet wide, marked by brecciation, cuts across the schistosity of the biotite-chlorite schists about 4½ miles northwest of Hill City. The zone trends northward, and the schistosity strikes N. 25° W. and dips steeply to the west. The material between the walls is crushed schist, which is cemented by sugar-grained quartz containing pyrite and filled with small lenses and veins of the same material. A little sphalerite and some free gold were noted. There are also larger veins of quartz, some as much as a foot thick, and small veinlets of dolomitic carbonate. Several shafts and cuts reveal 10 to 16 feet of brecciated rock, and one of them is reported to show 10 feet of vein matter between well-defined gouges. The vein is said to average at least $2 a ton in free gold, and concentrates are said to run $90 or more to the ton. The deposit is a replacement of brecciated sheared slate by quartz and pyrite along a line of movement.

MINERALIZED REPLACEMENT LODES FOLLOWING SLATE ZONES.

Along certain zones of black slate, with which are associated narrow bands of quartzite, there are replacement veins of iron sulphide and quartz. Some of them are of considerable extent, but the amount of the mineralization and the value of the minerals differ greatly from place to place. Most of the veins are marked by iron-stained siliceous gossan, which in places projects as a sharp comb above the softer schists. This gossan consists partly of silicified slate, partly of pure-white ribbon quartz, and partly of iron oxides, in places more or less shattered into a breccia of contorted fragmental material cemented into a dense chertlike mass that resembles the iron-bearing cherts of the Lake Superior region.

Some of these zones have been mapped. One that is known as the iron dike extends from a point three-fourths of a mile west of Deadwood to a point half a mile south of Kirk, and there are several in the region between Roubaix and Glendale. Prospecting has proved that the veins contain pyrite and chalcopyrite, but unfortunately their gold content is very low. When siliceous refractory ore was being smelted near Deadwood, the Montezuma & Whizzers mine, half a mile west of Deadwood, produced iron pyrite from one of these veins, and years ago the gossan of a similar deposit at the Blue lode, 4 miles north-northwest of Keystone, was mined for copper. The gossan of these lodes consists of chalcedonic quartz, limonite, bands of pure quartz, more or less brecciated, and darker areas of silica representing replaced schist or slate. The dense chalcedonic quartz contains many vuggy cavities lined with botryoidal silica. In deeper workings in the mines above mentioned the dense siliceous iron gossan grades down into friable carbonaceous, siliceous, pyritic slates, which at some places contain thin beds of quartzite. Surface waters have dissolved the pyrite from the gossan and also the abundant silica, which was present both as an original constituent and as introduced ribbon quartz, but the silica has been redeposited as opaline silica from a solution that contained iron. Microscopic examination shows that the pyrite has been deformed since its deposition, and the deformation masks the criteria indicating whether it is an original or a secondary deposit. However, as these pyritic deposits occur along zones of movement indicated by the intense brecciation, as they are invariably associated with basic intrusive sills, and as the large accessions of silica have undoubtedly been derived from neighboring quartzites, they are probably epigenetic, and their origin is perhaps connected with the intrusion of the diorite.

DEPOSITS IN PALEOZOIC ROCKS.

By J. D. IRVING.

REFRACTORY SILICEOUS REPLACEMENTS.

DEPOSITS IN DOLOMITES OF DEADWOOD FORMATION.

GENERAL FEATURES.

A detailed report on the ores in the Cambrian rocks by Irving[28] was published in 1904. Since that time development has progressed somewhat, although many mines then productive are now idle. The tenor of most of the ore has declined, but more efficient mining methods and improved metallurgic practice have made available large bodies of low-grade ore. The principal companies operating in 1914 were the Golden Reward, the Trojan, the Mogul, and the New Reliance. Since the World War most of these mines have been compelled to close.

The refractory siliceous gold ores occur in an area extending from Yellow Creek to Squaw Creek. The productive districts are Bald Mountain, Lead City, Yellow Creek, Garden City, Squaw Creek, and Two Bit. The ore occurs mainly in the "sandrock" of the miners, a dolomitic limestone of fine-grained crystalline texture, imparted by small cleavage faces of dolomite. The rock includes layers of greenish-black shale, weathers red, and decomposes to a red earthy "gouge." Ore bodies have been found in Cambrian dolomite of this character principally at two horizons. One of these horizons, known as the "lower contact," lies immediately above the basal quartzite, from 15 to 25 feet above the Algonkian schists; the other, known as the "upper contact," lies from 18 to 30 feet below the so-called "worm-eaten" sandstone, the top member of the Deadwood formation. Other beds of dolomite at intervening horizons have yielded a small amount of ore at some localities. The ore is extremely hard and brittle and is composed largely of secondary silica. Where unoxidized it carries pyrite, fluorite, and in places gypsum, barite, stibnite, arsenopyrite, and wolframite. In one place uranium mica (probably the variety uranocircite) was noted. The ore occurs in flat banded masses, in which the banding is continuous with the bedding planes of the adjoining strata. These masses have a regular channel-like form and are associated with zones of fracture whose trend is uniform locally but whose general direction differs in different districts. These ore bodies, known as shoots, range in width from a few inches to 300 feet, but most of them are from 5 feet to 100 feet wide, and their average width is about 30 feet. They are much longer than wide, the length of the Tornado-Mogul shoot, for example, being about three-quarters of a mile. Their thickness ranges from a few inches to 18 feet, and the average is about 6 feet. They generally follow either single fractures or zones of parallel or intersecting fractures and are overlain by shale or by sills of porphyry. The floor of the "lower contact" deposits is the basal quartzite in places, but elsewhere more or less dolomite intervenes between the ore and the quartzite. Where the floor is dolomite the widest part of the shoot is directly beneath the impervious roof, for there the solutions would naturally spread and replace dolomite to the greatest width. For this reason the shoots have taken the form of a wedge, in many places with the broadest part at the top.

[28] Irving, J. D., Emmons, S. F., and Jaggar, T. A., jr., Economic resources of the northern Black Hills: U. S. Geol. Survey Prof. Paper 26, 1904.

THE FRACTURES.

In some workings the removal of ore reveals numerous fractures called "verticals," through which the mineralizers passed and which are made prominent by a slight silicification of the adjoining rock that commonly causes them to project from the softer shaly material. Many of them are also iron-stained. These fractures generally show slightly warped movement surfaces or they may be in zones consisting of many small irregular fissures interjoined. The vertical displacement along these planes is generally not more than 2 or 3 inches, but in some places it is as much as 6 or 7 feet. With some notable exceptions the fractures are without appreciable open space and generally they have opened less than one-sixty-fourth of an inch. Most of them are vertical or nearly so, and although some terminate in the ore body others extend into the roof. So far as observed they traverse all the underlying strata, but they are not traceable into the pre-Cambrian rocks below because they are lost in the vertical lamination of the schists. Some of the fractures that extend above the ore bodies die out in a short distance, but many of them seem to extend far up into if not completely through the Deadwood formation. On many of the fractures that pass through several beds of dolomite ore bodies occur in all the beds traversed. The fractures are closely spaced in groups, and each group is a productive area of siliceous ore. The spacing of the fractures in a group is generally irregular. At some places they form a close network in which the individual fractures can hardly be distinguished; at others they are separated by unmineralized areas 400 to 500 feet wide. As a rule the fractures in any group closely follow two or more directions, and the ore bodies trend accordingly. At intersections of the fractures there is little if any displacement. Along these fractures mineral solutions, which seem to have been confined by the overlying impervious rocks, have replaced the country rock with silica and pyrite. Where this replacement has proceeded along single fractures it has produced long, narrow ore shoots, not more than 20 feet wide, but where it has followed groups of closely spaced parallel or intersecting fractures the shoot rising from one fracture has coalesced with that rising from the one next succeeding.

Evidence as to the relative age of fractures and igneous rocks seems conflicting, as fractures intersect the igneous rocks in some places and terminate against them in others. Probably, however, the porphyry intrusions and the fracturing alternated within a single long period of time. The warping of the Deadwood strata doubtless was caused by movement along planes of lamination in the underlying schists, which elevated the overlying beds at some points and depressed them at others, causing torsional stresses that resulted in the fractures. The mineralization developed later.

PRODUCTIVE AREAS.

The Bald Mountain area, southwest of Lead, is the most extensive and productive one. In it the ore-bearing strata dip southwestward and pass beneath the younger limestone, which is penetrated by shafts. In the Ruby Basin district the larger shoots are on the lower ore horizon; in the Portland district they are in the upper beds. The easterly or Buxton-Union group of shoots in the Ruby Basin district lies on or close to the basal quartzite or is separated from it by sills of porphyry, and the strata are cut through by Fantail and Stewart gulches. The general trend of these shoots, as well as of those in the westerly or Alpha-Plutus-Mogul group, is north-northwest, but a few large intersecting bodies strike approximately N. 25° E. Several faults that cross the western group are described on page 18.

In the mines of Green Mountain and those near Trojan, included in the Portland district at the north end of the Bald Mountain area, the shoots, with the exception of the Dividend, lie in a series of upper ore-bearing beds, 527 feet above the schists. They trend generally N. 20°-45° E., and the most prevalent trend is N. 35° E. In the Garden City area, where the Deadwood beds dip northeastward, the shoots so far mined have been on the lower contact and trend about N. 55° E.

The ore bodies in the sandstone that caps the hills north of Deadwood extend over the gold lode of the Homestake mine. The Hidden Fortune is one of the mines that yielded very rich ore. This ore contains much barite, wolframite, and free gold. In the Yellow Creek area, 2¼ miles south of Lead, the ore shoots lie on the basal quartzite, 15 to 26 feet above the schist, and contain much wolframite and barite. Ore-bearing beds in strata just beneath the scolithus or "worm-eaten" sandstone have been prospected near the mouth of Squaw Creek, south of Little Crow Peak.

TENOR OF THE ORES.

In the Bald Mountain area the content of the ore varies greatly, but most of it has ranged from $10 to $20 a ton, and some of the Ben Hur ore yielded more than $60 a ton. In most places the "upper contact" ores are less rich than the "lower contact" ores, and the proportion of silver, although variable, is about the same in both. Changes in richness occur within short distances, especially in the "upper contact" ores, and in general the larger ore bodies are of lower but more uniform grade. The ores in the Yellow Creek, Lead, and Maitland areas have been generally somewhat richer than those in the Bald Mountain district.

ORIGIN OF THE ORES.

The refractory siliceous ores have been formed through the gradual replacement of the original rock by the ore minerals, which are chiefly silica and pyrite, with which occur varying amounts of gold and silver. In most places the process proceeded with so little disturbance that both the character and the minute structure of the original strata are preserved in the ore. The mineral replaced seems to have been dolomite exclusively, for where vertical fissures pass through rocks of different composition only the dolomite has been affected. The ore minerals have been transported by circulating waters, which rose through fractures traversing the comparatively insoluble rocks that underlie the dolomites. That the ore was carried by ascending water is indicated by the following facts: (1) The ore bodies generally lie immediately below impervious rock, such as shale or porphyry; (2) the dolomite has been most widely replaced in such places because the impervious material stopped the rising solutions and caused them to spread; (3) the replacement seems to have been proportional to the degree of confinement of the solutions, for where fractures are wide and extend without interruption up through the barrier rock there has been but little replacement, and shoots are narrow and confined to the immediate vicinity of the fractures.

The metals in solution were probably derived in part from the small amounts widely disseminated in the Cambrian and Algonkian rocks and in part from hot solutions given off by the porphyries at the time of their intrusion. The presence of fluorite in the ores suggests the latter source.

DEPOSITS IN PAHASAPA LIMESTONE.

By SIDNEY PAIGE.

The deposits of gold and silver ores in Pahasapa limestone are small, and few of them have yielded largely. In the limestone plateau northwest of Ragged Top Mountain there is a series of nearly equally spaced vertical fissures or veins, of which the principal ones strike N. 36°–59° E. These fissures range from minute crevices to bodies 10 feet wide. Below the zone of surface alteration the ore passes laterally into the limestone walls and except for its superior hardness and yellow tint is so like the limestone in aspect that it is difficult to distinguish ore from rock. Nevertheless, the line of demarcation, though somewhat undulating, is sharp. The mineralized zone narrows downward, so that at a maximum depth of about 60 feet the ore bodies thin out. Toward the surface the ore becomes increasingly broken, and at the top much of it consists of angular, brecciated fragments of silica, which has replaced the limestone. These ores consist almost entirely of silica, one analysis showing 96 per cent of this mineral. Tellurium has been detected in some of the samples. At some places, notably in the Metallic Streak mine, on the south side of Ragged Top Mountain, flat bodies of ore occur apparently as lateral enrichments from vertical bodies. This ore is of practically the same character but generally carries much brilliant purple fluorite. Ore from the Ulster mine, about 1 mile north of Preston, some of which assayed $2,000 a ton in gold, consists of irregular masses of silicified limestone with fluorite. It occurs in the Pahasapa limestone at its contact with porphyry. Irregular bodies of silicified limestone carrying small amounts of gold have been found at many other localities northward to Spearfish and Squaw Creek and southward toward Annie Creek. They are associated with fractures, some of which on Ragged Top Mountain have been traced downward more than 300 feet. If these deposits were formed by ascending solutions the difference in the character of the containing formation accounts for the difference in form between these and the siliceous ore deposits. The massive homogeneous Pahasapa limestone seems to lack features that would favor a concentration of ore at any particular horizon, whereas in the Deadwood formation impervious shale or sheets of porphyry caused the mineralization to spread outward from the vertical fissures at definite horizons.

GOLD-BEARING CONGLOMERATE AT BASE OF DEADWOOD FORMATION.

In most parts of the northern Black Hills the basal conglomerate of the Deadwood formation averages 3 to 4 feet in thickness, and locally it carries gold. About Lead, where it occurs in small outlying areas capping the divides, it ranges from 2 to 30 feet in thickness and has yielded a large amount of gold. At this place the underlying schists carry the great mineralized zone of the Homestake mine, which consists of very hard rock and was probably a reef at the time of the deposition of the conglomerate and a source of much of its gold. The gold-bearing conglomerate occupies irregular depressions in the surface of the schists and was not uniformly distributed along the old shore line. It thins out along the strike of the Homestake lode, where the higher strata overlap the old ridge formed by the lode. Outside of the area of this conglomerate most of the basal rock in this general vicinity is quartzite. The conglomerate consists of pebbles of quartz or quartz schist and fragments of mica schist, but these seem to decrease in abundance with increasing distance from the Homestake lode. Most gold-bearing portions of the conglomerate are cemented by pyrite, which weathers to oxide of iron, so that they are readily distinguished from the barren conglomerate, which has a quartzitic or in a few places a slightly calcareous matrix.

The pyrite was evidently introduced after the conglomerate was deposited, for it penetrates cracks in the pebbles, and it probably replaced an original silica cement. The intrusive bodies of rhyolite that cut the conglomerate are also somewhat impregnated by pyrite. Much of the gold in the richest conglomerate is detrital and was derived by erosion from the gold-bearing lodes in the pre-Cambrian rocks and mechanically deposited as placers in Cambrian time. Assays of ores from the Gentle Annie, Monitor, and Hawkeye mines indicated that they had been considerably enriched by gold introduced with the pyrite in the matrix, but a small and fairly uniform quantity of the gold is of detrital origin. The solution of the gold during the oxidation of the pyrite and its redeposition in thin films in the underlying schists has also enriched the lowermost layers of conglomerate. Much of the gold can not be extracted by amalgamation, so most of the conglomerate ore is cyanided.

Placer gold occurs in horizontal basal beds of the Deadwood formation 10 miles N. 80° W. of Hill City. These beds appear to lie in an ancient river channel, about 1,200 feet wide, and contain gravel composed of well-rounded quartz and quartzite pebbles, the largest several inches in diameter, cemented by clayey material. The deposit is about 40 feet thick at the center and merges into sandstone upward and laterally. The gold in the deposit occurs principally within 2 feet of bedrock, and most of the visible grains and flakes are on bedrock. The deposit is said to average $2 a ton, but as it is not free-milling the gold will probably be extracted by cyaniding.

DEPOSITS IN TERTIARY PORPHYRY.

By J. D. IRVING.

At several localities veins carrying ore have been found in Tertiary eruptive rocks and in brecciated schist and porphyry. Some of these veins extend from the porphyry into the Deadwood formation. Although none of the deposits is very productive, yet one in Strawberry Gulch and another near the mouth of Squaw Creek have yielded considerable ore.

In Strawberry Gulch are the Hoodoo, Gilt Edge, Jupiter, Dakota Maid, Union Hill, and other small mines, which have been worked intermittently. Much of the ore, some of it rich, occurs in thin sheets of auriferous limonite filling small fractures or impregnates a decomposed portion of a large intrusive porphyry body. In general these deposits merge downward into unoxidized pyrite, but at a few places sphalerite and galena have been found. In the Old Ironsides mine, near the mouth of Squaw Creek, the ore, apparently sylvanite, occurs in connection with vertical fractures in a 40-foot sill of mica diorite porphyry in Deadwood strata. Silicification has occurred along these fractures, and the ore has been introduced into the adjacent igneous rock and to a less extent into the Deadwood strata.

RECENT PLACERS.

By SIDNEY PAIGE.

The gold that made the Black Hills famous in the early days was obtained in placers at Deadwood. Many other gravel deposits in the valleys of the central part of the hills have yielded gold, and some of them are still productive. This gold was all derived from pre-Cambrian rocks, but part of it was probably liberated by the disintegration of gold-bearing strata in the base of the Deadwood formation. Many of the high-level gravel deposits on the east side of the Black Hills contain considerable placer gold.

LEAD-SILVER ORES.

By SIDNEY PAIGE.

REPLACEMENTS IN PALEOZOIC ROCKS.

Many years ago the mines near Galena produced considerable ore, notably the Richmond or Sitting Bull mine, but the district has had long intervals of inaction. The principal producing mines near Galena were the Richmond, Florence, Hester A, Coletta, Merritt No. 2, Cora, Carpenter, Alexander, Romeo, and El Refugio. The generalizations on this district which follow are based on information supplied by G. W. Tower.

The fresh ore, which consists chiefly of pyrite, argentiferous galena, and in places sphalerite, either occurs in massive bodies or is scattered more or less thickly through Deadwood strata. Much of the galena occurs in seams or as druses lining cavities in the pyrite, hence the galena is of later origin than the pyrite. Some of the pyrite carries a little gold, but the chief valuable constituent is the silver contained in the galena. Most of the ores contain little silica, but the ore in the Florence and Richmond mines is intimately associated with much secondary silica. Through this silicified material argentiferous galena and pyrite are scattered in irregular bunches and stringers. The ore in this district lies in shoots or in long irregular lenticular bodies, which follow vertical fractures that traverse both the Deadwood strata and the intruded porphyry. Some of the fractures strike in one direction, usually constant in any single mineralized area, but in places there are intersecting systems. Displacement along the fractures is generally very slight, but in places it amounts to as much as 4 feet. The shoots range from small, scarcely perceptible seams to flat bodies 20 feet wide and from a few inches to 2 feet thick, and exceptionally 4 feet thick. Where the fractures are open the ore generally fills the space. The ore-bearing rocks consist of sandstone cemented by calcite and shaly limestone, presumably dolomitic. Most of the ore bodies lie in the uppermost layers, immediately below a cap of shale. Some of the fractures extend into these shale beds, others extend beyond them. In the Florence, Richmond, El Refugio, and Alexander mines the ore-bearing rock was near the top of the Deadwood formation, or about 300 feet above the schist. In the Carpenter and Washington mines the ore is contained in an impure sandy limestone about 100 feet above the schist, but in the Merritt No. 2, Cora, Hester A, Horseshoe, Comet, and Romeo it is contained in a calcareous sandstone that lies not more than 30 feet above the schist.

The silver content of these ores is very unevenly distributed; much of the ore from the Richmond (or Sitting Bull) mine was rich, some of it containing 2,000 ounces of silver to the ton, but most of the ore yielded only 6 or 8 ounces. The ores, like the refractory siliceous gold ores, follow vertical fractures and are chiefly replacements of the calcium and magnesium carbonates of the Deadwood strata. The mineralization was subsequent to the igneous intrusion, for in some places where the porphyry is cut by the fractures the sulphides extend into it.

REPLACEMENTS IN PAHASAPA LIMESTONE.

From 1885 to 1891 considerable silver and lead were produced at Carbonate, on Squaw Creek near its entrance into Spearfish Canyon. The rock is Pahasapa limestone penetrated by porphyry. The ore deposits were of two types, the first consisting of large, irregular bodies of lead carbonate merging into galena and occurring mainly near porphyry contacts, and the second of veins formed by the partial filling of crevices with galena, lead carbonate, and cerargyrite in connection with extensive replacement of the limestone by ferruginous jasper. A deposit of the first type, which was the chief source of silver, was worked most extensively by the Iron Hill mine, which followed the east side of a wide porphyry dike. Here also a large mass of vanadinite was found, and the minerals cerusite, cerargyrite, matlockite, wulfenite, pyromorphite, plattnerite, and atacamite were associated with the galena. A notable deposit of the second type was worked at the Seabury mine on an irregular crevice that strikes S. 85° W. and continues through the Iron Hill, Segregated Iron Hill, and Adelphi mines, and possibly to the Spanish R mine. The crevice ranges from 1 to 20 feet in width, and the sides consist of 2 or 3 feet of ferruginous jasperoid material, which replaces the limestone. Most of the cerargyrite formed a thin film covering druses of fine quartz crystals. The crevice itself was loosely filled with a soft ferruginous gougelike pinkish-red material, which contained gold. According to report large quantities of this ore were taken from the Seabury mine and from the west side of the porphyry dike in the Iron Hill mine. A series of shafts north of the Seabury mine was believed to be on another crevice, which had a strike of N. 74° W., and there are signs of still other crevices in the vicinity, none of which were productive.

TUNGSTEN ORES.

The occurrence of tungsten ore in the Black Hills has been described by Irving,[29] Hess,[30] and Ziegler,[31] from whose reports the following statements are condensed.

Wolframite has been mined from the Deadwood formation on top of the hill just north of Lead, where it occurs in irregular flat masses as much as 2 feet in thickness. One of these masses had an extent of 20 to 30 square feet. They occur in impure dolomite, in part very sandy, lying on the basal quartzite or conglomerate. Wolframite is a very heavy, dense black mineral with brilliant cleavage, resembling magnetite but heavier and with slightly brownish streak. In these deposits it represents a basic phase of the refractory siliceous ores with which it invariably occurs in intimate association. Some of it forms a rim around the outer edge of the siliceous ore shoots, even making a thin capping or partial envelope on the siliceous ore mass, a feature observed in the Harrison mine near Lead. Some margins of this kind are from 2 to 2½ feet thick,

[29] Irving, J. D., Economic resources of the northern Black Hills: U. S. Geol. Survey Prof. Paper 26, p. 163, 1904.

[30] Hess, F. L., Tin, tungsten, and tantalum deposits of South Dakota: U. S. Geol. Survey Bull. 380, pp. 131–163, 1909.

[31] Ziegler, Victor, The mineral resources of the Harney Peak pegmatites: Min and Sci. Press, vol. 108, pp. 604–608, 654-656, 1914. See also Runner, J. J., and Hartmann, M. L., The occurrence, chemistry, metallurgy, and uses of tungsten, with special reference to the Black Hills of South Dakota: South Dakota School of Mines Bull. 12, pp. 4–159, 11 pls., 1918.

but the capping is generally thinner. Wolframite is also scattered in irregular masses through the siliceous ore or occurs in lenses, stringers, and thin contorted layers in the partly silicified dolomite, notably in the Wasp No. 2 mine, in Yellow Creek. In the Two Strike mine, in the Yellow Creek area, it occurs in thin irregular layers replacing the uppermost and more calcareous portions of the basal quartzite. In general the ore is rather sharply separated from the nonmineralized country rock, but in places it merges into the country rock gradually, and the attendant silicification extends still farther. Most of the grains of wolframite in the ore are about one-thirty-second of an inch in diameter, but in some specimens they are much larger. Barite in radiating aggregates or in single tabular crystals is found in the ore, and the perfect development of these crystals shows that they are the earlier formed ingredients. Barite also fills some of the numerous cavities, such as are general in deposits that have originated from the replacement of one mineral by another. Parts of the surfaces of these cavities are coated with small but well-formed crystals of wolframite, not unlike marcasite in shape, and of yellowish or bright-green scheelite. Some specimens of the leaner wolframite from Yellow Creek show long, slender crystals of stibnite radiating from a common center.

Under the microscope the pure ore shows dense, opaque wolframite with the spaces between its crystal faces filled with clear glassy quartz. The lean ore, however, shows that the wolframite is made up of innumerable small crystals, which are generally well developed but interfere with one another at their extremities, and the many irregular spaces, invariably bounded by plane surfaces, are filled either with secondary quartz or with grains of original detrital quartz, about which later added silica has formed complete crystals. Scheelite occurs between the crystals of wolframite. Sections of ore at its contact with unreplaced rock show a moderately abrupt transition from massive wolframite to partly replaced material, with interlocking crystals, which gradually become more sparsely scattered until they finally disappear in the barren rock. Beyond the limits of the wolframite this rock is generally heavily silicified, and it shows the sharp outlines of irregular rhombs such as constitute the body of the usual type of unmineralized dolomite, the original carbonate having been replaced with such delicacy that its structure has been perfectly preserved.

Some wolframite has been found near Hill City, together with smaller amounts of scheelite, in part as an original mineral and in part as an alteration product of wolframite. The ore occurs in pegmatite dikes and quartz veins. In some of the veins north of Hill City the wolframite is intimately associated with cassiterite. In mines 5 miles southeast of Hill City the chief mineral is huebnerite, and ferberite occurs in pegmatite in a claim half a mile east of Hill City, where, according to Ziegler, the mineral occurs in veins of quartz that are 10 to 12 inches in average thickness but vary greatly. Some veins have been traced a thousand feet. The quartz is gray and pellucid and carries notable amounts of muscovite, a few blades of albite, needles of tourmaline near the contacts, and abundant minute flakes of graphite. The veins strike about north and dip steeply parallel with the schistosity of the inclosing schists. The wolframite is in bladed crystals, many of them 1 to 8 inches wide and grouped in irregularly distributed aggregates.

TIN ORES.

The following notes on tin deposits are taken from a report by Hess,[32] to which the reader is referred for the history of mining and detailed description of claims.

The mineral cassiterite, or tin oxide, occurs near Hill City, Keystone, Oreville, Custer, and some other places in the Black Hills. It has been mined to some extent but so far without profitable return. The deposits occur mostly in irregularly disseminated shoots in pegmatite dikes and in numerous quartz veins. Most of the dikes are 1 to 8 feet wide, but the Etta dike, near Keystone, is about 25 feet wide. The quartz veins are narrower than the dikes. In the dikes tourmaline, columbite, and tantalite are the principal constituents, but there are a large number of interesting accessory minerals, which O'Harra enumerates as follows:[33]

Albite	Graphite	Petalite
Almandite	Griphite	Rutile
Andalusite	Grossularite	Scheelite
Apatite	Heterosite	Scorodite
Arsenopyrite	Ilmenite	Sphene
Autunite	Lepidolite	Spinel
Barite	Leucopyrite	Spodumene
Beryl	Liebnerite	Stannite
Bismuth	Löllingite	Tantalite
Columbite	Melanite	Tourmaline
Corundum	Microcline	Triphylite
Cupro-cassiterite	Molybdenite	Triplite
Epidote	Monazite	Wolframite
Galena	Olivenite	Zircon

[32] Hess, F. L., Tin, tungsten, and tantalum deposits of South Dakota: U. S. Geol. Survey Bull. 380, pp. 131–163, 1908.

[33] O'Harra, C. C., Mineral resources of South Dakota: South Dakota Geol. Survey Bull. 3, p. 64, 1902.

Tin mining was most active from 1884 to 1894, when considerable ore was taken out, but it yielded on milling very low returns, the aggregate production being estimated as less than 5 tons. Most tin in other parts of the world is obtained from lodes in granite or from placers, but there appears to be no reason why the deposits in pegmatites and quartz veins in the Black Hills or other places might not be valuable.

COPPER ORES.

Small amounts of copper ore have been found at several localities in the schist. On the east side of City Creek, near the crest of the hill northwest of Deadwood, there is a deposit consisting of thin films of native copper between the lamellae of graphitic schists. Another deposit, on top of the divide between Whitewood and Yellow creeks, consists of irregular masses of malachite and azurite and a little tetrahedrite in quartzitic schist. Other small deposits have been reported, but they have not proved valuable.

MICA.[34]

Several mica mines and prospects have been opened in the Black Hills, most of them within a radius of 10 miles of Custer, and others are on the northern side of Harney Peak. The principal production began in 1906, when the development of mines by the Westinghouse Co. raised South Dakota to second rank among the mica-producing States. After 1912, however, production declined greatly.[35] The mica is muscovite, and as it occurs in pegmatite as an accessory in the aggregate of feldspar and quartz, only a few dikes carry enough to make mining profitable. Most of the feldspar is orthoclase or microcline, though a plagioclase albite or oligoclase is found in some pegmatites, and locally plagioclase is predominant. The proportions of the minerals differ widely not only in different bodies but from place to place in the same body. Some masses are chiefly feldspar with small amounts of quartz and accessory minerals, and others consist mainly of quartz. The mica-bearing pegmatites around Custer contain a remarkably uniform mixture of feldspar and quartz. Other accessory minerals occur in the pegmatites of the Black Hills, including much tourmaline, some of it in very large crystals. Dikes north of Harney Peak carry columbite, cassiterite, and beryl and large crystals of spodumene.

The pegmatite differs in texture in different parts of the dike, ranging from a very coarse granite to a rock in which the constituent minerals are separated into large crystals, some as much as several feet across. These masses may be very irregular in shape or may be arranged in bands that are generally parallel with the walls and give the body a veinlike structure. The mica-bearing pegmatites around Custer tend toward an evenly granular texture or an irregular segregation of mineral masses rather than a banded structure. In many places, however, a roughly banded arrangement results from segregation of the mica crystals along one or both walls. The pegmatite bodies near Custer differ widely in shape and size. Some are sheetlike dikes several hundred yards long, others form lenses that are either short and thick or long and slender; some are conformable with the schistosity of the inclosing rock through part or the whole of their extent, others cut across it. In general the dikes range in thickness from less than an inch to many yards, and the length of the lenses may be from 2 to more than 20 times the thickness. Most of the dikes around Custer are from 8 to 25 feet thick, but near Keystone the mica-bearing pegmatites are in irregular stocks or lenses, some of them 100 feet thick. The mica is of good quality, and most of it is known as "rum" or "wine" mica because of its pale rose or brown tint. Most of the books are faulty in being "ruled"—that is, in having an extra cleavage nearly perpendicular to the basal cleavage so that the plates break into narrow ribbons—or in being wedge-shaped so that they split into wedge-shaped sheets. Practically nothing but scrap mica has been produced near Keystone. The individual mica books found near Custer are, as a rule, larger than those found near Keystone. The most productive mines have been the Lost Bonanza, Climax, White Spar, New York, McMacken (or Crown), Old Mike, Firestone, and Window Light, near Custer. Many other claims, including the Monarch, Last Chance, Warren, Crook, Christianson (now Hugo), Etta, Bob Ingersoll, Wood Tin, and Everly, near Keystone, have produced in smaller quantity. Sterrett gives detailed descriptions of the mines in his reports.

LITHIUM.

Lithium-bearing minerals abound in some of the pegmatites of the Black Hills. The following account of these minerals is condensed from a report by Ziegler.[36]

The chief lithium-bearing minerals are amblygonite, triphylite, griphite, spodumene, lepidolite, and petalite. Griphite, petalite, and lepidolite are not used, although lepidolite contains much lithia. Amblygonite is the most useful of these minerals, on account of its high content of lithia and the ease with which the lithia can be extracted. It occurs in nodules that weigh from 10 to 300 pounds. It is usually white and is not quite so hard as spodumene, is a trifle heavier, and is not so easily cleavable. It can readily be distinguished from the associated albite and oligoclase by its greater specific gravity. Most of the amblygonite produced has been taken from the Hugo, Peerless, and Bob Ingersoll mines, near Keystone; the Nichols mine, near Hayward; the Tin Queen, near Oreville; and the Bond mine, near Custer. The relations at the Hugo mine, southwest of Keystone, are typical. The deposit is a large oval body of pegmatite similar to that in the Etta mine and widens downward. At the contact with the schists there are generally streaks and masses of black tourmaline, regularly arranged, near which lie large pockets and shoots of coarse books of muscovite, which are mined for scrap mica. The mica gives place irregularly to coarse granite, which grades into giant pegmatite made up of large masses of feldspar and quartz, interspersed with pockets of coarse plumose aggregates of muscovite and with streaks of muscovite-quartz rock carrying cassiterite and columbite. One large mass of columbite weighed 100 pounds. There is much coarse pale-green and white beryl, blue apatite, pale-green micaceous masses of lepidolite, masses of triphylite, the largest of which weighed 60 pounds, and loglike crystals of spodumene similar to those at the Etta mine. The amblygonite at the Hugo mine occurs in the central part of the deposit as irregular nodules and pockets. Many of the masses weighed more than 300 pounds, and one shoot measured 15 by 22 by 40 feet. It occurs mostly in places where the masses of milk-white quartz carry triphylite, spodumene, and lepidolite, and where it lies near triphylite it generally contains more lithia than where it lies near spodumene. In this mine cassiterite, columbite, beryl, apatite, triphylite, and lepidolite were all saved. Some of the lithia in the amblygonite is replaced by soda, which diminishes its value considerably. In the Peerless, Bob Ingersoll, and Nichols mines the conditions of occurrence are similar, but the associated spodumene occurs only in small crystals. In the Bond mine, near Custer, the amblygonite deposit is smaller and occurs in a pegmatite dike that strikes nearly north. At the Nichols mine, near Hayward, it occurs in boulder-like nodules in a loose brecciated material immediately beneath the basal sandstones of the Deadwood formation, but it contains too much secondary iron oxide to be valuable. Apparently this material formed a surface deposit of boulders before the Deadwood formation was laid down.

Until about 1910 spodumene was the chief source of lithia, and about 1,400 tons of it was produced at the Etta mine, near Keystone, before it was displaced in use by amblygonite. (See Pl. VII.) Its value ranged from \$19 to \$40 a ton. The mineral occurs in huge crystals, is mostly white, rather hard, fairly heavy, and has strong cleavage. On weathering most of it becomes chalky white, and it disintegrates into a fine granular or splintery form, some being almost fibrous. Spodumene is abundant at the Etta, Bull Con, Swanzy, and Wood Tin mines, and at the Dyke Lode claim, near Keystone, and some occurs in the Hugo mine and the Equality lode, near Keystone, and in the Bond mine, near Custer. It is not being produced at present but will be utilized when the amblygonite deposits are exhausted. In the Etta mine the pegmatite in a zone at its outer contact consists of a coarse aggregate of alkali feldspar, quartz, and abundant muscovite and biotite, approaching typical granite in composition. Within a short distance this rock grades irregularly into giant pegmatite having a roughly zonal structure and consisting essentially of masses of milk-white quartz penetrated in every direction by huge crystals of spodumene, which together resemble a jumbled mass of logs. At a few places the crystals are arranged in star-shaped clusters. Many crystals attain a length of 30 feet and a thickness of 3 feet, and one was 42 feet long and 5 feet 4 inches thick. The best and largest crystals of spodumene occur on the east side of the deposit. Some are surrounded by fine scaly muscovite. Near the middle of this outer zone of pegmatite there are irregular aggregates of muscovite and quartz carrying moderate amounts of cassiterite and columbite in disseminated grains, large flakes of mica, some stannite, triphylite in nodules as much as a foot across, and small disseminated crystals of amblygonite, tapiolite, struverite, and cuprocassiterite. This central part of the outer zone contains considerable spodumene, but microcline, oligoclase, and quartz predominate. The feldspar is in large masses, some of them 7 feet across, together with large masses of pale-green beryl, aggregates of green scaly lepidolite, and lamellar albite.

Huge crystals of spodumene occur in the Hugo, the Dyke Lode, the Bond, and the Wood Tin mines, and smaller ones occur in the Bull Con and Swanzy mines, all under conditions similar to those at the Etta mine. Spodumene may contain 8.4 per cent of lithia, which, however, is generally replaced by soda, a series of samples assaying from 1.8 to 6.16 per cent of lithia.

[34] Sterrett, D. B., Mica deposits of South Dakota: U. S. Geol. Survey Bull. 380, pp. 382–397, 1909; Mica deposits of the United States: South Dakota: U. S. Geol. Survey Bull. 740, pp. 289–302, 1923.

[35] Ziegler, Victor, The mineral resources of the Harney Peak pegmatites: Min. and Sci. Press, vol. 108, p. 606, 1914.

[36] Ziegler, Victor, Lithia deposits of the Black Hills: Eng. and Min. Jour., vol. 96, pp. 1053-1056, 1913.

The triphylite is brownish black but is commonly coated with purple or deep-red purpurite. It has a submetallic to dull luster and poor cleavage. It occurs much like amblygonite but is more persistent. Nodules of triphylite as much as a foot in diameter are common, especially in the coarser pegmatites. Small amounts were taken from the Dyke Lode, northwest of Bismuth, and from the Lost Bonanza (now the Mica King) mine, about 1 mile south of the Etta mine. Like spodumene it has been superseded in use by amblygonite, but owing to its high content of lithia it will probably be utilized again when the deposits of amblygonite are exhausted.

Lepidolite occurs mostly in aggregates of mica-like layers but at some places in dense masses. It is white or of green, brown, lavender, and lilac tints, the lavender and lilac tinted varieties containing the most lithia. It is abundant at the Bob Ingersoll and Peerless mines, occurring at the former in irregular shoots, one of which, 2½ feet thick, is exposed for 5 or 6 feet. Some pale-lilac lepidolite occurs at the Bond mine, and the green variety is abundant at the Peerless, Hugo, and some other mines.

Griphite, a dark-brown to black resinous mineral known only from the Black Hills, occurs in the pegmatites in nodules and masses. It contains only a small percentage of lithia. Petalite, a massive pearly lithia mineral, is rare.

TANTALUM.[37]

Columbite and tantalite occur at many localities, mainly in association with the tin ore. A mixture of the minerals carrying an excess of columbium is the most common, and it has been obtained chiefly in mining spodumene. A demand for the mineral began with the development of the tantalum incandescent lamp, in 1904, but there was strong competition from richer ores from Western Australia, so only a few tons has been produced.

The columbite and tantalite appear to occur only in pegmatites, or in placers derived from them, and the largest masses are in the more coarsely crystalline rock. Some individual crystals are much larger than those of the associated cassiterite. In the Etta mine most of the crystals are embedded in the feldspar and associated with quartz, albite, muscovite, and beryl, or they may be wholly immersed in the beryl. Ilmenite and leucopyrite occur with the columbite and tantalite. The crystals grow into one another and inclose other minerals. They are tabular and range in width from a fraction of an inch to several inches, but they are somewhat longer than wide and comparatively thin.

W. P. Headden[38] has made a series of analyses of columbite and tantalite from the Etta mine and other localities, which showed Cb_2O_5 from 30 to 54 per cent and Ta_2O_5 mostly from 34 to 53 per cent, with a wide range in totals and of ratios in ores from the same dike.

STRUCTURAL AND OTHER MATERIALS AND MINERAL FUELS.

By N. H. Darton.

Gypsum.—The Spearfish red beds carry extensive deposits of gypsum, a mineral which is made into plaster of Paris by baking off most of its combined water and pulverizing the residue. Gypsum occurs in thick beds in most parts of the Red Valley on both sides of the Black Hills, and it has been quarried and burned at Sturgis, Piedmont, Blackhawk, and other places. Some of these enterprises, however, have not been profitable because of the long distance to market. The production in 1923, as reported by the State Mine Inspector, was 9,621 tons, valued at $76,968.

East of Spearfish a bed of gypsum, generally from 8 to 15 feet thick, crops out near the top of the Spearfish formation along the northern and eastern sides of Centennial Valley and extends thence through Whitewood, Sturgis, and Rapid City. At Sturgis it is 12 feet thick and north of Tilford 25 feet. From Whitewood Creek to Rapid City there is also a lower bed, about 100 feet above the base of the formation, which averages about 12 feet in thickness. The quarry at the plaster mill at Blackhawk exposes a 6-foot face of the lower gypsum, which from this place southward is the principal bed. West of Hermosa it is 15 feet thick, but it becomes thinner south of Squaw Creek and may be absent at places west of Fairburn. The gypsum is conspicuous in the vicinity of Fuson Gap and in Martin Valley, where it thickens in a short distance to 40 feet or more. It lies about 100 feet above the base of the Spearfish formation. An analysis of a representative specimen of the gypsum from this vicinity, made in the laboratory of the United States Geological Survey, is given below:

Analysis of gypsum from vicinity of Hot Springs, S. Dak.

[George Steiger, analyst.]

Lime (CaO)	32.44
Magnesia (MgO)	.33
Alumina (Al_2O_3)	.12
Silica (SiO_2)	.10
Sulphuric anhydride (SO_3)	45.45
Carbon dioxide (CO_2)	.85
Water (H_2O)	20.80
	100.09

[37] Mainly from Hess, F. L., Tin, tungsten, and tantalum deposits of South Dakota: U. S. Geol. Survey Bull. 380, pp. 131-163, 1908.

[38] Headden, W. P., Columbite and tantalite from the Black Hills of South Dakota: Am. Jour. Sci., 3d ser., vol. 41, p. 95, 1891.

The sample contains about 97 per cent of the pure mineral, and the appearance of much of the white gypsum at other places indicates that it is equally pure. A large quantity of gypsum crops out in the southwest corner of the area treated in this folio. In Hell Canyon and vicinity there are two beds, each 25 feet thick, near the top of the formation and a local bed 12 feet thick near its base. Near the north end of Elk Mountain there are two thick beds about 200 feet above the base of the formation, each 30 feet thick at places.

Fuller's earth.—A large part of the fine-grained deposits of the Chadron formation of the White River group consists of hydrous aluminum silicate mixed with other material. Much of it is fuller's earth, which is used for decolorizing oils and other substances. It differs from ordinary clay in being amorphous and spongy rather than plastic, and most of the water that it contains appears to be combined in a relatively definite ratio. Its economic usefulness, however, depends entirely upon its physical constitution and can be determined only by practical tests.

Large deposits of material of this character lie east of Hermosa and about Fairburn and extend far eastward into the Big Badlands. Much of it has the chemical and physical properties of fuller's earth, but the amount available for commercial use is unknown. There is also more or less of it in White River beds near Rapid and Deadwood. Several years ago it was mined 3 miles southwest of Argyle and 3 miles south of Fairburn, but the material shipped failed to yield satisfactory results, apparently because it was not excavated with care to exclude sand and dirt. Small samples from these places had all the characteristics of high-class fuller's earth and when tested with cottonseed oil and other materials gave excellent results. Further trials should be made of selected material, properly dried and pulverized. The following analyses show the chemical composition of some of the deposits:

Analysis of fuller's earth from the Black Hills, S. Dak.

	1	2	3	4	5	6
Silica (SiO_2)	68.23	60.16	56.18	55.45	57.00	58.72
Alumina (Al_2O_3)	14.93	10.38	23.23	18.58	17.37	16.90
Ferrous oxide (FeO)	3.15	14.87	[a]1.26	3.82	2.63	4.00
Lime (CaO)	2.93	4.97	5.88	3.40	3.00	4.06
Magnesia (MgO)	0.87	1.71	3.29	3.50	3.03	2.56
Loss on ignition	6.20	7.20	11.45	14.15	15.35	10.40
Alkalies (Na_2O+K_2O)						2.30
	96.31	99.29	101.29	98.90	98.38	98.45

[a] Fe_2O_3.

1. Material from pits just north of Fairburn.
2, 3. Material from locality 3 miles south of Fairburn.
4, 5. Material from Argyle mines.
6. Material from locality southeast of Fairburn.

Analyses 1 to 5 by Prof. Flintermann, of South Dakota School of Mines, Rapid City, S. Dak.

Analysis 6 by E. J. Riederer.

Cement materials.—Most of the limestones and shales in the Black Hills could be used for making Portland cement, and parts of the Niobrara formation contain calcium carbonate and clay in approximately the right proportions for this use. The excellent Portland cement manufactured at Yankton, S. Dak., is made from Niobrara chalkstone mixed with clay taken from the overlying Pierre shale. Information regarding cement materials on the west slope of the Black Hills is given by Ball and O'Harra.[39]

An analysis of Graneros shale from lower beds of the formation half a mile from the center of Rapid City indicates the following composition:

Analysis of Graneros shale.

[M. F. Coolbaugh, analyst, South Dakota School of Mines.]

Silica (SiO_2)	58.74
Ferric oxide (Fe_2O_3)	3.87
Alumina (Al_2O_3)	18.97
Titanium oxide (TiO_2)	.71
Lime (CaO)	.93
Magnesia (MgO)	1.62
Sulphur (S)	.21
Potash (K_2O)	1.49
Soda (Na_2O)	.58
Phosphorus pentoxide (P_2O_5)	1.44
Manganese oxide (MnO)	Trace.
Loss on ignition	11.93
	100.24

The following analysis of material from the Niobrara formation, obtained near Antelope Creek, 10 miles east of Tilford, is of interest:

Analysis of material from Niobrara formation.

[M. F. Coolbaugh, analyst, South Dakota School of Mines.]

Silica (SiO_2)	15.51
Iron and alumina oxide (Fe_2O_3, Al_2O_3)	5.80
Lime (CaO)	38.85
Magnesia (MgO)	1.08
Potash and soda (K_2O, Na_2O)	1.50
Sulphur (S)	Trace.
Loss on ignition (CO_2)	36.67
	99.41

[39] Ball, S. H., Portland cement materials in eastern Wyoming: U. S. Geol. Survey Bull. 315, pp. 232-239, 1907. O'Harra, C. C., Cement resources of the Black Hills: South Dakota School of Mines Bull. 8, 1908.

Fire clay.—Portions of the Fuson and Morrison shales are true fire clays, and the Fuson beds have been mined for that material to some extent in pits 2 miles south of Rapid City. The product proved satisfactory in the local smelter, and some of it was shipped to other places. A sandy bed of the Morrison shale was also worked for fire clay on the north side of Rapid Creek near the reservoir. It has been found that only certain portions of the Fuson shale are sufficiently refractory. The following analyses were made by R. A. Slagle at the South Dakota School of Mines:

Analyses of fire clays from Rapid City, S. Dak.

	1	2	3	4
Silica (SiO_2)	87.05	83.30	76.78	81.98
Alumina (Al_2O_3)	6.56	12.30	14.43	13.08
Ferric oxide (Fe_2O_3)	.64	.80	.18	.21
Lime (CaO)	.95	1.30	2.18	1.46
Magnesia (MgO)	1.24	Trace.	.95	.31
Alkalies (Na_2O, K_2O)	3.01		Trace.	Trace.
Loss on ignition	1.80		4.62	4.07
	101.25	99.40	99.14	100.86

1, 2. Samples of varieties tried at an earlier stage of experimentation.
3. Sample from middle Fuson beds on the eastern slope of the ridge; gave the best results.
4. Sample of soft clay from Rockerville Hill, which has been used for cementing the harder varieties.

In the region about Spring Creek, north of Sturgis, the Fuson formation consists largely of a white sandy clay which appears to be fire clay.

Pottery clay and brick clay.—Many of the shales above the Dakota sandstone, as well as those of the Fuson, Morrison, and Sundance formations, consist of clay that could be used for making pottery and tile. Sandy clay that could be used for making brick occurs along many of the alluvial flats, and it has been utilized for this purpose to a small extent, notably at Sturgis.

Volcanic ash.—Volcanic ash, such as occurs in the lower part of the White River group, is of value as polishing powder, and it is extensively mined in Nebraska, Kansas, and elsewhere for use as the base of abrasive soaps and cleaning powders. A 3-foot bed of ash of unknown extent is exposed in the fuller's earth mine 3 miles southwest of Argyle. The grains are small and of uniform size and have sharp cutting edges. An analysis is given on page 15. Ash is also exposed 8 miles southwest of Custer, near Fourmile Creek.

Bentonite.—Deposits of bentonite, a decomposed volcanic ash that forms a clay which will absorb three times its weight of water and which is used for decoloring oils and for other purposes, are found in this general region in the Graneros and Pierre shales. Only thin deposits have been noted in the area here considered, but thicker beds, of economic value, may yet be discovered. Some bentonite has been mined in the Pierre shale a few miles south of Buffalo Gap[40] from beds that may extend northeastward to or beyond the valley of Lame Johnny Creek.

Glass sand.—Some of the soft white sandstone of the Unkpapa formation is sufficiently pure for use in manufacturing glass.

Limestone.—Much of the limestone in the Black Hills can be used for lime or flux. The Pahasapa rock is extensively quarried and burned a short distance south of Pringle. An output of 13,500 tons is reported for 1923. Limestone from cliffs on Spearfish Creek at the mouth of Hellgate Gulch was found by George Steiger to contain 5 to 10 per cent of magnesia. A sample from the vicinity of Jewel Cave contained less than 1 per cent of impurities, including a trace of iron but no magnesia; the thick mass of limestone in Morrison shale near Sturgis is about 90 per cent pure; and the Minnewaste limestone, near Buffalo Gap, is 92 per cent pure. The three specimens last named are free from magnesia but contain clay, sand, and a small amount of iron. The Minnekahta limestone and the limestones in the White River group vary in character, but some of them are more than 90 per cent pure, the principal impurities being sand and clay. A sample from outcrops in the northwestern part of T. 5 S., R. 1 E., contained 72 per cent of calcium carbonate and 0.2 per cent of phosphoric acid. A sample of Minnekahta limestone from the vicinity of Hot Springs contained 20 per cent of magnesia, but two samples from the area east of the L A K ranch, on the west slope of the Black Hills, contained nearly 95 per cent of calcium carbonate and less than 1 per cent of magnesia. Some of the limestone in the lower part of the Minnelusa formation is of good quality, one sample from Hell Canyon containing nearly 90 per cent of calcium carbonate. The Whitewood limestone has been extensively quarried on Whitewood Creek about 2 miles below Deadwood for flux in the smelter.

Lithographic stone.—Some of the Pahasapa limestone west of Custer is of suitable texture for lithographic stone, and a slab of moderate size is said to have proved satisfactory in practical tests. It is difficult to find a market for lithographic

[40] Wherry, E. T., Clay derived from volcanic dust in the Pierre in South Dakota: Washington Acad. Sci. Jour., vol. 7, pp. 576-583, 1917.

stone until users are convinced that large slabs of perfect texture, free from hard veins or cracks, can be supplied.

Building stone.—Many of the more massive sandstones, limestones, granites, and porphyries in the Black Hills are good building stones, but owing to their long distance to markets they have not been extensively utilized. Considerable building stone has been quarried from the Dakota sandstone at several places a short distance southwest of Buffalo Gap. The material is a light-gray to pinkish stone of fine appearance and great durability, and it is easy to quarry and dress. It has been used for many structures in the Black Hills and elsewhere. Similar rock is obtainable at intervals along the outcrop. The massive Unkpapa sandstone is of pleasing color and uniform texture and lies in thick, unbroken bodies, but most of it so far tested has proved to be too soft for building stone, and some of it is likely to disintegrate on weathering. It is 140 feet thick north of Rapid City, where some of the white rock has been quarried. Much of the Pahasapa limestone would yield a light-colored marble, and some of it is of the pale cream color that is in demand. Sandstone in the lower part of the Graneros shale has been quarried for building stone a mile north of Rapid City. The ledge exposes 25 feet of gray to buff stone of compact, uniform texture and soft enough to be easily dressed. Apparently it is durable. Metamorphosed limestone included in the granite a short distance south of Harney Peak has been prospected to some extent as an ornamental building stone.

Coal.—Workable coal beds occur at the base of the Lakota sandstone at several localities on the northwestern and southern slopes of the Black Hills, but no coal has been observed at that horizon in the area considered in this folio. At most places the outcrop is hidden by talus derived from the sandstone cliffs above; moreover, even if coal is present it generally crumbles or burns away at the surface, and the overlying sandstone sinks and hides it. Therefore it is barely possible that local coal beds may yet be found.

Attempts have been made to prospect for coal in the basal Graneros shale because it is similar to the black shale that occurs with coal, and some of it will burn for a few seconds, but there is not the slightest likelihood that any coal will be found at this horizon.

Petroleum.—The eastern slope of the Black Hills is underlain by the rocks that have yielded small amounts of petroleum on the western slope near Newcastle, Lance Creek, Osage, Moorcroft, and Rockyford, and although no oil has been noted on the eastern side it may yet be found there. The principal oil-bearing beds on the western side of the Black Hills are the sandstone that lies below the Mowry shale member at some localities, the Lakota sandstone, and the sandstone in the upper part of the Minnelusa, but oil may possibly occur in the Dakota sandstone, in the sandstone of the Sundance formation, and in some of the thin sandstone layers of the Carlile and Pierre shales.

A number of well-defined anticlines and domes have been found, but as holes bored in some of them and in other structural features have found no oil, the prospects are in general unfavorable. A large dome in Martin Valley, west of Buffalo Gap, has recently been tested by a hole 1,417 feet deep, drilled to granite, but no oil was found in strata from the Sundance to the Deadwood. A hole in the fine dome just west of Bear Butte only reached the Minnelusa sandstone, which yielded a very large flow of water. Borings at several points northwest of Sturgis and east of Rapid City tested strata from Dakota to Minnelusa on the eastward-sloping monocline of the uplift. The prominent anticline in the Red Valley northwest of Rapid City has been tested by three holes to the Minnelusa sandstone, which yields artesian water. Several domes, such as Elkhorn Peak, Crook Mountain, and Whitewood Peak, were formed by the laccolithic intrusion of igneous rocks. A strongly marked northward-pitching anticline, which extends through Whitewood, involves beds on the surface from Deadwood sandstone southeast of Sturgis to Spearfish red beds about Whitewood. A small anticline occurs in the Red Valley south of Blackhawk, and a local anticline and syncline occur on the Hogback Ridge, 3 miles southeast of Piedmont. In the southeast corner of T. 3 S., R. 7 E., 8 miles southwest of Hermosa, a small anticline appears in the Dakota sandstone, which may extend through Fairburn, where Greenhorn limestone is flexed somewhat. A small dome brings up Minnekahta limestone on Dry Creek, 7 miles northwest of Fairburn. The anticline of Martin Valley above mentioned extends northward to a point beyond the western end of Fuson Canyon. A small flat anticline in the Hogback Ridge near Lame Johnny Creek is marked by sandstone outcrops near the railroad. On Battle Creek, near the west line of Range 9, there is a small anticline or dome in Niobrara limestone. Two small domes in the Red Valley near Hell Canyon are marked by Spearfish red beds and Minnekahta limestone. Apparently the Pierre shale is flexed by a low anticline east of the Belle Fourche, 20 miles east of Sturgis. Doubtless many other flexures would be disclosed by detailed surveys.

SOILS.

By N. H. Darton.

Derivation.—Most of the soils in this region are closely related to the underlying rocks, from which they were derived by decay and disintegration. At some places the soil consists of alluvial deposits or wind-blown material. Soil develops from the disintegration of rocks more or less rapidly, the rate depending on the character of the cement that holds the particles together. Siliceous cement dissolves rather slowly, so quartzite and sandstone produce a scanty soil. The lime of limestone and of calcareous cement is dissolved more readily, leaving clay and sand, which in places form a deep soil, especially where the rock contained a large proportion of these materials. The amount of soil remaining, however, depends mainly on the rate of erosion, for on many slopes the erosion is sufficient to remove the soil as rapidly as it forms, leaving bare rock surfaces. Crystalline schists and granitic rocks are decomposed mostly by the hydration of a part of their feldspar, and the result is mainly a mixture of kaolin, quartz grains, and mica. Shales are disintegrated by changes of temperature, by frost, and by water, and thus by softening and washing give rise to clay soils. Sandy shales form sandy loam. As soils are so closely related to the underlying rocks the areal-geology map serves to a large extent also as a soil map. However, where the strata comprise alternating beds of different materials, such as shales and sandstones alternating with limestone, there are abrupt transitions in the resulting soils, which may differ widely in composition and agricultural capabilities in zones that lie side by side and that are too narrow to map. The soils and the underlying rock formations do not correspond in areas of alluvial deposits, sand dunes, or high-level gravels, or in parts of the smaller valleys and upon steep slopes, where material derived from rocks high up the slope has washed down and mingled with or covered the soils derived from the rocks below. Soils of this class are known as overplaced soils, and a large-scale map would be required to show their distribution.

Distribution.—The arable lands of the central Black Hills region are irregularly distributed. By far the most extensive areas available for farms are in the alluvial deposits along Spearfish, Whitewood, Bear Butte, Alkali, Boxelder, Elk, Rapid, Battle, French, Beaver, and the two Spring creeks and in the parklike areas of the region that are underlain by schist. Many areas with suitable soils lie at an altitude so high that they are subject to frosts, and the scantiness of the rainfall is a serious obstacle to farming in the greater part of the area, especially where there is not sufficient water for irrigation.

The alluvium in the larger valleys ranges from sandy loam to clay, and most of its materials have been transported by water, in part from the mountains and in part from the adjoining slopes. Much of it yields excellent crops when irrigated. Alfalfa, grass, and grain are the principal products. The alluvial flats along the larger creeks east of the foothills are half a mile to a mile wide, but only parts of them are cultivated. The alluvium along Cheyenne and Belle Fourche rivers is very sandy and is subject to overflow by the heavy freshets. The highland valleys are narrow, yet many of them are farmed. The old high terrace deposits have level surfaces and rich soils, but most of them are too high for irrigation. The character of the soil in the White River deposits varies greatly. The badlands areas are barren, but some of the wide sandstone flats between Fairburn and Hermosa and between Battle and Spring creeks, north of Hermosa, have a thin but fertile soil, which is cultivated to some extent. Owing to lack of water, however, the crops usually fail or are very scanty. The great series of shales that forms most of the surface rock east of the Black Hills has thin clay soils, which are not favorable for agriculture but which sustain an excellent growth of "buffalo grass" and other grasses that afford valuable pasturage.

On the Hogback Ridge the soil is thin and sandy but sustains considerable grass. In the Red Valley most of the soils are scant and barren, but at some places there are areas of overlying alluvium, parts of which are farmed, notably on Spearfish, Rapid, Squaw, Spring, Battle, and Beaver creeks. The limestone foothills are rocky ridges with extensive bare slopes, and the surface underlain by the Minnelusa sandstone is mostly sandy. The high plateau on the western side of the Black Hills has rich limestone soil, a few small areas of which are under cultivation, but their altitude is too high for satisfactory farming. The parks of the schist region have deep rich soil, which at many places yields oats, hay, and vegetables.

WATER SUPPLY.

By N. H. Darton.

SURFACE WATER.

The average annual precipitation in the Black Hills region is about 25 inches, but it is greater on the highlands and less on the plains, where it is not more than 20 inches. Considerable snow falls, especially in the mountains, and most of the rain comes in heavy showers of short duration during the spring and early summer. The mountains and high plateau receive many showers and snowfalls that do not extend to the adjacent foothills and plains. Much of the water of rains and melting snow runs off rapidly in freshets that follow storms or the rapid melting of snow. Therefore the volume of the running water varies greatly, and during most of the year the small watercourses in the foothills and plains are dry. There are many excellent springs in the highlands, but springs are rare and of small volume in the foothills and plains.

A large part of the run-off could be held by dams and made available for irrigation. There are many excellent dam sites on most of the larger creeks that flow out of the Black Hills, especially in the foothill belt, and the results obtained with dams in the plains region northeast of the Black Hills indicate that considerable water could be held in almost all parts of the area near and east of the Hogback Ridge. However, as the evaporation is about 6 feet a year, a large quantity of water would have to be impounded to compensate for this loss. Cheyenne River carries a large volume of water at times of freshets, 11,000 to 29,000 second-feet having been recorded, but is a very insignificant stream during the dry periods of midsummer. Ordinarily its flow ranges from 10 to 40 second-feet, but the water is not much used because of the difficulty of maintaining headgates and ditches during freshets.

The Belle Fourche is similar in character to Cheyenne River, but it has a greater volume of flow. The amount, however, varies greatly from year to year and at different seasons of the same year. The average summer and autumnal flow is about 300 second-feet, as indicated by the gagings not far below Belle Fourche, supplemented by an estimate of the additional flow received from Whitewood and Bear Butte creeks. Floods usually occur in early summer, but the water is now taken into the reservoir east of Belle Fourche, so that all the flow can be utilized. The flow of Spearfish Creek above Spearfish ordinarily ranges from 50 to 100 second-feet, but in the early summer this stream is subject to freshets, one of which in June, 1904, had a volume of 4,158 second-feet and one in July, 1905, of 517 second-feet. Its principal affluent is Little Spearfish Creek, which in summer generally has a flow of about 10 second-feet. A large part of the water of these two streams is diverted by a tunnel near Spearfish Crossing, which carries it across the divide to supply the mills at Lead.

Whitewood Creek ordinarily has small volume of its own, but it receives from the mills near Lead much water that has been taken from Spearfish Creek.

Bear Butte Creek flows in moderate volume except for a short distance west of Fort Meade, where it sinks into the Minnelusa sandstone; it emerges again near Sturgis. Spring Creek, its chief branch, usually flows, but its volume is small.

Elk Creek is a small stream, and most of its water sinks in crossing the Minnelusa, Lakota, and Dakota sandstones. During dry seasons it does not flow in the region east of Piedmont Butte. Boxelder Creek is a stream of moderate size in the central area. Its flow averages about 25 second-feet, but in 1905 it was 40 second-feet. Most of its water is lost in crossing the sandstones, especially the Minnelusa, and ordinarily the stream is intermittent in the Red Valley and farther east.

Rapid Creek has a moderate flow, which diminishes greatly during drought. Much of its water sinks in passing over the Minnelusa sandstone. A gaging station near Rapid City showed in 1903 a maximum flow of 240 second-feet in June and a minimum flow of 33 second-feet in December; the mean for June, July, and August was about 120 second-feet, and for the last four months of the year about 55 second-feet. In 1904 there was a maximum flow of 798 second-feet in June and an average of 230 second-feet for the three summer months and of 84 second-feet for the last four months. In 1905 the maximum was 880 second-feet in July, and the summer average was 230 second-feet. In 1906 the maximum was 480 second-feet, and the summer average was 130 second-feet. The yearly mean for 1903 to 1906 was about 140 second-feet.

Spring Creek has a moderate volume until it reaches the Lakota sandstone, into which much of its water sinks. The average flow south of Rapid City from July, 1903, to November, 1905, was about 25 second-feet, but it rose to 400 second-feet in summer floods and diminished to 10 second-feet or less in dry weather. During dry weather the volume at Rockerville was from 15 to 60 times as much as at the station south of Rapid City.

Battle Creek receives several branches, of which the largest are Squaw and Iron creeks, all of which carry a moderate volume of water. In crossing the Deadwood, Minnelusa, Lakota, and Dakota sandstones, Battle Creek and its branches lose considerable water. Gagings at Keystone in May, 1900, gave 3 second-feet; in June, 2.3 second-feet; and at Hermosa at the same times 9 and 2.3 second feet, respectively. Squaw Creek at Otis at the same times gave 8 and 2.8 second-feet, respectively.

French Creek is fed by springs at the foot of the limestone escarpment west of Custer and receives many small rivulets in its passage across the area of schist. It loses considerable water in crossing the sandstone on the eastern side of the Black Hills and in dry weather does not receive any water from its affluents in that part of its course. In May and June, 1900, its flow 10 miles above Fairburn was 13 second-feet and 5 second-feet, respectively; at Fairburn at the same times the flow was 3.3 and 0.2 second-feet, respectively. Dry Creek, one of its chief branches, often contains pools of water but rarely flows.

The Beaver Creek that flows through Buffalo Gap has a small though nearly continuous flow for many miles near its head, but much or all of it sinks in crossing the outcrop of the Minnelusa sandstone. Its flow is replenished by large springs in the anticline which exposes the Minnekahta limestone at the west end of Buffalo Gap, below which it is utilized for irrigation near the village of Buffalo Gap. Gagings at a point 3 miles northwest of Buffalo Gap in May and June, 1900, gave 12 second-feet and 15 second-feet, respectively. Gagings 7 miles southeast of Buffalo Gap at the same times gave 1.2 and 6 second-feet, respectively.

Lame Johnny Creek loses most of its small flow in crossing the Minnelusa outcrop.

UNDERGROUND WATER.

Source.—Several sheets of porous sandstone, among them the Minnelusa, Lakota, and Dakota sandstones, rise to the surface on the slopes of the Black Hills in regular succession, as shown in the structure-section sheet. They crop out in wide zones encircling the uplift, and their general outward dip carries them far beneath the adjoining plains, where they are buried under relatively impermeable shales. These sandstones receive a large quantity of water, part of which comes from the rainfall on their outcrops and part from streams which sink into them wholly or in part in crossing their outcrops. The sinking of streams is observed in almost every valley that leads out of the central area. The streams carry into the Belle Fourche or Cheyenne River only a small part of the original run-off of their drainage basins. Although the water thus absorbed is carried to considerable depths, much of it is recoverable, for these water-bearing sandstones at one horizon or another can be reached by well borings of moderate depth in most parts of the foothills and plains. As this lower area is semiarid and most of the scanty surface water is of bad quality, there is need for an additional supply. Only a few deep wells have been bored in this region, but most of them have been successful and give encouragement that abundant supplies can be obtained.[41]

Deep borings made prior to 1912 on the east side of the Black Hills from Rapid City to Spearfish, S. Dak.

Location or owner.	Depth.	Diameter.	Yield per minute.	Depth to main flow.	Remarks.
	Feet.	*Inches.*	*Gallons.*	*Feet.*	
N. P. Hansen, NE. ¼ SW. ¼ sec. 15, T. 6 N., R. 5 E.	1,116	2	85	1,090	Flows 5 feet above surface; soft water; pressure 30+ pounds.
R. Stephens, NE. ¼ sec. 22, T. 6 N., R. 5 E.	377	2	60	357	Soft water; pressure 18 pounds, was 50 pounds
Eklund (old "oil well"), SE. ¼ SE. ¼ sec. 8, T. 6 N., R. 5 E.	755	6, 3¾	60	600+	Iron water; pressure low.
K. F. Kaubisch, NE. ¼ SW. ¼ sec. 20, T. 6 N., R. 5 E.	720	2	Few.	480	No water below 400 feet; water stands within 4 feet of surface; soft but some iron.
J. S. Jensen, NW. ¼ SE. ¼ sec. 8, T. 6 N., R. 5 E.	632	4½, 2	30	600	Soft water; some iron; pressure 20 pounds.
J. Dacy, SE. ¼ SE. ¼ sec. 12, T. 6 N., R. 4 E.	570	----	Many.	570	First flow at 330 feet.
Fort Meade	1,450	----	12	322	No water below the flow at 322 feet.
Sturgis, Furth Hotel	1,050(?)	----	----	----	No water.
Enskert:					
Lot 2, sec. 26, T. 6 N., R. 5 E.	1,310	2, 1¼	Few.	740	
Lot 1, sec. 26, T. 6 N., R. 5 E.	480	2	¾	400	
Normal school near Spearfish.	411	6¼	160	300	Water rises 50 feet or more above surface; good water.
Half a mile southeast of Spearfish.	275	6¼	312	215	Good water; pressure 3½ pounds.
Fairgrounds ¾ mile northwest of Spearfish.	300	5	115	260	Good water; pressure 15 pounds.
Electric plant 1½ miles south of Spearfish.	415	----	50	323–398	Flows.
Three-fourths of a mile northeast of Spearfish.	701	----	----	666	Water to —150 feet.
Lime plant 2 miles northwest of Rapid City.	250	----	100	215	Excellent water; moderate pressure.
Allender, 1¾ miles northwest of Rapid City (NE. ¼ sec. 33, T. 2 N., R. 7 E.).	205	----	100+	205	Do.
Burch, 1 mile west of Rapid City (SW. ¼ sec. 34, T. 2 N., R. 7 E.).	500	----	60	500	Do.

Dakota and Lakota sandstones.—The Dakota and Lakota sandstones are the principal water-bearing beds in the plains adjoining the Black Hills. The greatest volume of water is in the Lakota sandstone, but the Dakota sandstone may also contain a moderate supply. In their wide outcrop in the Hogback Ridge they receive a considerable proportion of the rainfall by direct absorption and by sinkage from streams. This water flows very slowly through the permeable sandstones, but much of it passes completely under the surface of South Dakota and emerges in great springs and general seepage in the outcrops of Dakota sandstone in the Missouri Valley, in the southeast corner of the State. The water enters the beds at altitudes of 3,000 to 3,500 feet above sea level and emerges at the surface to the east at about 1,200 feet; under the intervening area its head therefore gradually diminishes from source to outflow. In eastern South Dakota and in the area north of Belle Fourche many wells, 400 to 1,000 feet deep, furnish large volumes of water from the Dakota and associated sandstones, and this water is probably available in the Black Hills and their vicinity under conditions which are shown on the artesian water maps in this folio. The area of flow, as determined by the head of the water, is restricted to the valleys of Cheyenne and Belle Fourche rivers and Beaver, French, Dry, Battle, Spring, Rapid, Boxelder, Elk, Alkali, Bear Butte, and Volunteer creeks. The altitudes to which the water may be expected to rise decrease regularly toward the east, for in that direction, or away from the source, there is a gradual decrease of head. This diminution of head or "hydraulic grade," is shown on the artesian water maps by lines at vertical intervals of 100 feet, indicating the altitude above sea level to which the underground waters may rise. These lines afford means for ascertaining how near the surface the water will probably rise in wells which do not flow and also the pressure of the water in the area of flow. The depth below the surface at which water would stand in a well in the nonflowing area may be found by subtracting the feet of head from the feet of altitude shown by the brown contour lines on the topographic map. For instance, at benchmark 3280, 4 miles east-northeast of Hermosa, which is at an altitude of 3,280 feet and is midway between the 3,100 and 3,200-foot contour lines of head, the water should be expected to rise to a level within about 130 feet of the surface, and, as is shown by the depth lines, it would be necessary to drill about 2,000 feet to reach the top of the Dakota sandstone. Possibly it might be necessary to penetrate also the Fuson shale and the Minnewaste limestone and to enter the Lakota sandstone before a large volume of water could be obtained.

On the columnar-section sheet are shown the formations that have to be penetrated by borings east of the Hogback Ridge, and these can be recognized by their characteristics as described in the table. There are two fossils which are most useful guides to geologic horizons. One of these fossils is *Ostrea congesta*, crowded masses of which constitute thin limy layers in the upper part of the Niobrara chalk beds, which, although bright yellow in most outcrops, are pale blue-gray underground. The other, *Inoceramus labiatus*, abounds in the Greenhorn limestone, which is hard and light buff on the surface but soft and dark gray underground. The concretions and the thin layers of sandstone in the Carlile shale should be recognized in well borings by their hardness and their position in relation to other beds.

In the wells north and northwest of Sturgis that tap Lakota and Dakota sandstones the maximum depth to the top sandstone is only 1,000 feet, but the depth increases to nearly 3,000 feet in the eastern part of the area to which this folio relates. The Lakota sandstone, which contains the principal water supply, lies from 100 to 200 feet deeper. Most of the wells that have penetrated these sandstones yield large flows of excellent water. One of these wells, which was sunk for oil at the Eklund ranch, 6 miles north-northwest of Sturgis, in the southeastern part of sec. 8, T. 6 N., R. 5 E., is 755 feet deep but obtains its principal water supply at a depth of 600 feet in a bed of soft sandstone (Lakota) 85 feet thick. The flow is estimated at 60 gallons a minute, and the pressure was reported to be 20 pounds to the square inch. It was 5 pounds in 1910. A small flow was also found in the Dakota sandstone at a depth of 440 feet. The following record is given:

Record of artesian well at the Eklund ranch, 6 miles north-northwest of Sturgis, S. Dak.

	Feet.
Dark shale (Graneros)	0–275
Shale and sandstone; small flow of water at 440 feet (Graneros and Dakota)	275–445
Clay, red (Fuson)	445–505
"Rocks" (Lakota?)	505–585
Sandstone, soft; main flow at 600 feet (Lakota)	585–670
Sand, dry, under 1 inch of coal (Lakota)	670–685
Shale, black; 2 inches of coal (Lakota)	685–705
Shale, green; thin limestone layers (Morrison)	705–755

The Jensen well, about one-third of a mile northwest of the Eklund well, yields at 600 feet a 30-gallon flow, which is used for the irrigation of an orchard and garden. It passed through 40 feet of surface material, 25 feet of shale, 10 feet of sandstone, 240 feet of hard shale, and 92 feet of sandstone, reaching a total depth of 632 feet. In a well 720 feet deep at the Kaubisch ranch, in sec. 20, T. 6 N., R. 5 E., the main supply comes from a depth of 300 to 400 feet. Good water in fair volume comes within 4 feet of the surface and is carried by a trench to lower ground. There was water in sandstone at a depth of about 200 feet, and the next sandstone, at 400 feet, also yielded water. At 720 feet the boring was in Sundance beds containing belemnites. The Dacey well, 2 miles west of the Eklund well, found a small flow at 330 feet, and a large flow under pressure of 15 pounds to the square inch at 570 feet.

A 1,340-foot boring at the Enskert ranch, 3 miles northeast of Sturgis, stopped near the bottom of the Sundance formation. It obtained a 2-gallon flow of very hard water from sandstone, presumably Dakota, at a depth of 740 to 755 feet.

Record of Enskert well, lot 2, sec. 26, T. 6 N., R. 5 E., 3 miles northeast of Sturgis, S. Dak.

	Feet.
Clay, yellow (Graneros)	0–80
Shale, blue (Graneros)	80–555
Sandstone	555–565
Shale, gray (formation?)	565–740
Sandstone, flows 1 to 2 gallons, very hard water (Dakota?)	740–755
Shale, gray (Fuson and Lakota)	755–980
Sandstone (Lakota?)	980–1,000
Soapstone (Morrison)	1,000–1,050
Sand and shale and ironstone (Morrison and Sundance)	1,050–1,240
"Limestone" (probably sandstone; Morrison and Sundance)	1,240–1,310
Not reported	1,310–1,340

A 480-foot well completed in 1912 on the next lot to the east obtained a flow of three-fourths of a gallon of good water at 400 to 450 feet. Dakota sandstone was entered at 345 feet, and below 450 feet came 12 feet of white shale and 20 feet of red shale. As the 480-foot well is northeast of the deep boring, it found the water-bearing strata at much less depth. Apparently the poor results in these two borings are due to the fact that the Lakota sandstone is here too fine, probably a very local condition.

In the Hansen well, 5 miles due north of Sturgis and 1,116 feet deep, sandstone was entered at 700 feet and the flow began at 1,090 feet, doubtless in the lower part of the Lakota sandstone. The pressure at the mouth of the well, which was reported to be 30 pounds, indicates a head of 69 feet, equivalent to an altitude of 3,220 feet, which is somewhat higher than the altitude of the outcrop of the Dakota sandstone in the area a mile to the east.

The Stephens well, a mile southeast of the Hansen well, penetrated 250 feet of blue shale (Graneros), 25 feet of sandstone (Dakota), 80 feet of gray shale (Fuson), and 22 feet of water-bearing sandstone (Lakota). The pressure appears to be about 21 pounds, equal to a head having an altitude of 3,250 feet, which indicates that flowing water may be expected in all of the lower lands east of the Hogback Ridge in this vicinity. In most places the Dakota sandstone yields only a very small supply, but flows of large volume are generally obtainable from the underlying Lakota sandstone.

A few borings east of Rapid City have not reached the Dakota sandstone, the depth of which increases greatly in a short distance east of the Hogback Ridge. In the eastern part of Rapid City its depth is 500 feet, whereas along the eastern margin of R. 8 E. it is probably considerably more than 2,500 feet. Doubtless flowing wells could be obtained along the valley of Rapid Creek west of the center of R. 8 E., at depths of 500 to 1,500 feet, and in the wide flats west of Boxelder Creek, 2 miles northeast of Rapid City, at a depth of about 1,500 feet. At Brennan the sandstone is about 1,300 feet below the surface, but this place is near the limit of the area in which wells may be expected to flow.

In the Hermosa region the conditions are closely similar to those about Rapid City, and the probability is strong that flowing wells can be obtained in the bottom lands and lower slopes of all the valleys east of the Hogback Ridge.

Formations between the Lakota and Minnelusa sandstones.—There are no prospects for much water in the Morrison and Sundance shales, although the lower sandstone member of the Sundance formation contains a small amount, as illustrated by the flowing well at the Bowman ranch, 6 miles north of Sturgis. Apparently the Unkpapa sandstone and the Minnekahta limestone are too compact to carry much water. The gypsiferous red shale of the Spearfish and Opeche formations also does not contain water, as is demonstrated by the deep boring at Fort Meade.

A 1,450-foot boring at Fort Meade, just east of the Hogback Ridge, developed a 12-gallon flow of excellent water at a depth of 322 feet. The boring was continued to the Minnekahta limestone but unfortunately did not test the upper sandstones of the Minnelusa formation, not far below, in which there were fairly good prospects of obtaining water. The record, based mainly on samples furnished by the quartermaster, is as follows:

Record of boring at Fort Meade, S. Dak.

	Feet.
Sandstone and gravel	0–25
Sandstone, buff, fine-grained at top, coarser in middle, and medium-grained toward the base	25–100
Shale, gray	100–125
Sandstone, yellow, fine grained	125–153
Shale, gray	153–185
Sandstone, coarse, dark gray; some shale below	185–225
Shale, light gray above, dark and carrying pyrite below	225–288
Sandstone, fine-grained (basal Lakota); shale layers; at 322 feet water of good quality, which rose 2 feet above the surface and flowed 10 to 20 gallons a minute	288–322
Shale, light greenish-gray	322–600
Shale, very dark	600–603
Shale, blue	603–745
Shale, red	745–770
Shale, blue	770–771
Shale, red; gypsum at 890 feet; some gray shale at 850 and 940 feet; gypsum, 910 to 930 feet	771–1,440
Limestone (Minnekahta)	1,440–1,450

[41] Darton, N. H., Artesian waters in the vicinity of the Black Hills, S. Dak.: U. S. Geol. Survey Water-Supply Paper 428, 1918.

Minnelusa sandstone.—As shown on the structure-section sheet, the slopes of the Black Hills and the adjoining plains are underlain by the Minnelusa sandstone, which, however, lies at great depth not far east of the Hogback Ridge. In their outcrops the sandstones of this formation appear to consist mostly of very porous sand, which is likely to imbibe much surface water and to constitute a water-bearing stratum available for deep wells. The many springs that emerge at places from the upper sandstone are a further indication of its water-bearing properties, but in wells at Cambria and Edgemont the sandstone was found to be so fine or so closely cemented by lime that it contained only a little water. In the northern part of the Black Hills, however, the rock is much coarser grained and appears to be less calcareous, especially the upper beds of white sandstone, which supply excellent flowing wells near Rapid City, Sturgis, and Spearfish and would probably yield flowing water in most other parts of the area treated in this folio. This sandstone lies within 1,500 feet of the surface along the Red Valley from Spearfish to Martin Valley (west of Buffalo Gap), but its depth gradually increases to several thousand feet near Cheyenne and Belle Fourche rivers. The depth to its top in the area west of the Hogback Ridge is shown on the artesian water maps in this folio.

In the boring at Fort Meade the Spearfish formation is 695 feet thick and the Minnekahta limestone and the Opeche red beds 130 feet thick, so that the maximum depth to the top of the Minnelusa sandstone is only 825 feet along the eastern margin of the Spearfish outcrop and less than 500 feet in most parts of the Red Valley. Possibly it would be necessary to sink 300 or 400 feet through the Minnelusa beds to reach the lower sandstone, but the prospects are good that a supply of water will be found in the upper sandstone. As the outcrop on the slopes of the ridges west and southwest of the Red Valley is at a high altitude, the Minnelusa water may be expected to show considerable pressure when it is tapped by wells on the lower lands. Its capabilities have been tested by several wells about Spearfish and Rapid City. One of these wells, a 415-foot well at the electric-light plant in the canyon $1\frac{1}{2}$ miles south of Spearfish, pierces the Minnelusa sandstone and penetrates about 17 feet into the underlying Pahasapa limestone. A 32-gallon flow in yellow sandstone at a depth of 323 feet increased to 50 gallons as the remaining 75 feet of the lower Minnelusa sandstone was penetrated. The 300-foot flowing well at the fair grounds, just northwest of Spearfish, draws its principal supply from a depth of 260 feet, probably from the top of the Minnelusa sandstone. The pressure is 15 pounds and the flow 115 gallons. A similar well at the normal school is 411 feet deep and has a 160-gallon flow from a depth of 300 feet and a pressure of 20 pounds. The Harriman boring, three-fourths of a mile northeast of Spearfish, which is 701 feet deep, penetrated Minnekahta limestone from a depth of 453 to 483 feet and the characteristic purple clay at the top of the Opeche formation from 483 to 486 feet. Some water struck at a depth of 666 feet, presumably in the upper part of the Minnelusa sandstone, rises to a level within 150 feet of the surface. Two wells 2 and $2\frac{1}{2}$ miles north of Spearfish have good flows from this horizon at depths of 312 and 370 feet, respectively.

Flowing wells in the Red Valley 2 miles northwest of Rapid City indicate that water is obtainable from the Minnelusa sandstone in that district. A 250-foot well in the SE. $\frac{1}{4}$ sec. 28, T. 2 N., R. 7 E., has a 100-gallon flow from the middle of the upper sandstone of the Minnelusa. Another well a short distance to the south obtains a similar supply from a depth of 205 feet. A third well, nearly a mile southeast of the second, obtains a 60-gallon flow from the same bed, at a depth of 500 feet.

A boring that was in progress during 1922 in Martin Valley, in sec. 20, T. 6 S., R. 6 E., entered Minnelusa sandstone at 337 feet and between that depth and 630 feet found considerable water, which, however, rose only to a level within 120 feet of the surface. Considerable water was found at about 1,000 feet, which rose to a level within 20 feet of the surface and was thought to be from the base of the Minnelusa. This boring was continued to 1,417 feet to a rock supposed to be granite.

Another boring, 962 feet deep, at the Martin ranch, in sec. 15 of the same township, was begun in Opeche shale and apparently penetrated the Minnelusa formation from a depth of 150 feet to the bottom. Some water was found at 150, 695, and 724 feet, but most of the beds penetrated contain much limestone.

An unsuccessful boring at the Furth Hotel, in Sturgis, is said to have reached a depth of 1,050 feet. The figure is probably greatly exaggerated, for at that depth the boring should have passed through the Minnelusa sandstone and obtained a flow.

An 800-foot boring recently sunk for petroleum in the dome just west of Bear Butte obtained a very large artesian flow from the Minnelusa sandstone.

Pahasapa limestone.—The Pahasapa limestone appears to be too dense to yield water, except perhaps in some cavernous layers near the surface.

Deadwood formation.—The sandstone members of the Deadwood formation contain water, for they are the source of many springs in the area of their outcrop. These sandstones supply the two 2,965-foot wells at Edgemont and the deep well at Cambria and doubtless contain water throughout the greater part of their extent. They could be reached by borings of moderate depth in the limestone region and in the Red Valley, but as shown in the cross sections they lie 3,000 feet or more below the surface near the foot of the Hogback Ridge and still deeper in the plains on the east. The boring in Martin Valley above referred to penetrated this formation from 1,320 to 1,417 feet and obtained no water.

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December, 1924.

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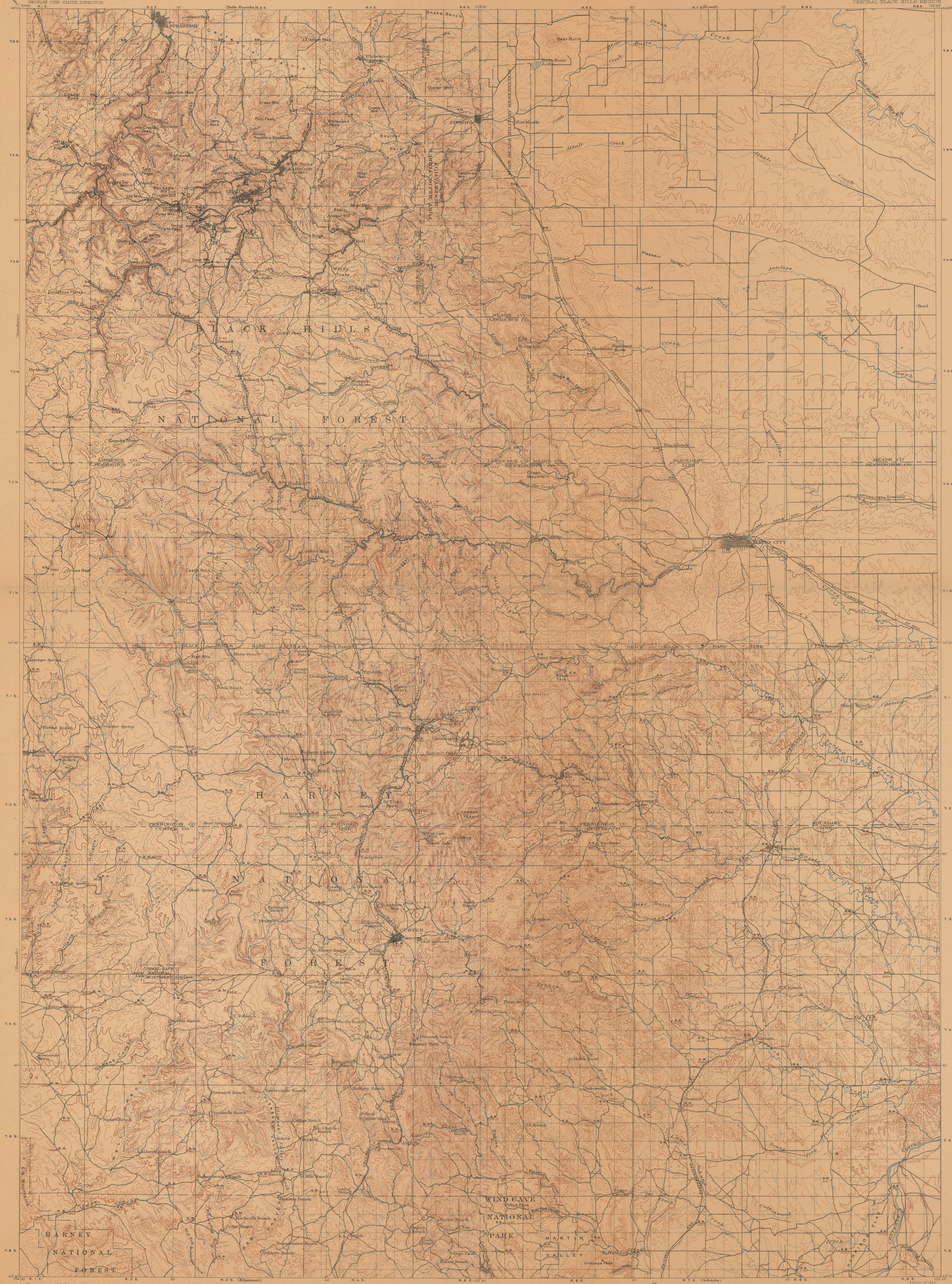
TOPOGRAPHY

SOUTH DAKOTA
CENTRAL BLACK HILLS REGION



EXPLANATION

RELIEF
printed in brown

Altitude
above mean sea level instrumentally determined

Contours
showing height above sea, horizontal form, and steepness of slope of the surface

Depression contour

DRAINAGE
printed in blue

Streams

Intermittent streams

Abandoned stream beds

Lake

Intermittent lake

Marsh

CULTURE
printed in black

Roads and buildings

Schoolhouse

Private or poor roads

Trails

Railroad

Tunnel

U.S. township and section lines and located corner

County line

Reservation line

City, village, or borough line

Triangulation station

Bench mark

A.H. Thompson and E.M. Douglas, Geographers in charge.
Topography from U.S. Geological Survey maps of Deadwood, Harney Peak, Hermosa, and Rapid quadrangles.
Surveyed in 1891-1899.
Partially revised in 1913-1915.

DIAGRAM OF QUADRANGLES
Lead, Deadwood, Rapid, Harney Peak, Hermosa

Scale $\frac{1}{125000}$

Contour interval 100 feet.
Datum is mean sea level.

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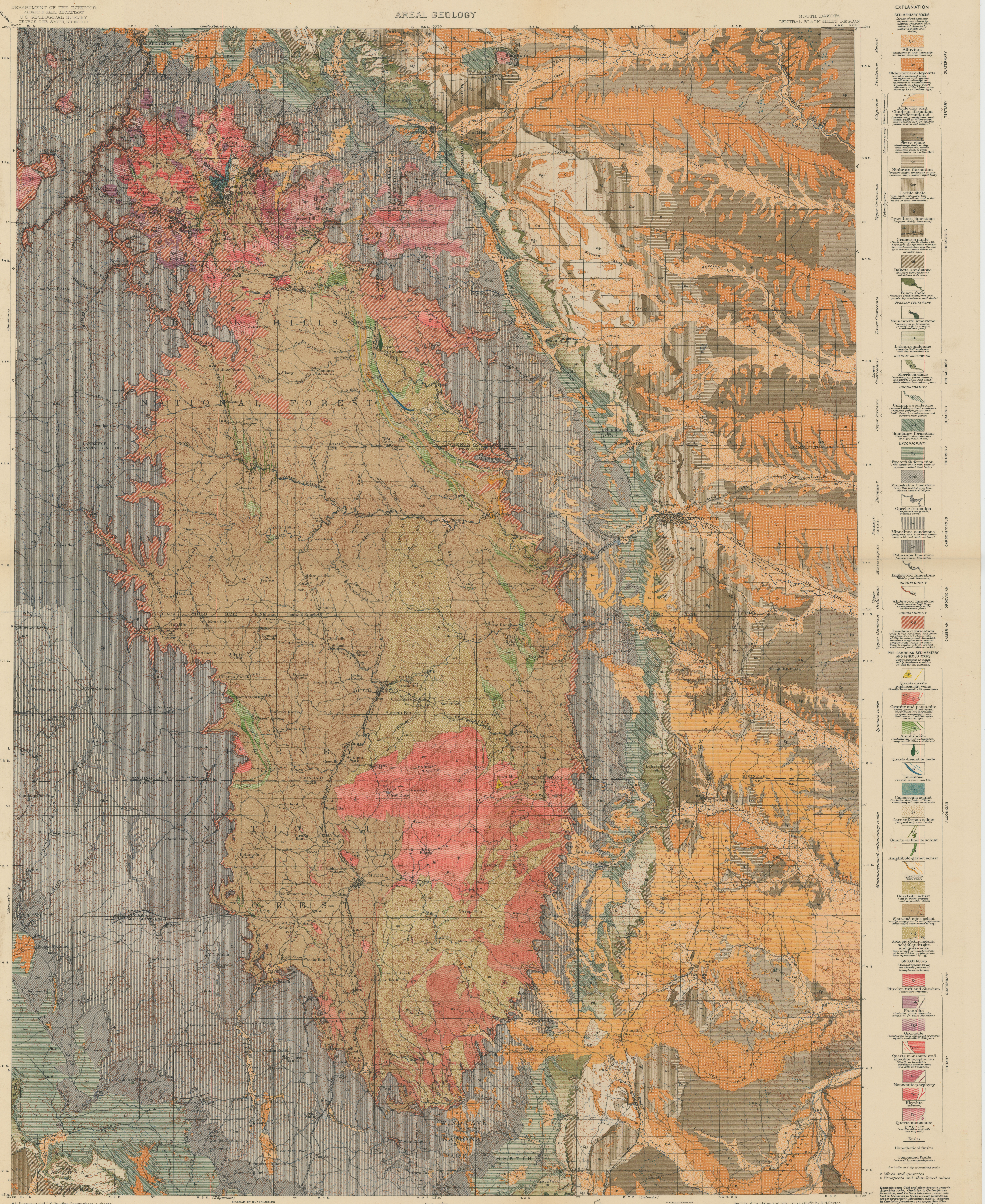
AREAL GEOLOGY

SOUTH DAKOTA
CENTRAL BLACK HILLS REGION



Economic note: *Gold and silver deposits occur in Algonkian rocks, Cambrian to Carboniferous formations, and Tertiary intrusives; silver and lead in Cambrian to Carboniferous formations; copper prospects in Algonkian schists; tungsten in Cambrian formations and pegmatitic dikes and veins; tin and mica in pegmatitic dikes and veins; spodumene and amblygonite (lithia rock) in pegmatitic dikes. Deposits of gypsum occur in Spearfish formation; fullers earth and volcanic ash in White River group; limestone for lime, flux, and cement manufacture in Minnekahta, Whitewood, Pahasapa, Englewood, and Niobrara limestones; clay for brick, tile, and cement manufacture in Morrison, Graneros, Carlile, and Pierre shales; fireclay in Fuson shale; marble in Algonkian limestone. Building stone can be obtained from various igneous rocks, limestones, and sandstones, especially Dakota sandstone. Artesian water resources are shown on the Artesian-water maps.*

A.H. Thompson and E.M. Douglas, Geographers in charge.
Topography from U.S. Geological Survey maps of Deadwood, Harney Peak, Hermosa, and Rapid quadrangles.
Surveyed in 1891-1899.
Partially revised in 1913-1915.

DIAGRAM OF QUADRANGLES

Scale $\frac{1}{125000}$

Contour interval 100 feet.
Datum is mean sea level.
Edition of Nov. 1921.

APPROXIMATE MEAN DECLINATION, 1920.

DIAGRAM OF TOWNSHIP.

Geology of Cambrian and later rocks chiefly by N.H. Darton, assisted in southeastern quarter by C.A. Fisher, G.B. Richardson, and C.C. O'Harra; in the Lead quadrangle by Sidney Paige and N.H. Darton.
Geology of pre-Cambrian rocks by Sidney Paige.
Surveyed in 1900-1915.

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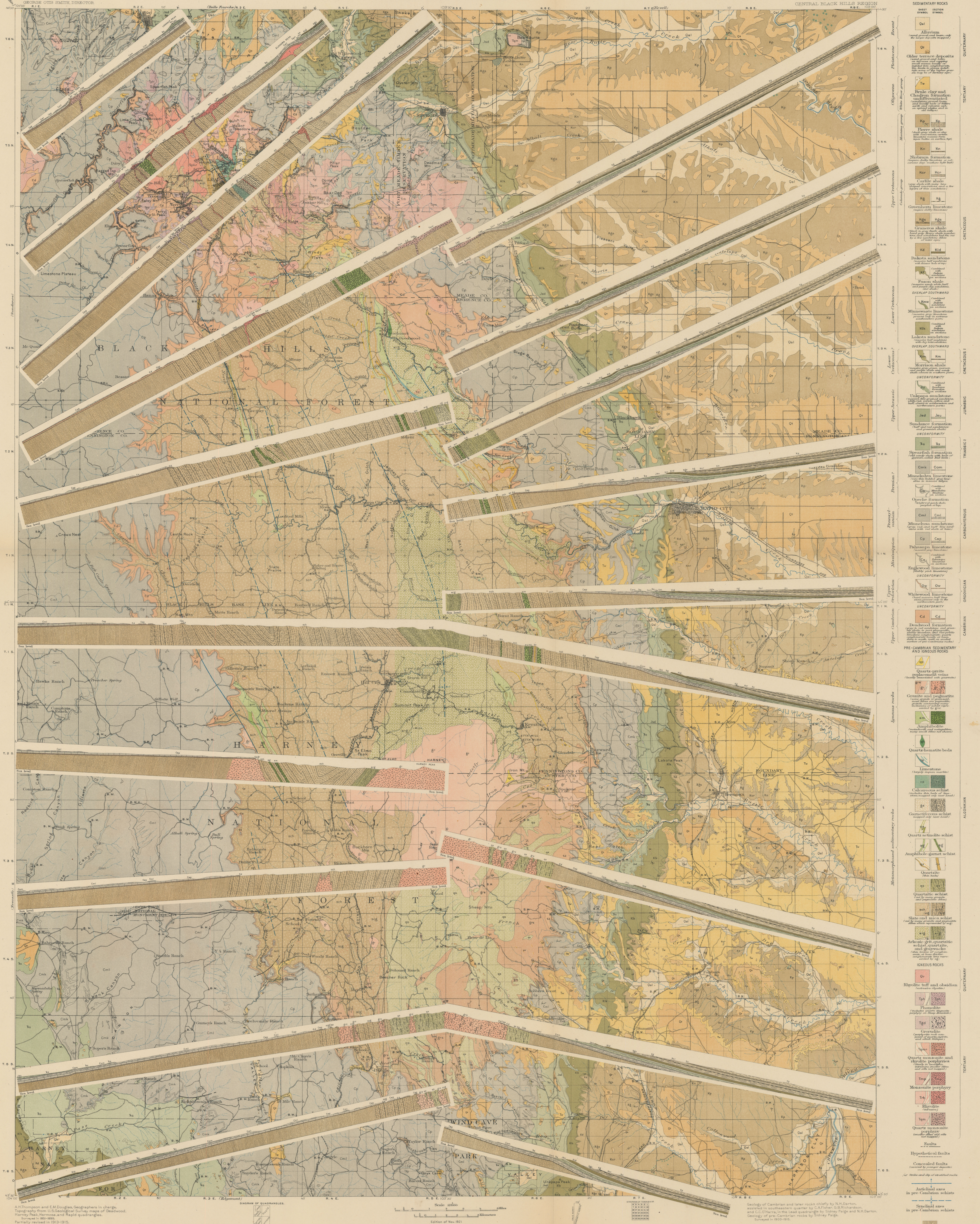
STRUCTURE SECTIONS

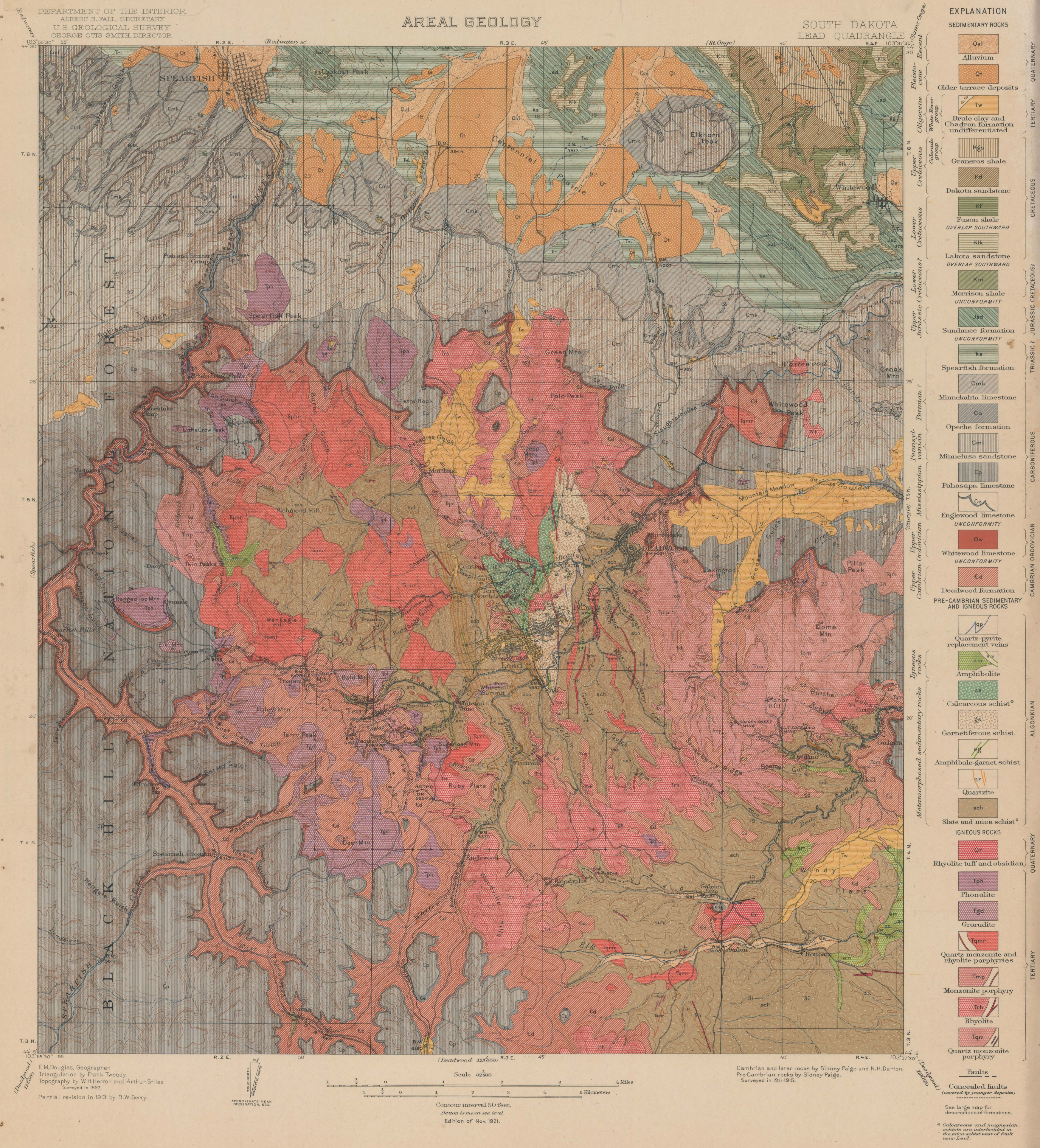
SOUTH DAKOTA
CENTRAL BLACK HILLS REGION



A.H. Thompson and E.M. Douglas, Geographers in charge.
Topography from U.S. Geological Survey maps of Deadwood, Harney Peak, Hermosa, and Rapid quadrangles.
Surveyed in 1891-1899.
Partially revised in 1913-1915.

Edition of Nov. 1921

Geology of Cambrian and later rocks chiefly by N.H. Darton, assisted in southeastern quarter by C.A. Fisher, G.B. Richardson, and C.C. O'Harra; in the Lead quadrangle by Sidney Paige and N.H. Darton.
Geology of pre-Cambrian rocks by Sidney Paige.
Surveyed in 1900-1915.


DEPARTMENT OF THE INTERIOR
ALBERT B. FALL, SECRETARY
U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR
AREAL GEOLOGY
SOUTH DAKOTA
LEAD QUADRANGLE
EXPLANATION
SEDIMENTARY ROCKS
Qal Alluvium
Qt Older terrace deposits
Tw Brule clay and Chadron formation undifferentiated
Kgs Graneros shale
Kd Dakota sandstone
Kf Fuson shale
OVERLAP SOUTHWARD
Klk Lakota sandstone
OVERLAP SOUTHWARD
Km Morrison shale
UNCONFORMITY
Jsd Sundance formation
UNCONFORMITY
Ꞧs Spearfish formation
Cmk Minnekahta limestone
Co Opeche formation
Cml Minnelusa sandstone
Cp Pahasapa limestone
Ce Englewood limestone
UNCONFORMITY
Ow Whitewood limestone
UNCONFORMITY
Ꞓd Deadwood formation
Recent
Pleistocene
Oligocene
White River group
Upper Cretaceous
Colorado group
Lower Cretaceous
Lower Cretaceous?
Upper Jurassic
Permian?
Pennsylvanian
Mississippian
Upper Ordovician
Upper Cambrian
QUATERNARY
TERTIARY
CRETACEOUS
JURASSIC CRETACEOUS?
TRIASSIC?
CARBONIFEROUS
ORDOVICIAN
CAMBRIAN
PRE-CAMBRIAN SEDIMENTARY AND IGNEOUS ROCKS
qp Quartz-pyrite replacement veins
am Amphibolite
cs Calcareous schist*
gs Garnetiferous schist
ag Amphibole-garnet schist
qz Quartzite
sch Slate and mica schist*
Igneous rocks
Metamorphosed sedimentary rocks
ALGONKIAN
IGNEOUS ROCKS
Qr Rhyolite tuff and obsidian
Tph Phonolite
Tgd Grorudite
Tqmr Quartz monzonite and rhyolite porphyries
Tmp Monzonite porphyry
Trh Rhyolite
Tqm Quartz monzonite porphyry
QUATERNARY
TERTIARY
Faults
Concealed faults (covered by younger deposits)
See large map for descriptions of formations.
* Calcareous and magnesian schists are interbedded in the mica schist west of fault near Lead.
SPEARFISH
Lookout Peak
Spearfish Peak
Elkhorn Peak
Whitewood
Centennial Prairie
Crook Mtn
Whitewood Peak
Green Mtn
Polo Peak
Terry Peak
Richmond Hill
Twin Peaks
Rugged Top Mtn
Ruby Flats
Pillar Peak
Dome Mtn
Mountain Meadow
Windy Flats
Woodville
Spearfish Crossing
BLACK HILLS NATIONAL FOREST
(Redwater)
(St. Onge)
(Saint Onge)
(Spearfish)
(Sturgis)
(Deadwood 1/125000)
R.2 E.
R.3 E.
R.4 E.
T.6 N.
T.5 N.
T.4 N.
T.3 N.
103°55'30"
103°37'30"
44°30'
44°15'
E.M. Douglas, Geographer.
Triangulation by Frank Tweedy.
Topography by W.H. Herron and Arthur Stiles.
Surveyed in 1897.
Partial revision in 1913 by R.W. Berry.
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 1920.
Scale 1/62500
4 Miles
5 Kilometers
Contour interval 50 feet.
Datum is mean sea level.
Edition of Nov. 1921.
Cambrian and later rocks by Sidney Paige and N.H. Darton.
Pre-Cambrian rocks by Sidney Paige.
Surveyed in 1911-1915.

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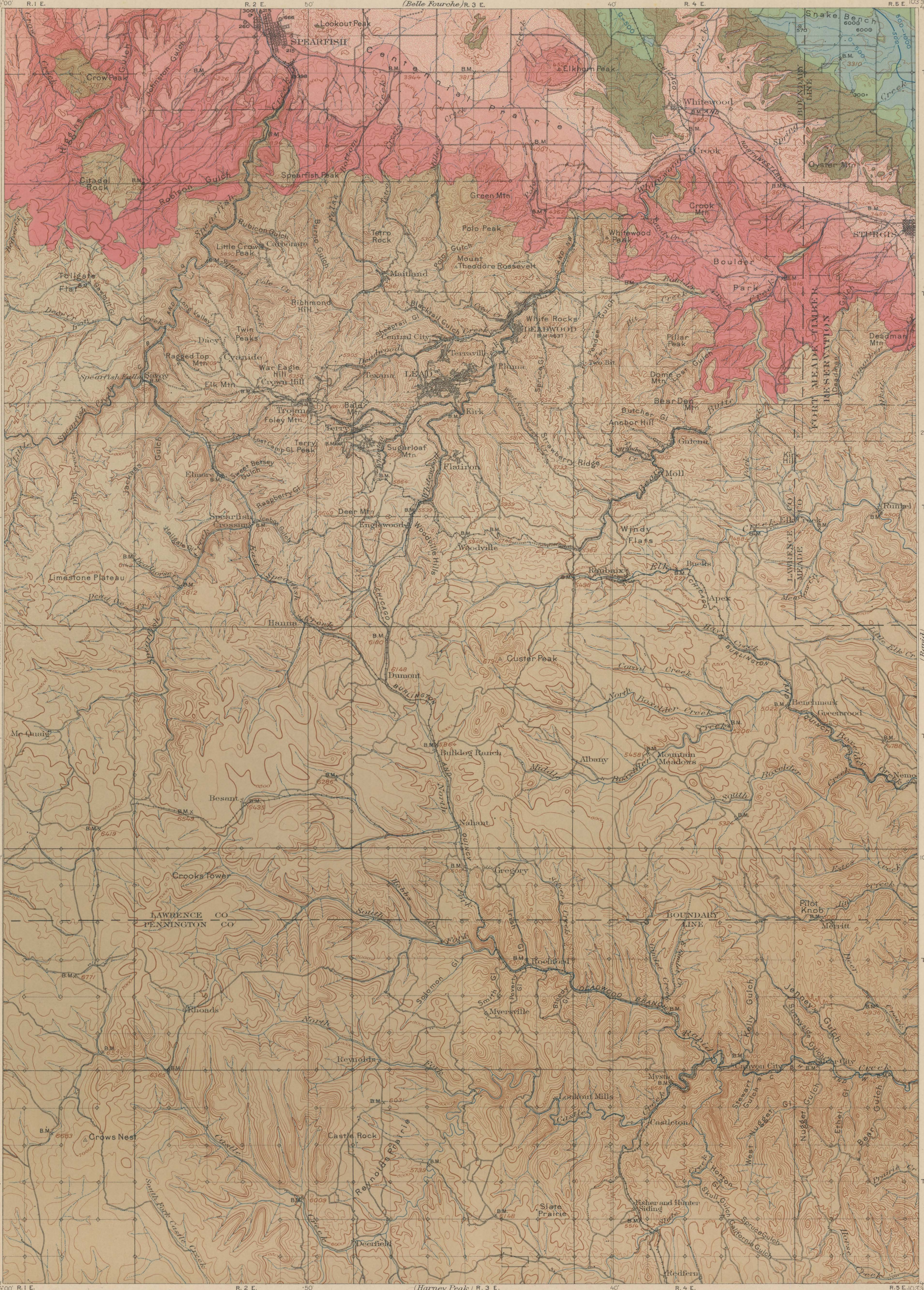
ARTESIAN WATER

SOUTH DAKOTA
DEADWOOD QUADRANGLE



EXPLANATION

Area of Dakota sandstone that will probably yield flowing wells
(flowing water may be expected from 25 to 200 feet below the top of the formation)

Area of Dakota sandstone that will probably yield pumping wells

Depth to top of Dakota sandstone

Outcrop of Dakota and associated underlying sandstones
(area in which surface waters enter water-bearing strata; in part covered by Tertiary and Quaternary deposits)

Outcrop
0-500
500-1200
Outcrop of and depths to Minnelusa sandstone
(flowing water may probably be obtained in valleys from the Minnelusa sandstone at depths indicated. The artesian water enters the formation in its area of outcrop which is in part covered by Tertiary and Quaternary deposits)

Area probably not underlain by water-bearing formations
(the Deadwood formation, which underlies a considerable part of the area, is probably not here generally waterbearing)

⊙600 Flowing Wells
Depth in feet to principal flow

E.M. Douglas, Geographer in charge.
Triangulation by E.M. Douglas and Frank Tweedy.
Topography by W. H. Herron, A.F. Dunnington and Arthur Stiles.
Surveyed in 1897-98.
Partially revised in 1913 by R.W. Berry.

TRUE NORTH
MAGNETIC NORTH
15½°
APPROXIMATE MEAN DECLINATION, 1920.

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 100 feet.
Datum is mean sea level.
Edition of Nov. 1922.

DIAGRAM OF TOWNSHIP

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

Hydrology by N.H. Darton
Surveyed in 1900-1915.

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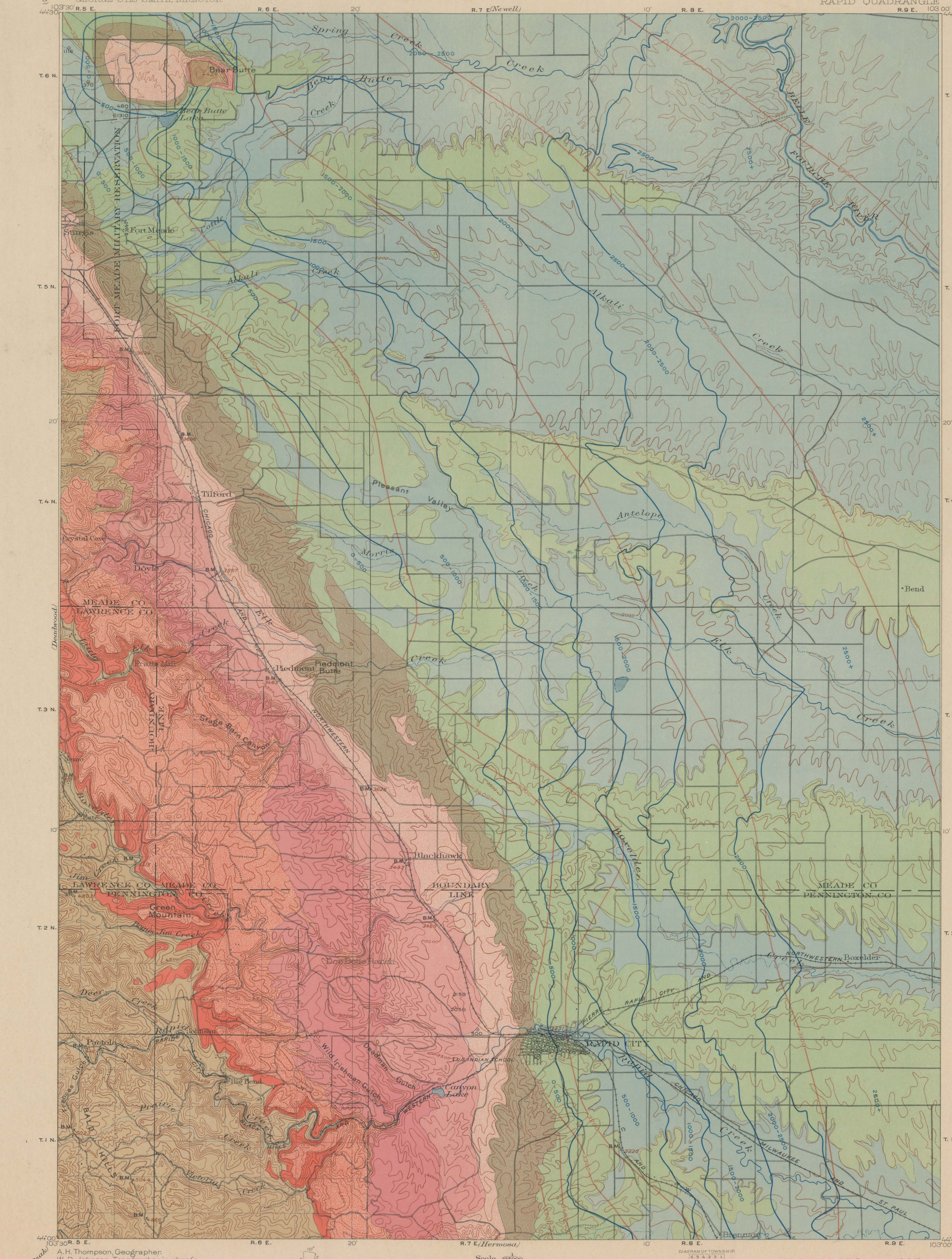
GEORGE OTIS SMITH, DIRECTOR

ARTESIAN WATER

SOUTH DAKOTA
RAPID QUADRANGLE



EXPLANATION

Area of Dakota sandstone that will probably yield flowing wells
(flowing water may be expected from 25 to 200 feet below the top of the formation)

Area of Dakota sandstone that will probably yield pumping wells

Depth to top of Dakota sandstone

Contour lines showing head or approximate altitude above sea level to which artesian water in Dakota sandstone may rise

Outcrop of Dakota and associated underlying sandstones
(area in which surface waters enter water-bearing strata; in part covered by Tertiary and Quaternary deposits)

Outcrop of and depths to Deadwood sandstone	Outcrop of and depths to Minnelusa sandstone
Outcrop	
0-500	
500-1000	Outcrop
1000-1500	0-500
1500-2200	500-1200
2200-2500	1200-1500

(flowing water may probably be obtained in valleys from the Minnelusa sandstone or the underlying Deadwood sandstone at depths indicated. The formations also underlie region to the east at gradually increasing depths. The artesian water enters the respective formations in their area of outcrop which is in part covered by Tertiary and Quaternary deposits)

Area not underlain by water-bearing formations

⊙1116 Flowing Wells
Depth in feet to principal flow

A. H. Thompson, Geographer.
W. D. Johnson, Topographer in charge.
Triangulation by E. M. Douglas.
Topography by R. A. Farmer and W. J. Lloyd.
Surveyed in 1891-98.

APPROXIMATE MEAN DECLINATION 1920.

Scale $\frac{1}{125000}$

Contour interval 100 feet.
Datum is mean sea level.
Edition of Nov. 1922.

DIAGRAM OF TOWNSHIP

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

Hydrology by N. H. Darton and C. C. O'Harra.
Surveyed in 1900-1915.

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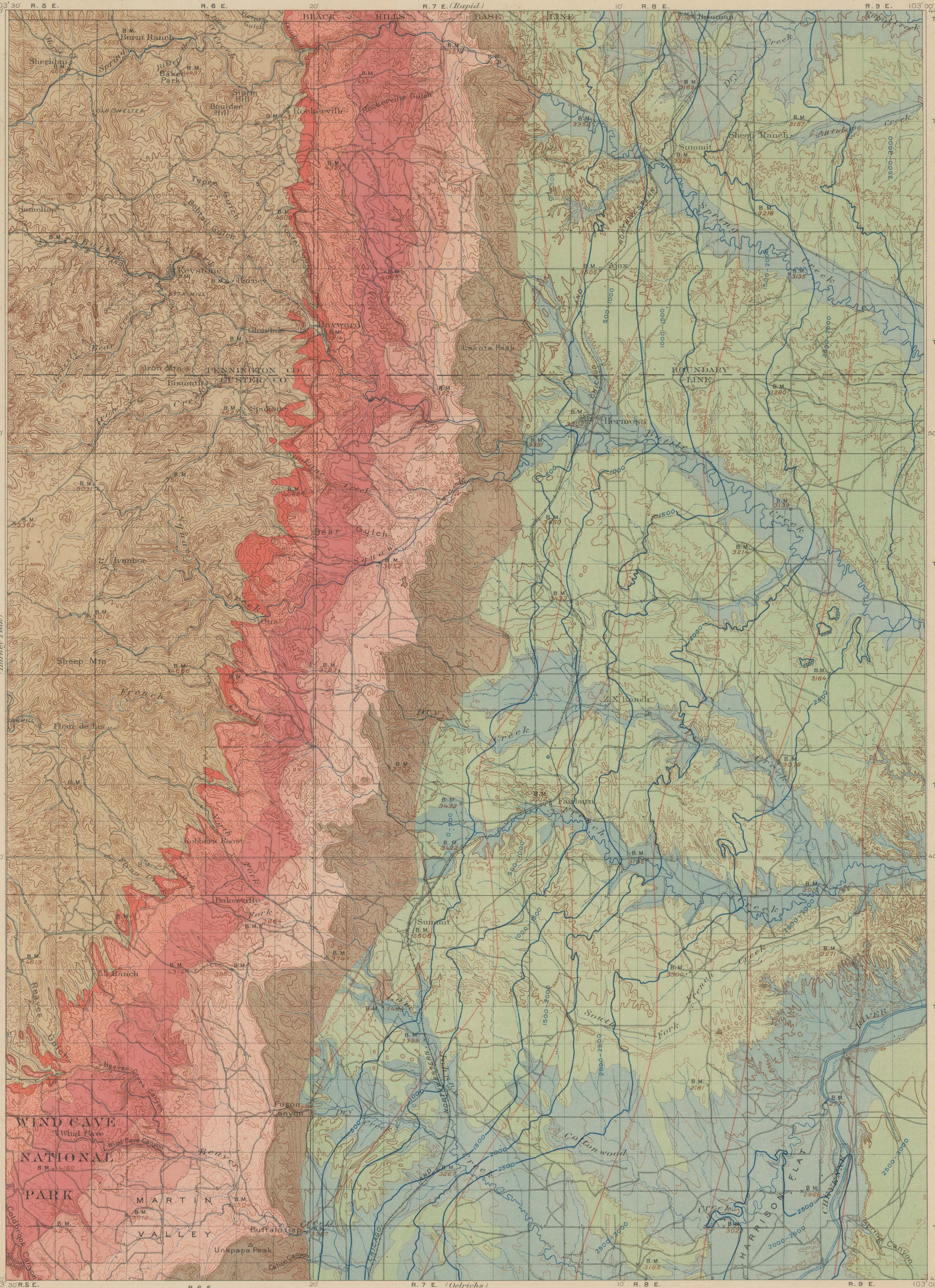
ARTESIAN WATER

SOUTH DAKOTA
HERMOSA QUADRANGLE



EXPLANATION

Area of Dakota sandstone that will probably yield flowing wells (flowing water may be expected from 25 to 200 feet below the top of the formation)

Area of Dakota sandstone that will probably yield pumping wells

Depth to top of Dakota sandstone

Contour lines showing head or approximate altitude above sea level to which artesian water in Dakota sandstone may rise

Outcrop of Dakota and associated underlying sandstones (area in which surface waters enter water-bearing strata; in part covered by Tertiary and Quaternary deposits)

Outcrop of and depths to Deadwood sandstone	Outcrop of and depths to Minnelusa sandstone
Outcrop	
0-350	
350-800	Outcrop
800-1300	0-500
1300-2000	500-1200
2000-2400	1200-1500

(flowing water may probably be obtained in valleys from the Minnelusa sandstone or the underlying Deadwood sandstone at depths indicated. The formations also underlie region to the east at gradually increasing depths. The artesian water enters the respective formations in their area of outcrop which is in part covered by Tertiary and Quaternary deposits)

Area not underlain by water-bearing formations

E.M. Douglas, Geographer in charge.
Triangulation by E.M. Douglas.
Topography by A.F. Dunnington.
Surveyed in 1898-99.

APPROXIMATE MEAN DECLINATION, 1920.

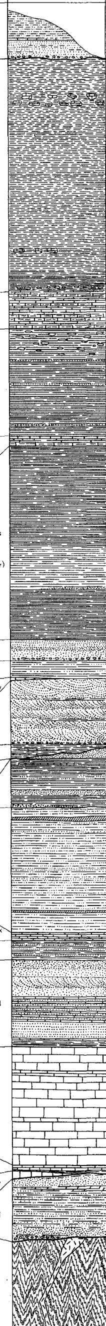
Scale $\frac{1}{125000}$

Contour interval 100 feet.
Datum is mean sea level.
Edition of Nov. 1922.

DIAGRAM OF TOWNSHIP

Hydrology by N.H. Darton.
Surveyed in 1900-1915.

COLUMNAR SECTION

GENERALIZED SECTION OF THE SEDIMENTARY ROCKS OF THE CENTRAL BLACK HILLS, SOUTH DAKOTA. SCALE: 1 INCH=500 FEET.							
System.	**Series or Group.**	**Formation.**	**Symbol.**	**Section.**	**Thickness in Feet.**	**Character of Rocks.**	**Character of Topography and Soil.**
TERTIARY	OLIGOCENE; WHITE RIVER GROUP	Brule clay and Chadron formation undifferentiated.	Tw		0-250	Sand, gravel, clay, fuller's earth, sandstone, and limestone.	Valleys and saddles among the ridges and plateaus, with badlands.
		UNCONFORMITY					
CRETACEOUS	UPPER CRETACEOUS; MONTANA GROUP	Pierre shale.	Kp		1,000-1,200	Principal horizon of limestone lenses giving rise to tepee buttes. Dark-gray shale containing scattered concretions. Widely scattered limestone masses giving rise to small tepee buttes. Black fissile shale containing cone-in-cone and other concretions.	Small rocky, sharply conical hills or tepee buttes. Wide, rolling plains with shallow valleys. Clay soil, in greater part sodded.
CRETACEOUS	UPPER CRETACEOUS; COLORADO GROUP	Niobrara formation.	Kn		175-225	Impure chalky limestone or calcareous clay, containing many shells of *Ostrea congesta*.	Valleys or flat areas with fertile soil.
CRETACEOUS	UPPER CRETACEOUS; COLORADO GROUP	Carlile shale.	Kcr		500-750	Light-gray shale containing numerous large concretions and sandy layers. Dark-gray shale.	Rolling plains and valleys. Clay soil.
CRETACEOUS	UPPER CRETACEOUS; COLORADO GROUP	Greenhorn limestone.	Kg		50-65	Impure slabby limestone which weathers light buff and contains many shells of *Inoceramus labiatus*.	Low ridges with thin soil.
CRETACEOUS	UPPER CRETACEOUS; COLORADO GROUP	Graneros shale. (Mowry shale member.)	Kgs (Kmr)		900-1,150 (225-250)	Dark-gray shale. Shale that weathers light gray and contains numerous fish scales. Sandstone locally at base. Dark fissile shale.	Wide rolling plains. Clay soil. Wooded ridges. Rolling plains and valleys. Clay soil.
CRETACEOUS	UPPER CRETACEOUS	Dakota sandstone.	Kd		25-200	Massive sandstone, weathering brown, thinner-bedded at top. Conglomerate locally at base.	Rocky slopes and cliffs. Sandy soil.
CRETACEOUS	LOWER CRETACEOUS	Fuson shale.	Kf		30-188	Massive gray to purple shale or clay.	Slopes with clay soil, partly bare.
		OVERLAP					
CRETACEOUS	LOWER CRETACEOUS	Minnewaste limestone.	Kmw		0-25	Massive gray limestone; present only in extreme southeastern part.	Outer slope of hogback ridges.
CRETACEOUS	LOWER CRETACEOUS	Lakota sandstone.	Klk		70-485	Coarse hard cross-bedded sandstone, mostly buff to gray. Conglomerate at base.	Hogback ridges, sloping plateaus, cliffs, and canyons. Thin sandy soil.
		OVERLAP SOUTHWARD					
CRETACEOUS?		Morrison shale.	Km		0-220	Greenish to maroon shale and thin limestone. Absent in southern part.	Inner slope of hogback ridges. Clay soil.
		UNCONFORMITY					
JURASSIC	UPPER JURASSIC	Unkpapa sandstone.	Ju		0-225	Soft massive fine-grained sandstone. Absent in western and northwestern parts.	Steep slopes, mostly covered by talus.
JURASSIC	UPPER JURASSIC	Sundance formation.	Jsd		70-300	Sandstone, shale, and thin fossiliferous limestone.	Inner slopes of hogback ridges, mostly covered by talus.
		UNCONFORMITY					
TRIASSIC ?		Spearfish formation.	Ꞧs		500-700	Gypsum overlain by red shale. Red sandy shale, soft red sandstone, and gypsum beds. Gypsum locally near base.	Wide valley with thin barren red soil except where covered by alluvium.
(?)	(?)						
CARBONIFEROUS	PERMIAN ?	Minnekahta limestone.	Cmk		30-50	Massive gray, thinly laminated limestone.	Rocky slopes and canyon walls. Thin soil.
CARBONIFEROUS	PERMIAN ?	Opeche formation.	Co		75-115	Red shale and red slabby sandstone.	Slopes of limestone ridges, mostly covered by talus.
CARBONIFEROUS	PENNSYLVANIAN	Minnelusa sandstone.	Cml		400-600	Massive granular sandstone, slabby sandstone, and limestone of reddish, buff, and white colors. Red shale and white concretionary limestone at base.	Rocky ridges, mountain slopes, and canyon walls. Sandy soil.
CARBONIFEROUS	MISSISSIPPIAN	Pahasapa limestone.	Cp		300-630	Mostly massive light-colored limestone weathering dove-colored.	High ridges, plateaus, and cliffs. Thin fertile soil.
CARBONIFEROUS	MISSISSIPPIAN	Englewood limestone.	Ce		30-60	Pale-pink to buff slabby limestone, with shale locally at base.	Slopes, mostly covered by talus.
		UNCONFORMITY					
ORDOVICIAN	UPPER ORDOVICIAN	Whitewood limestone.	Ow		0-80	Massive buff limestone. Present only in northwestern part.	Cliff or bench in canyon wall.
		UNCONFORMITY					
CAMBRIAN	UPPER CAMBRIAN	Deadwood formation.	€d		40-500	Massive buff to brown sandstone at top locally overlain by green shale. Greenish glauconitic shale, flaggy dolomite, and flat-pebble limestone conglomerate. Sandstone and locally quartz conglomerate at base.	Wide high plateaus, ridges, slopes, and canyon walls. Sandy soil.
		UNCONFORMITY					
PRE-CAMBRIAN		Schist, slate, grit, granite, and other igneous rocks.				Micaceous, quartzitic, garnetiferous, calcareous, and other schists, slate, quartzite, and arkosic grit, intruded by granite, amphibolite, monzonite, and other igneous rocks in laccoliths, sills, and dikes.	High rocky ridges and valleys. Fertile soil in parts of intervening valleys.

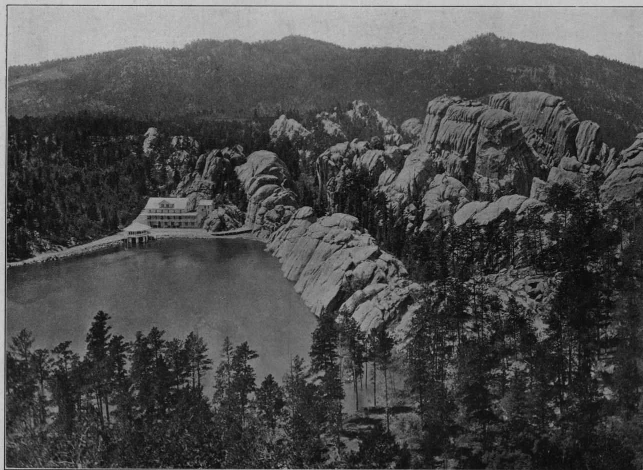


PLATE I.—CHARACTERISTIC EROSION FORMS IN MASSIVE GRANITE AT SYLVAN LAKE.
View northeastward. Harney Peak in distance.

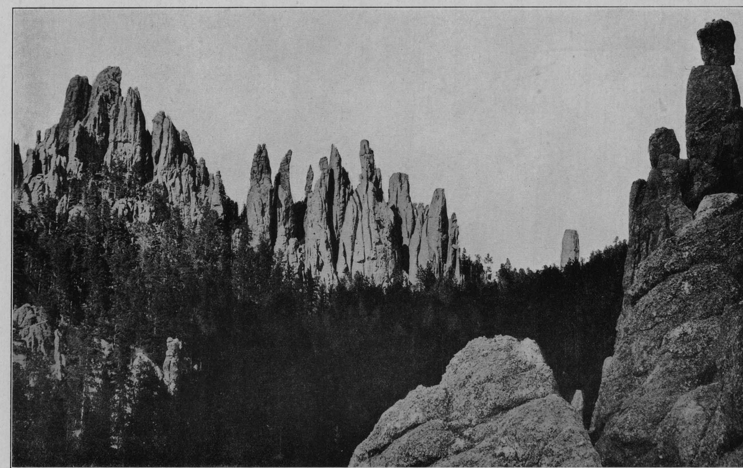


PLATE II.—THE NEEDLES: EROSION FORMS OF MASSIVE GRANITE AT SOUTH END OF HARNEY PEAK RIDGE, EAST OF SYLVAN LAKE.
View southeastward.

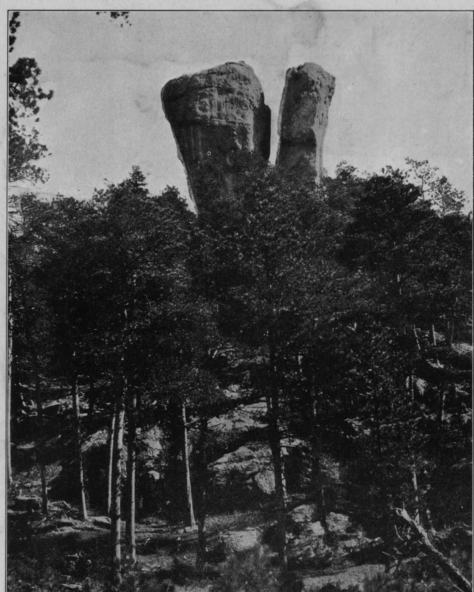


PLATE III.—BEECHER ROCKS: PINNACLED EROSION FORM OF GRANITE DIKE 6 MILES SOUTH OF CUSTER.

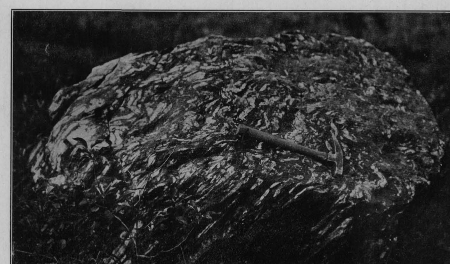


PLATE IV.—TYPICAL BRECCIATION IN OXIDIZED OUTCROP OF PROMINENT QUARTZ-PYRITE REPLACEMENT VEIN THAT EXTENDS SOUTHWARD FROM HAY CREEK.

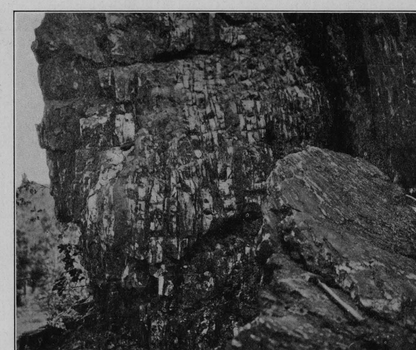


PLATE V.—BANDING OF QUARTZITE AND SLATE IN OXIDIZED WALL-LIKE OUTCROP OF QUARTZ-PYRITE REPLACEMENT VEIN THAT EXTENDS SOUTHWARD FROM HAY CREEK.

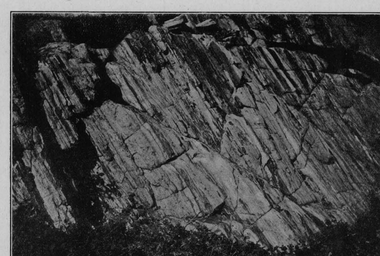


PLATE VI.—QUARTZITE-SLATE BANDING IN ALGONKIAN QUARTZITE IN OUTCROP ON ELK CREEK 1½ MILES WEST OF FORMER ELK CREEK POST OFFICE.

PLATE VII.—LARGE CRYSTALS OF SPODUMENE IN GRANITE DIKE AT ETTA MINE, NEAR KEYSTONE.

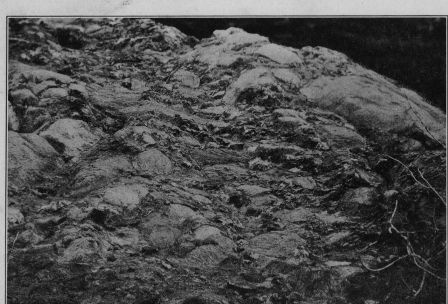


PLATE VIII.—VERY COARSE CONGLOMERATE IN ALGONKIAN ROCKS ON NORTH SIDE OF ESTES CREEK.

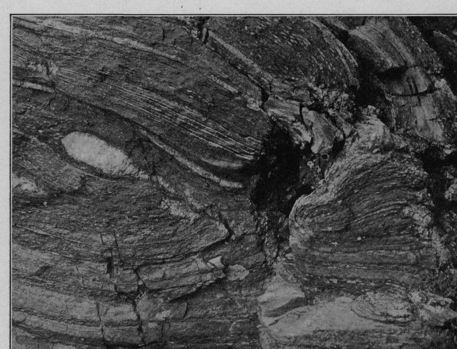


PLATE IX.—INTRICATE INJECTION OF GRANITE INTO ALGONKIAN SCHIST AT SOUTHERN BORDER OF HARNEY PEAK INTRUSIVE MASS.

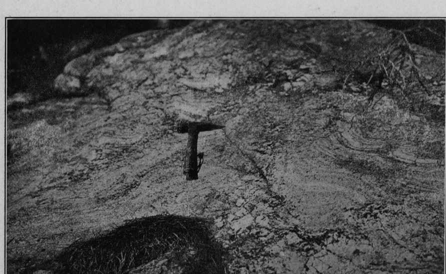


PLATE X.—REMNANT OF MASS OF ALGONKIAN SCHIST, RECOGNIZABLE BY BANDING, NEARLY ASSIMILATED BY INVADING GRANITE IN CONTACT ZONE NORTH OF CUSTER.

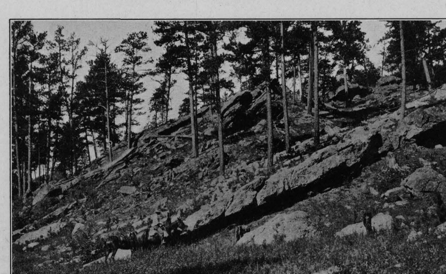


PLATE XI.—GRANITE INVADING ALGONKIAN SCHIST IN NUMEROUS PARALLEL SILLS IN BORDER ZONE OF GRANITE INTRUSION NORTHEAST OF CUSTER.

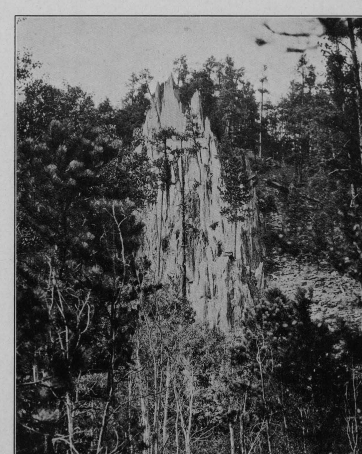


PLATE XII.—ALGONKIAN SILICEOUS SCHIST AND ARKOSIC GRIT WEATHERED INTO PINNACLES WEST OF NEMO.

PLATE XIII.—CONGLOMERATE AT BASE OF DEADWOOD FORMATION ON ELK CREEK.
Boulders of Algonkian quartzite and schist in matrix of yellow sand.

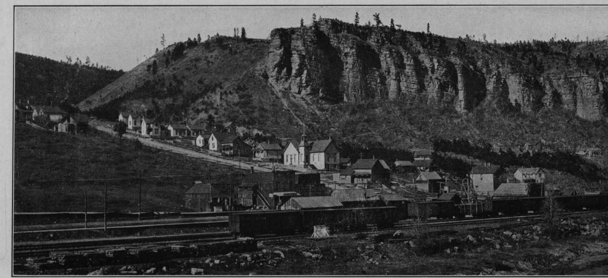


PLATE XIV.—DEADWOOD FORMATION IN NORTHERN PART OF DEADWOOD.
Thick mass of regularly bedded sandstone near top of formation. View northwestward.

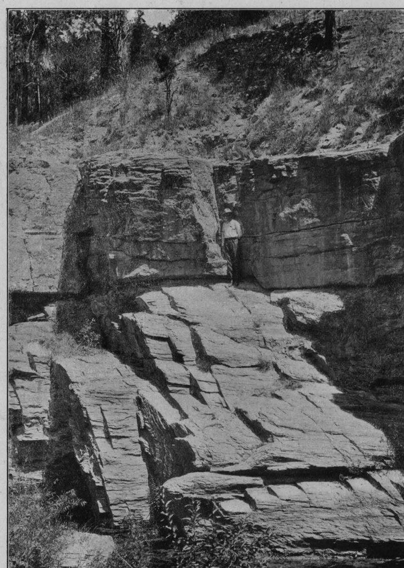


PLATE XV.—CONTACT OF NEARLY HORIZONTAL DEADWOOD FORMATION WITH UNDERLYING JOINTED ALGONKIAN SCHIST IN COLDBROOK CANYON 4 MILES SOUTHWEST OF WIND CAVE.
The man stands at the contact. View northward.

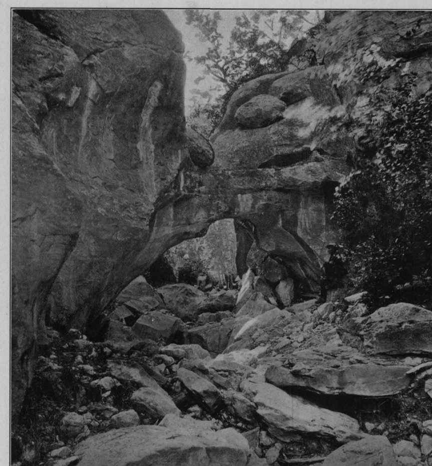


PLATE XVI.—NATURAL BRIDGE IN BANDED UNKPAPA SANDSTONE 2 MILES WEST OF BUFFALO GAP.
Shows massive structure and cross-bedding of formation.

PLATE XVII.—TYPICAL CLIFFS OF PAHASAPA LIMESTONE AT MOUTH OF HELLGATE GULCH, IN SPEARFISH CANYON 6 MILES WEST OF ENGLEWOOD.

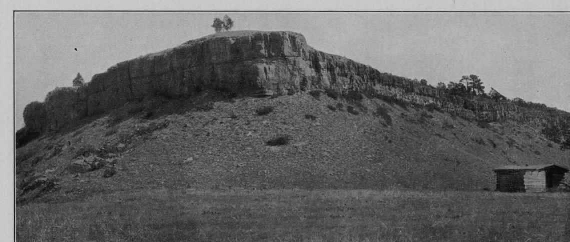


PLATE XVIII.—TYPICAL ESCARPMENT OF MINNEKAHTA LIMESTONE CAPPING HILL AND SURMOUNTING RED SHALE OF OPECHE FORMATION ON SLOPE IN GILLETTE CANYON.

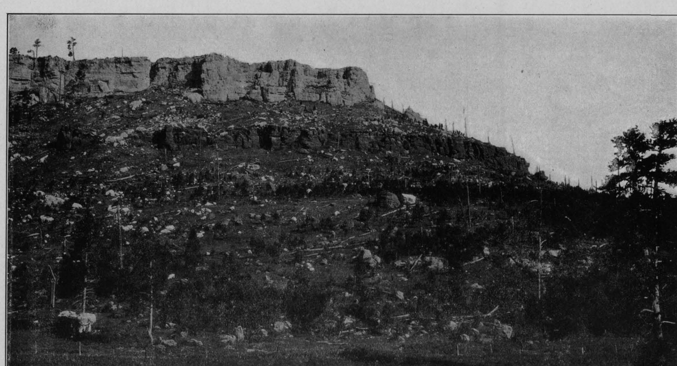


PLATE XIX.—PAHASAPA LIMESTONE CAPPING MESA AND DEADWOOD FORMATION ON STEEP SLOPES OF CANYON OF BOXELDER CREEK OPPOSITE MOUTH OF JIM CREEK.
View northward Upper dark ledge is massive purplish sandstone near top of Deadwood formation.

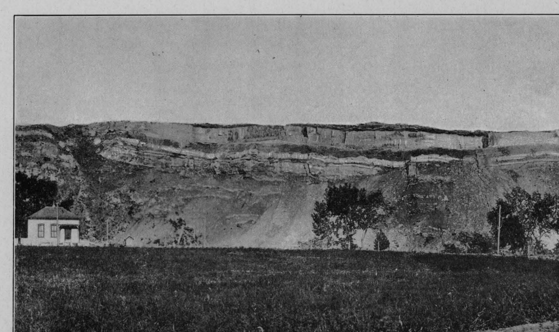


PLATE XX.—THICK BEDS OF WHITE GYPSUM IN SPEARFISH FORMATION IN EAST BANK OF COLD BROOK 1 MILE ABOVE HOT SPRINGS.

PLATE XXI.—TYPICAL GORGE IN MINNEKAHTA LIMESTONE (IN FOREGROUND) WORKING BACK INTO VALLEY OF RED SHALE OF SPEARFISH FORMATION SOUTH OF SPEARFISH.

PLATE XXII.—INCLINED BEDS OF MINNELUSA SANDSTONE DIPPING WESTWARD INTO BOULDER PARK SYNCLINE ON BEAR BUTTE CREEK 4 MILES WEST-SOUTHWEST OF STURGIS.

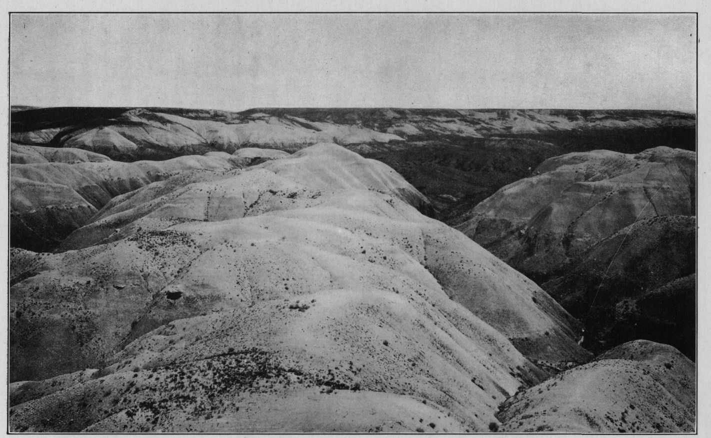


PLATE XXIII.—CHADRON FORMATION OF WHITE RIVER GROUP ON DIVIDE BETWEEN FRENCH CREEK AND CHEYENNE RIVER 7 MILES SOUTHEAST OF FAIRBURN.
View eastward. Underlying dark Pierre shale is exposed in ravines.

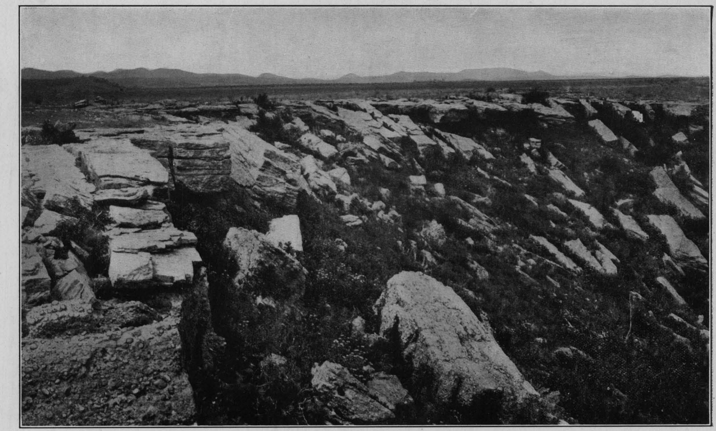


PLATE XXIV.—CONGLOMERATE OF WHITE RIVER GROUP FORMING MESA SOUTH OF RAPID CITY.
View northwestward toward slope of Hogback Ridge (in distance).

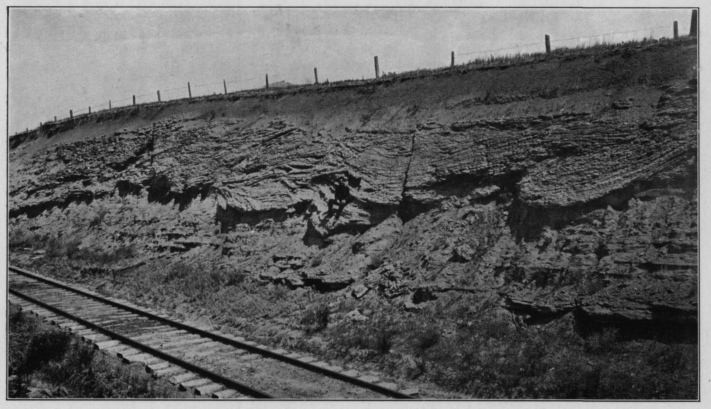


PLATE XXV.—CROSS-BEDDED CONGLOMERATE OF WHITE RIVER GROUP IN CUT OF CHICAGO & NORTHWESTERN RAILWAY 6 MILES SOUTHWEST OF FAIRBURN.

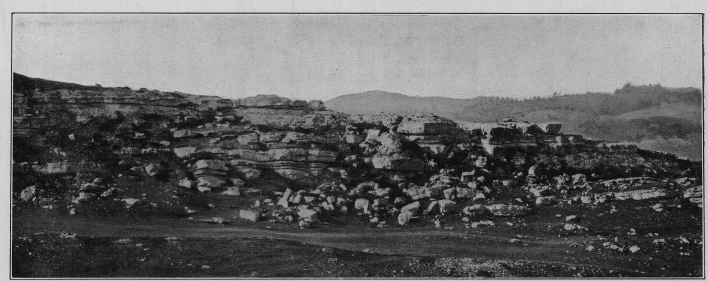


PLATE XXVI.—LIMESTONE IN WHITE RIVER GROUP IN RED VALLEY 9 MILES NORTHWEST OF HERMOSA.
View northeastward. Hogback Ridge in distance at right.

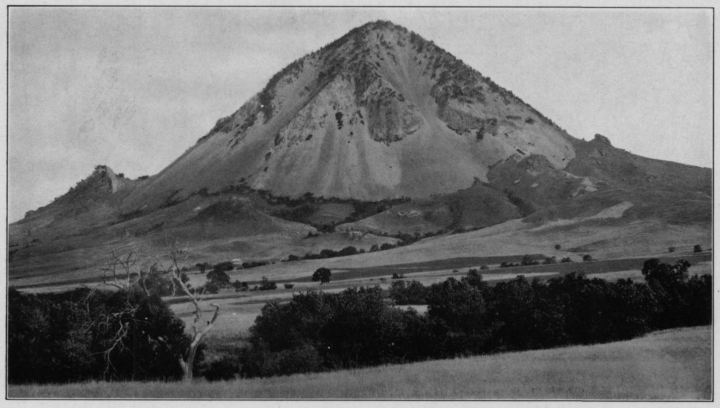


PLATE XXVII.—BEAR BUTTE AS SEEN FROM THE NORTH.
A conical laccolithic intrusive mass. Ridge of vertical Pahasapa limestone at left; knob of Minnelusa sandstone and slopes of Sundance formation at right.

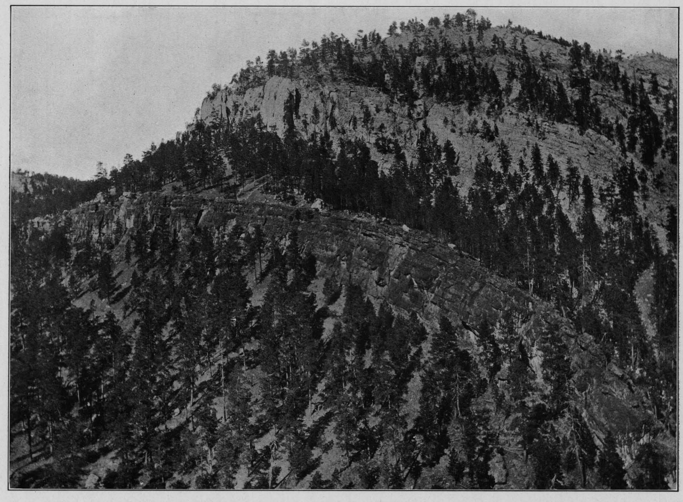


PLATE XXVIII.—GREAT ARCH OF UPPER PURPLISH SANDSTONE MEMBER OF DEADWOOD FORMATION IN LOWER CLIFF AND WHITE PAHASAPA LIMESTONE IN UPPER CLIFFS IN CANYON OF LITTLE ELK CREEK, 2 MILES WEST OF PIEDMONT.
View northeastward.

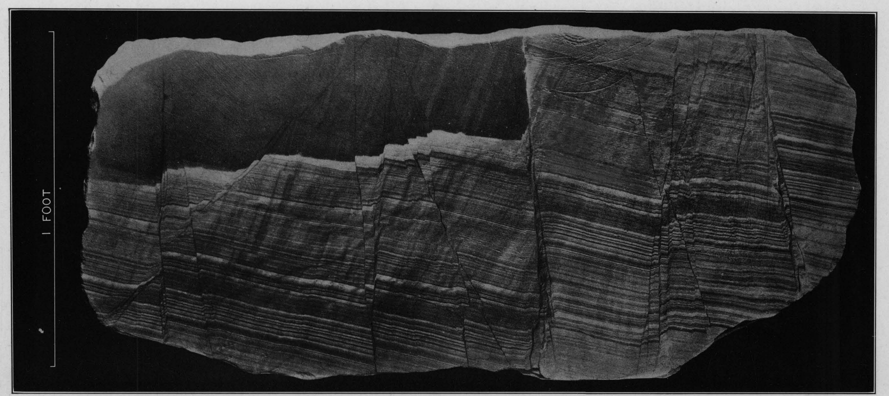


PLATE XXIX.—SAWED BLOCK OF UNKPAPA SANDSTONE FROM LOCALITY WEST OF BUFFALO GAP, SHOWING MINUTE LAMINAE OFFSET BY STEP FAULTS.

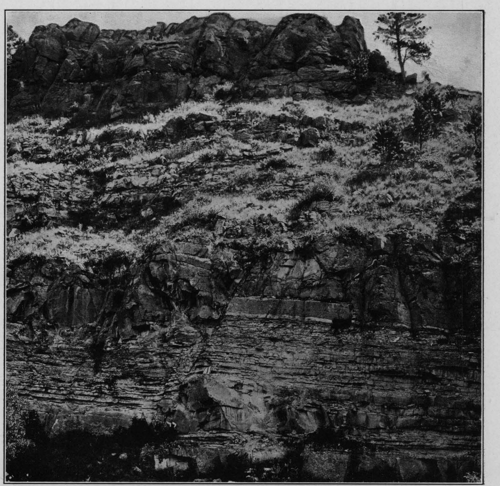


PLATE XXX.—DROP FAULT IN LAKOTA SANDSTONE IN NORTH WALL OF CANYON OF DRY CREEK 5 MILES NORTHWEST OF FAIRBURN.

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