DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

GEOLOGIC ATLAS

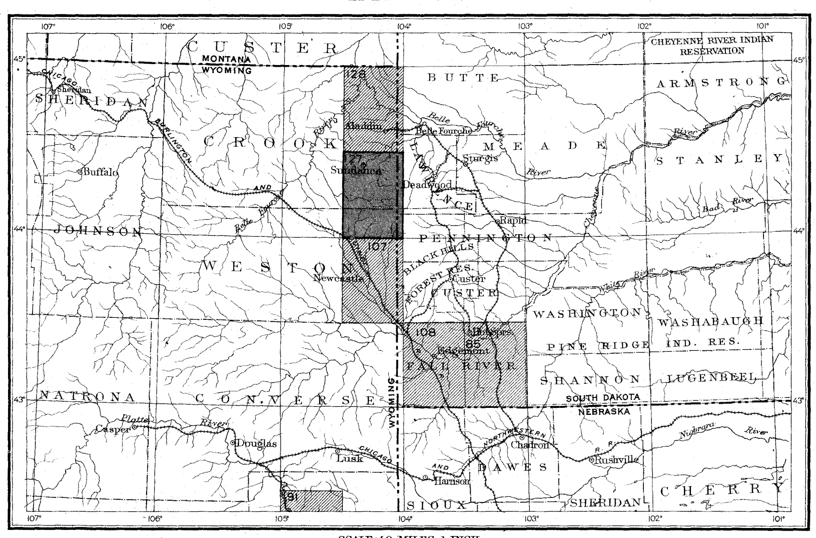
OF THE

UNITED STATES

SUNDANCE FOLIO

WYOMING - SOUTH DAKOTA

INDEX MAP



SCALE: 40 MILES - 1 INCH

SUNDANCE FOLIO

OTHER PUBLISHED FOLIOS

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GEORGE W. STOSE, EDITOR OF GEOLOGIC MAPS   S. J. KUBEL, CHIEF ENGRAVER

1905

GEOLOGIC AND TOPOGRAPHIC ATLAS OF UNITED STATES.

The Geological Survey is making a geologic map of the United States, which is being issued in parts, called folios. Each folio includes a topographic map and geologic maps of a small area of country, together with explanatory and descriptive texts.

THE TOPOGRAPHIC MAP.

The features represented on the topographic map are of three distinct kinds: (1) inequalities of surface, called *relief*, as plains, plateaus, valleys, hills, and mountains; (2) distribution of water, called *drainage*, as streams, lakes, and swamps; (3) the works of man, called *culture*, as roads, railroads, boundaries, villages, and cities.

Relief.—All elevations are measured from mean sea level. The heights of many points are accurately determined, and those which are most important are given on the map in figures. It is desirable, however, to give the elevation of all parts of the area mapped, to delineate the outline or form of all slopes, and to indicate their grade or steepness. This is done by lines each of which is drawn through points of equal elevation above mean sea level, the altitudinal interval represented by the space between lines being the same throughout each map. These lines are called *contours*, and the uniform altitudinal space between each two contours is called the *contour interval*. Contours and elevations are printed in brown.

The manner in which contours express elevation, form, and grade is shown in the following sketch and corresponding contour map (fig. 1).

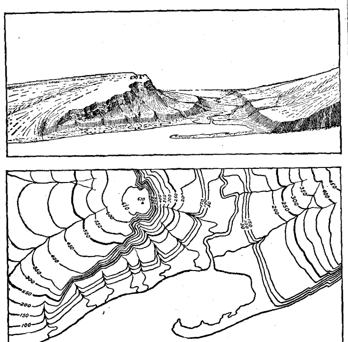


FIG. 1.—Ideal view and corresponding contour map.

The sketch represents a river valley between two hills. In the foreground is the sea, with a bay which is partly closed by a hooked sand bar. On each side of the valley is a terrace. From the terrace on the right a hill rises gradually, while from that on the left the ground ascends steeply, forming a precipice. Contrasted with this precipice is the gentle slope from its top toward the left. In the map each of these features is indicated, directly beneath its position in the sketch, by contours. The following explanation may make clearer the manner in which contours delineate elevation, form, and grade:

1. A contour indicates a certain height above sea level. In this illustration the contour interval is 50 feet; therefore the contours are drawn at 50, 100, 150, and 200 feet, and so on, above mean sea level. Along the contour at 250 feet lie all points of the surface that are 250 feet above sea; along the contour at 200 feet, all points that are 200 feet above sea; and so on. In the space between any two contours are found elevations above the lower and below the higher contour. Thus the contour at 150 feet falls just below the edge of the terrace, while that at 200 feet lies above the terrace; therefore all points on the terrace are shown to be more than 150 but less than 200 feet above sea. The summit of the higher hill is stated to be 670 feet above sea; accordingly the contour at 650 feet surrounds it. In this illustration all the contours are numbered, and those for 250 and 500 feet are accentuated by being made heavier. Usually it is not desirable to number all the contours, and then the accentuating and numbering of certain of them—say every fifth one—suffice, for the heights of others may be ascertained by counting up or down from a numbered contour.

2. Contours define the forms of slopes. Since contours are continuous horizontal lines, they wind smoothly about smooth surfaces, recede into all reentrant angles of ravines, and project in passing about prominences. These relations of contour curves and angles to forms of the landscape can be traced in the map and sketch.

3. Contours show the approximate grade of any slope. The altitudinal space between two contours is the same, whether they lie along a cliff or on a gentle slope; but to rise 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 ones.

For a flat or gently undulating country a small contour interval is used; for a steep or mountainous country a large interval is necessary. The smallest interval used on the atlas sheets of the Geological Survey is 5 feet. This is serviceable for regions like the Mississippi delta and the Dismal Swamp. In mapping great mountain masses, like those in Colorado, the interval may be 250 feet. For intermediate relief contour intervals of 10, 20, 25, 50, and 100 feet are used.

Drainage.—Watercourses are indicated by blue lines. If a stream flows the entire year the line is drawn unbroken, but if the channel is dry a part of the year the line is broken or dotted. Where a stream sinks and reappears at the surface, the supposed underground course is shown by a broken blue line. Lakes, marshes, and other bodies of water are also shown in blue, by appropriate conventional signs.

Culture.—The works of man, such as roads, railroads, and towns, together with boundaries of townships, counties, and States, are printed in black.

Scales.—The area of the United States (excluding Alaska and island possessions) is about 3,025,000 square miles. A map representing this area, drawn to the scale of 1 mile to the inch, would cover 3,025,000 square inches of paper, and to accommodate the map the paper would need to measure about 240 by 180 feet. Each square mile of ground surface would be represented by a square inch of map surface, and one linear mile on the ground would be represented by a linear inch on the map. This relation between distance in nature and corresponding distance on the map is called the *scale* of the map. In this case it is "1 mile to an inch." The scale may be expressed also by a fraction, of which the numerator is a length on the map and the denominator the corresponding length in nature expressed in the same unit. Thus, as there are 63,360 inches in a mile, the scale "1 mile to an inch" is expressed by $\frac{1}{63,360}$.

Three scales are used on the atlas sheets of the Geological Survey; the smallest is $\frac{1}{250,000}$, the intermediate $\frac{1}{125,000}$, and the largest $\frac{1}{62,500}$. These correspond approximately to 4 miles, 2 miles, and 1 mile on the ground to an inch on the map. On the scale $\frac{1}{62,500}$ a square inch of map surface represents about 1 square mile of earth surface; on the scale $\frac{1}{125,000}$, about 4 square miles; and on the scale $\frac{1}{250,000}$, about 16 square miles. At the bottom of each atlas sheet the scale is expressed in three ways—by a graduated line representing miles and parts of miles in English inches, by a similar line indicating distance in the metric system, and by a fraction.

Atlas sheets and quadrangles.—The map is being published in atlas sheets of convenient size, which represent areas bounded by parallels and meridians. These areas are called *quadrangles*. Each sheet on the scale of $\frac{1}{250,000}$ contains one square degree—i. e., a degree of latitude by a degree of longitude; each sheet on the scale of $\frac{1}{125,000}$ contains one-fourth of a square degree; each sheet on the scale of $\frac{1}{62,500}$ contains one-sixteenth of a square degree. The areas of the corresponding quadrangles are about 4000, 1000, and 250 square miles.

The atlas sheets, being only parts of one map of the United States, disregard political boundary lines, such as those of States, counties, and townships. To each sheet, and to the quadrangle it represents, is given the name of some well-known town or natural feature within its limits, and at the sides and corners of each sheet the names of adjacent sheets, if published, are printed.

Uses of the topographic map.—On the topographic map are delineated the relief, drainage, and culture of the quadrangle represented. It should portray to the observer every characteristic feature of the landscape. It should guide the traveler; serve the investor or owner who desires to ascertain the position and surroundings of property; save the engineer preliminary surveys in locating roads, railways, and irrigation reservoirs and ditches; provide educational material for schools and homes; and be useful as a map for local reference.

THE GEOLOGIC MAPS.

The maps representing the geology show, by colors and conventional signs printed on the topographic base map, the distribution of rock masses on the surface of the land, and the structure sections show their underground relations, as far as known and 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.—These are rocks which have cooled and consolidated from a state of fusion. Through rocks of all ages molten material has from time to time been forced upward in fissures or channels of various shapes and sizes, to or nearly to the surface. Rocks formed by the consolidation of the molten mass within these channels—that is, below the surface—are called *intrusive*. When the rock occupies a fissure with approximately parallel walls the mass is called a *dike*; when it fills a large and irregular conduit the mass is termed a *stock*. When the conduits for molten magmas traverse stratified rocks they often send off branches parallel to the bedding planes; the rock masses filling such fissures are called *sills* or *sheets* when comparatively thin, and *laccoliths* when occupying larger chambers produced by the force propelling the magmas upward. Within rock inclosures molten material cools slowly, with the result that intrusive rocks are generally of crystalline texture. When the channels reach the surface the molten material poured out through them is called *lava*, and lavas often build up volcanic mountains. Igneous rocks thus formed upon the surface are called *extrusive*. Lavas cool rapidly in the air, and acquire a glassy or, more often, a partially crystalline condition in their outer parts, but are more fully crystalline in their inner portions. The outer parts of lava flows are usually more or less porous. Explosive action often accompanies volcanic eruptions, causing ejections of dust, ash, and larger fragments. These materials, when consolidated, constitute breccias, agglomerates, and tuffs. Volcanic ejecta may fall in bodies of water or may be carried into lakes or seas and form sedimentary rocks.

Sedimentary rocks.—These rocks are composed of the materials of older rocks which have been broken up and the fragments of which have been carried to a different place and deposited.

The chief agent of 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 are then said to be mechanical. Such are gravel, sand, and clay, which are later consolidated into conglomerate, sandstone, and shale. In smaller portion the materials are carried in solution, and the deposits are then called organic if formed with the aid of life, or chemical if formed without the aid of life. The more important rocks of chemical and organic origin are limestone, chert, gypsum, salt, iron ore, peat, lignite, and coal. Any one of the deposits may be separately formed, 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 glacial deposits is till, a heterogeneous mixture of bowlders and pebbles with clay or sand.

Sedimentary rocks are usually made up of layers or beds which can be easily separated. These layers are called *strata*. Rocks deposited in layers are said to be stratified.

The surface of the earth is not fixed, as it seems to be; it very slowly rises or sinks, with reference to the sea, over wide expanses; and as it rises or subsides the shore lines of the ocean are changed. As a result of the rising of the surface, marine sedimentary rocks may become part of the land, and extensive land areas are in fact occupied by such rocks.

Rocks exposed at the surface of the land are acted upon by air, water, ice, animals, and plants. They are gradually broken into fragments, and the more soluble parts are leached out, leaving the less soluble as a *residual* layer. Water washes residual material down the slopes, and it is eventually carried by rivers to the ocean or other bodies of standing water. Usually its journey is not continuous, but it is temporarily built into river bars and flood plains, where it is called *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. Their upper parts, occupied by the roots of plants, constitute soils and subsoils, the soils being usually distinguished by a notable admixture of organic matter.

Metamorphic rocks.—In the course of time, and by a variety of processes, rocks may become greatly changed in composition and in texture. When the newly acquired characteristics are more pronounced than the old ones such rocks are called *metamorphic*. In the process of metamorphism the substances of which a rock is composed may enter into new combinations, certain substances may be lost, or new substances may be added. There is often a complete gradation from the primary to the metamorphic form within a single rock mass. Such changes transform sandstone into quartzite, limestone into marble, and modify other rocks in various ways.

From time to time in geologic history igneous and sedimentary rocks have been deeply buried and later have been raised to the surface. In this process, through the agencies of pressure, movement, and chemical action, their original structure may be entirely lost and new structures appear. Often there is developed a system of division planes along which the rocks split easily, and these planes may cross the strata at any angle. This structure is called *cleavage*. Sometimes crystals of mica or other foliaceous minerals are developed with their laminæ approximately parallel; in such cases the structure is said to be schistose, or characterized by *schistosity*.

As a rule, the oldest rocks are most altered and the younger formations have escaped metamorphism, but to this rule there are important exceptions.

FORMATIONS.

For purposes of geologic mapping 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, a rapid alternation of shale and limestone. When the passage from one kind of rocks to another is gradual it is sometimes necessary to separate two contiguous formations by an arbitrary line, and in some cases the distinction depends almost entirely on the contained fossils. An igneous formation is constituted of one or more bodies either containing the same kind of igneous rock or having the same mode of occurrence. A metamorphic formation may consist of rock of uniform character or of several rocks having common characteristics.

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

AGES OF ROCKS.

Geologic time.—The time during which the rocks were made is divided into several *periods*. Smaller time divisions are called *epochs*, and still smaller ones *stages*. The age of a rock is expressed by naming the time interval in which it was formed, when known.

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

(Continued on third page of cover.)

As sedimentary deposits or strata accumulate the younger rest on those that are older, and the relative ages of the deposits may be determined by observing their positions. This relationship holds except in regions of intense disturbance; in such regions sometimes the beds have been reversed, and it is often difficult to determine their relative ages from their positions; then *fossils*, or the remains and imprints of plants and animals, indicate which of two or more formations is the oldest.

Stratified rocks often contain the remains or imprints of plants and animals which, at the time the strata were deposited, lived in the sea or were washed from the land into lakes or seas, or were buried in surficial deposits on the land. Such rocks are called fossiliferous. By studying fossils it has been found that the life of each period of the earth's history was to a great extent different from that of other periods. Only the simpler kinds of marine life existed 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 peculiar forms, which 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. When two sedimentary formations are remote from each other and it is impossible to observe their relative positions, the characteristic fossil types found in them may determine which was deposited first. Fossil remains found in the strata of different areas, provinces, and continents afford the most important means for combining local histories into a general earth history.

It is often difficult or impossible to determine the age of an igneous formation, but the relative age of such a formation can sometimes be ascertained by observing whether an associated sedimentary formation of known age is cut by the igneous mass or is deposited upon it.

Similarly, the time at which metamorphic rocks were formed from the original masses is sometimes 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 of their metamorphism.

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.

Symbols and colors assigned to the rock systems.

	System.	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		TR	Peacock-blue.
Paleozoic	Carboniferous	Permian; Pennsylvanian; Mississippian	C	Blue.
	Devonian		D	Blue-gray.
	Silurian		S	Blue-purple.
	Ordovician		O	Red-purple.
	Cambrian	Saratogan; Acadian; Georgian	Є	Brick-red.
	Algonkian		A	Brownish-red.
	Archean		AR	Gray-brown.

Patterns composed of parallel straight lines are used to represent sedimentary formations deposited in the sea or in lakes. 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 known to be of sedimentary or of igneous origin.

The patterns of each class are printed in various colors. With the patterns of parallel lines, colors are used to indicate age, a particular color being assigned to each system. The symbols by which formations are labeled consist each of two or more letters. If the age of a formation is known the symbol includes the system symbol, which is a capital letter or monogram; otherwise the symbols are composed of small letters. The names of the systems and recognized series, in proper order (from new to old), with the color and symbol assigned to each system, are given in the preceding table.

SURFACE FORMS.

Hills and valleys and all other surface forms have been produced by geologic processes. For example, most valleys are the result of erosion by the streams that flow through them (see fig. 1), and the alluvial plains bordering many streams were built up by the streams; sea cliffs are made by the eroding action of waves, and sand spits are built up by waves. Topographic forms thus constitute part of the record of the history of the earth.

Some forms are produced in the making of deposits and are inseparably connected with them. The hooked spit, shown in fig. 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, and these are, in origin, independent of the associated material. 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 first built and afterwards partly eroded away. The shaping of a marine or lacustrine plain, is usually a double process, hills being worn away (*degraded*) and valleys being filled up (*aggraded*).

All parts of the land surface are subject to the action of air, water, and ice, which slowly wear them down, and streams carry the waste material to the sea. As the process depends on the flow of water to the sea, it can not be carried below sea level, and the sea is therefore called the *base-level* of erosion. When a large tract is for a long time undisturbed by uplift or subsidence it is degraded nearly to base-level, and the even surface thus produced is called a *peneplain*. If the tract is afterwards uplifted the peneplain at the top is a record of the former relation of the tract to sea level.

THE VARIOUS GEOLOGIC SHEETS.

Areal geology map.—This map shows the areas occupied by the various formations. On the margin is a *legend*, which is the key to the map. To ascertain the meaning of any colored pattern and its letter symbol the reader should look for that color, pattern, and symbol in the legend, where he will find the name and description of the formation. If it is desired to find any given formation, its name should be sought in the legend and its color and pattern noted, when the areas on the map corresponding in color and pattern may be traced out.

The legend is also a partial statement of the geologic history. In it the formations are arranged in columnar form, grouped primarily according to origin—sedimentary, igneous, and crystalline of unknown origin—and within each group they are placed in the order of age, so far as known, the youngest at the top.

Economic geology map.—This map represents the distribution of useful minerals and rocks, showing their relations to the topographic features and to the geologic formations. The formations which appear on the areal geology map are usually shown on this map by fainter color patterns. The areal geology, thus printed, affords a subdued background upon which the areas of productive formations may be emphasized by strong colors. A mine symbol is printed at each mine or quarry, accompanied by the name of the principal mineral mined or stone quarried. For regions where there are important mining industries or where artesian basins exist special maps are prepared, to show these additional economic features.

Structure-section sheet.—This sheet exhibits the relations of the formations beneath the surface. In cliffs, canyons, shafts, and other natural and artificial cuttings, the relations of different beds to one another may be seen. Any cutting which exhibits those relations is called a *section*, and the same term is applied to a diagram representing the relations. The arrangement of rocks in the earth is the earth's *structure*, and a section exhibiting this arrangement is called a *structure section*.

The geologist is not limited, however, to the natural and artificial cuttings for his information concerning the earth's structure. Knowing the manner of formation of rocks, and having traced out the relations among the beds on the surface, he can infer their relative positions after they pass beneath the surface, and can draw sections representing the structure of the earth to a considerable depth. Such a section exhibits what would be seen in the side of a cutting many miles long and several thousand feet deep. This is illustrated in the following figure:

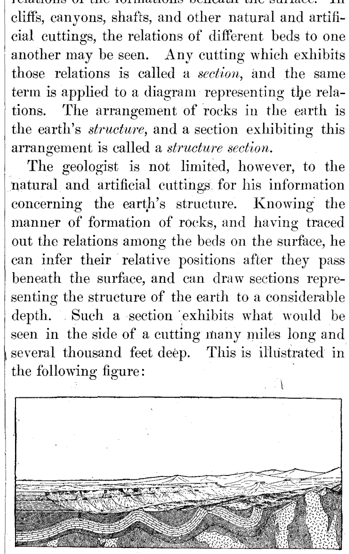


Fig. 2.—Sketch showing a vertical section at the front and a landscape beyond.

The figure represents a landscape which 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 symbols of lines, dots, and dashes. These symbols admit of much variation, but the following are generally used in sections to represent the commoner kinds of rock:

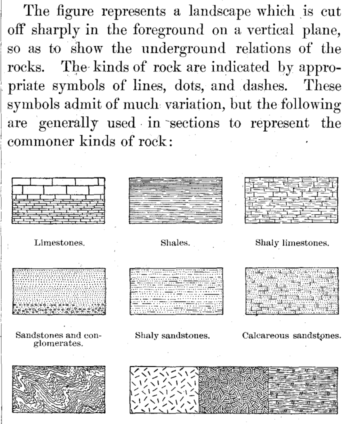


Fig. 3.—Symbols used in sections to represent different kinds of rocks.

The plateau in fig. 2 presents toward the lower land an escarpment, or front, which is made up of sandstones, forming the cliffs, and shales, constituting the slopes, as shown at the extreme left of the section. The broad belt of lower land is traversed by several ridges, which are seen in the section to correspond to the outcrops of a 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 strata appear at the surface their thickness can be measured and the angles at which they dip below the surface can be observed. Thus their positions underground can be inferred. The direction that the intersection of a bed with a horizontal plane will take is called the *strike*. The inclination of the bed to the horizontal plane, measured at right angles to the strike, is called the *dip*.

Strata are frequently curved in troughs and arches, such as are seen in fig. 2. The arches are called *anticlines* and the troughs *synclines*. But the sandstones, shales, and limestones were deposited beneath the sea in nearly flat sheets; that they are now bent and folded is proof that forces have from time to time caused the earth's surface to wrinkle along certain zones. In places the strata are broken across and the parts have slipped past each other. Such breaks are termed *faults*. Two kinds of faults are shown in fig. 4.

On the right of the sketch, fig. 2, the section is composed of schists which are traversed by masses of igneous rock. The schists are much contorted and their arrangement underground can not be

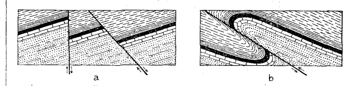


Fig. 4.—Ideal sections of strata, showing (a) *normal* faults and (b) a *thrust* fault.

inferred. Hence that portion of the section delineates what is probably true but is not known by observation or well-founded inference.

The section in fig. 2 shows three sets of formations, distinguished by their underground relations. The uppermost of these, seen at the left of the section, is a set of sandstones and shales, which lie in a horizontal position. These sedimentary strata are now high above the sea, forming a plateau, and their change of elevation shows that a portion of the earth's mass has been raised from a lower to a higher level. The strata of this set are parallel, a relation which is called *conformable*.

The second set of formations consists of strata which form arches and troughs. These strata were once continuous, but the crests of the arches have been removed by degradation. The beds, like those of the first set, are conformable.

The horizontal strata of the plateau rest upon the upturned, eroded edges of the beds of the second set at the left of the section. The overlying deposits are, from their positions, evidently younger than the underlying formations, and the bending and degradation of the older strata must have occurred between the deposition of the older beds and the accumulation of the younger. When younger rocks thus rest upon an eroded surface of older rocks the relation between the two is an *unconformable* one, and their surface of contact is an *unconformity*.

The third set of formations consists of crystalline schists and igneous rocks. At some period of their history the schists were plicated by pressure and traversed by eruptions of molten rock. But the pressure and intrusion of igneous rocks have not affected the overlying strata of the second set. Thus it is evident that a considerable interval elapsed between the formation of the schists and the beginning of deposition of the strata of the second set. During this interval the schists suffered metamorphism; they were the scene of eruptive activity; and they were deeply eroded. The contact between the second and third sets is another unconformity; it marks a time interval between two periods of rock formation.

The section and landscape in fig. 2 are ideal, but they illustrate relations which actually occur. The sections on the structure-section sheet are related to the maps as the section in the figure is related to the landscape. The profile of the surface in the section corresponds to the actual slopes of the ground along the section line, and the depth from the surface of any mineral-producing or water-bearing stratum which appears in the section may be measured by using the scale of the map.

Columnar section sheet.—This sheet contains a concise description of the sedimentary formations which occur in the quadrangle. It presents a summary of the facts relating to the character of the rocks, the thickness of the formations, and the order of accumulation of successive deposits.

The rocks are briefly described, and their characters are indicated in the columnar diagram. The thicknesses of formations are given in figures which state the least and greatest measurements, and the average thickness of each is shown in the column, which is drawn to a scale—usually 1000 feet to 1 inch. The order of accumulation of the sediments is shown in the columnar arrangement—the oldest formation at the bottom, the youngest at the top.

The intervals of time which correspond to events of uplift and degradation and constitute interruptions of deposition are indicated graphically and by the word "unconformity."

CHARLES D. WALCOTT,

Director.

Revised January, 1904.

DESCRIPTION OF THE SUNDANCE QUADRANGLE.

By N. H. Darton.

GEOGRAPHY.

POSITION AND EXTENT OF THE QUADRANGLE.

The Sundance quadrangle embraces the quarter of a square degree which lies between parallels 44° and 44° 30′ north latitude and meridians 104° and 104° 30′ west longitude. It measures approximately 34 miles from north to south and 25 miles from east to west, and its area is 856⅗ square miles. It comprises the southeast corner of Crook County and the northeast corner of Weston County, Wyo., and includes also a narrow area of Pennington and Lawrence counties, S. Dak. The quadrangle lies mainly in the Black Hills, but a small portion of its southwest corner extends out into the Great Plains. The district is drained by tributaries of Belle Fourche and Cheyenne rivers, the divide passing diagonally across the southern half of the quadrangle. Many features of the Black Hills are exhibited in this quadrangle, and, as its area is small, a general account of that region will be given before the detailed description of the quadrangle is presented.

THE BLACK HILLS.

General features.—In western South Dakota and eastern Wyoming a small group of mountains known as the Black Hills rises several thousand feet above the plains. The abundant rainfall and consequent vegetation and streams make the locality an oasis in the semiarid region. The hills are carved from a dome-shaped uplift of the earth's crust, and consist largely of rocks which are older than those forming the surface of the Great Plains and which contain valuable minerals. The length of the more elevated area is about 100 miles, and its greatest width is 50 miles. The hills rise abruptly from the plains, although the flanking ridges are of moderate elevation. The salient features are an encircling hogback ridge, constituting the outer rim of the hills; next a continuous depression, the Red Valley, which extends completely around the uplift; then a limestone plateau with infacing escarpment; and, finally, a central area of high ridges culminating in the precipitous crags of Harney Peak at an altitude of 7216 feet. Two branches of Cheyenne River nearly surround the hills and receive many tributaries from them.

The central area.—The central area of the Black Hills comprises an elevated basin, eroded in crystalline schists and granite, in which scattered rocky ridges and groups of mountains are interspersed with park-like valleys. The wider valleys are above the heads of canyons of greater or less size, which become deeper and steeper sided as they extend outward to the northeast, east, and south.

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 portion is much more extensive than its eastern and is broad and flat, sloping gently downward near its outer margin, but being level near its eastern inner side, which presents a line of cliffs many miles long and often 800 feet above the central valleys. It attains altitudes slightly more than 7000 feet, locally almost equaling Harney Peak in height, and forms the main divide of the Black Hills. The streams which flow down its western slope are affluents of Beaver Creek to the southwest and of the Belle Fourche to the northwest. They rise in shallow, park-like valleys in the plateau and sink into deep canyons with precipitous walls of limestone, often many hundred feet high. The limestone plateau extending southward swings around to the eastern side of the hills, where, owing to the greater dip of the strata, it narrows to a ridge having a steep western face. This ridge is intersected by the water gaps of all the larger streams in the southeastern and eastern portions of the hills. These streams rise in the high limestone plateau, cross the region of crystalline rocks, and flow through canyons in the flanking regions of the eastern side to Cheyenne River. All around the Black Hills the limestone plateau slopes outward, but near its base there is a low ridge of Minnekahta limestone with a steep infacing escarpment from 40 to 50 feet high, surmounted by a bare, rocky incline which descends several hundred feet into the Red Valley. This minor escarpment and slope is sharply notched at intervals by canyons, which on each stream form a characteristic narrows or "gate."

The Red Valley.—The Red Valley is a wide depression that extends continuously around the hills, with long, high limestone slopes on the inner side and the steep hogback ridge on the outer. It is in some places 2 miles wide, though it is much narrower where the strata dip steeply, and is one of the most conspicuous features of the region, owing in no small degree to the red color of its soil and the absence of trees, the main forests of the Black Hills ending at the margin of the limestone slopes. The larger streams flowing out of the hills generally cross it without material deflection, and their valleys lie between divides which are usually so low as to give the Red Valley the appearance of being continuous, but in its middle eastern section it is extensively choked with Oligocene deposits.

The hogback rim.—The hogback range constituting the outer rim of the hills is usually a single-crested ridge of hard sandstone, varying in prominence and in steepness of slope. At the north and south and locally along the middle western section it spreads out into long, sloping plateaus. It nearly always presents a steep face toward the Red Valley, above which its crest line rises several hundred feet, but on the outer side it slopes more or less steeply down to the plains that extend far out from the Black Hills in every direction. The hogback rim is crossed by numerous valleys or canyons, which divide it into level-topped ridges of various lengths. At the southern point of the hills Cheyenne River has cut a tortuous valley through the ridge for several miles, and the Belle Fourche does the same at the northern end of the uplift.

GEOGRAPHIC FEATURES OF THE QUADRANGLE.

Limestone slopes.— This quadrangle presents many characteristic features of the Black Hills, but does not extend into the central region of granites and schists. Its southeast corner includes a portion of the limestone plateau which, in a modified form, extends northwestward to the region south of the Nigger Hill uplift. In this extension, however, it is cut by numerous deep canyons and branch draws, which produce an irregular, rolling surface in a wide area underlain by the Minnelusa formation. The slope of Minnekahta limestone is of wide extent in this quadrangle, but it is deeply incised by valleys and canyons. To the east it is terminated by the canyons of Stockade Beaver Creek and Cold Springs Creek, toward which it presents a high escarpment. Much of its surface slopes gently to the west and presents broad expanses, which appear very smooth.

Red Valley.—The Red Valley is a strongly marked feature which extends north and south through the center of the quadrangle. To the south it is interrupted by numerous high ridges, and it is almost completely blocked by Strawberry Mountain, but north of Inyankara Creek it is broad, with gentle slopes and low buttes. Near Black Flat and on Sundance Creek it attains a width of 6 miles. A narrow branch of the Red Valley extends past Sundance far to the northwest.

Hogback range.—To the west lies a region of rolling hills interspersed with mesas, which are capped by the Lakota sandstone, usually giving rise to steep cliffs. These mesas are outlying portions of the hogback range, which in this area is represented by a westward-sloping plateau that descends gradually to the plains. These plains are underlain by the soft shales of the upper Cretaceous, which outcrop in low, rolling ridges and wide valleys.

Mountains.—The greater part of the igneous masses of the quadrangle are marked by prominent elevations, the most extensive of which is the Bear Lodge Mountains. This range rises in steep, rocky slopes crossed by numerous canyons, and has a central range of high peaks culminating in Warren Peaks, the altitude of which is somewhat over 6700 feet. Sundance Mountain, another igneous mass, just south of the town of Sundance, is a steep-sided butte which rises to an altitude of over 5800 feet or more than 1000 feet above the surrounding valleys. Its steep, rocky sides with long slopes of talus are a characteristic feature (see fig. 7 on illustration sheet). Inyankara Mountain is a somewhat similar feature rising to an altitude of 6313 feet and so isolated from high lands that it is a very prominent landmark. Black Buttes, which are composed mainly of igneous rocks, have less marked topographic features, consisting of a series of rocky knobs, mostly steep sided, that rise considerably above the level of the plateau on the east and appear very prominent when viewed from the west and north. The Nigger Hill uplift is marked by a series of irregular high ridges with summits several hundred feet higher than the adjoining plateaus. Cement Ridge, a part of its southeast rim and its highest portion, rises prominently to an altitude of 6600 feet. Lytle Hill, on the north, is another prominent feature of this uplift, its summit reaching 5800 feet above sea level. The Needles are sharp peaks of igneous rock occupying a small area east of Lytle Hill.

Valleys and creeks.—The Sundance quadrangle is traversed by deep valleys of various kinds, including numerous canyons. In the Red Valley and in the area west of it the valleys are wide and shallow. Skull Creek and Oil Creek flow in canyons with walls of considerable height, and the adjoining ridges are cut by deep canyons or branches of these streams. Stockade Beaver Creek flows in a canyon about 500 feet deep and, like Oil Creek, Skull Creek, Turner Creek, and Iron Creek, runs southward into Beaver Creek, a tributary of Cheyenne River. Soldier Creek flows in a high-walled valley of considerable width and empties into Inyankara Creek near Inyankara post-office. Beaver Creek and Mason Creek also flow into Inyankara Creek, which joins the Belle Fourche northwest of the Sundance quadrangle. Hewston and Miller creeks are part of the same drainage system. Cold Springs Creek, as well as the drainage eastward for several miles, flows into Sand Creek, which also receives the waters from Red Canyon and eventually joins the Redwater, a branch of the Belle Fourche. Sundance and Rocky Ford creeks are branches of the same drainage systems. These two creeks rise on the slopes of Bear Lodge Mountains, pass out of the mountains in deep canyons, cross the Red Valley in broad depressions, and cut deep canyons through the limestone and sandstone in the region farther east. The lower part of the Cold Springs Creek drainage and the many branch streams which enter the creek from the east flow in steep-walled canyons, which in Grand Canyon have a depth of 600 feet. Sand Creek, into which Cold Springs Creek empties, and its branches also flow in deep canyons. East of the Nigger Hill uplift and along the east-central margin of the quadrangle are the headwaters of Little Spearfish Creek, a branch of Spearfish Creek, which also belongs to the Redwater and Belle Fourche drainage. The streams on the north side of the Nigger Hill uplift flow in deep canyons having high, rocky walls and narrow, even-crested, separating ridges that slope gently northward.

GEOLOGY.

DESCRIPTION OF THE ROCKS.

In the Sundance quadrangle there are three classes of rocks—metamorphic, sedimentary, and igneous. The first are exposed in small areas at the base of the sedimentary series in the Nigger Hill uplift and in the Bear Lodge uplift. The sedimentary rocks are a succession of limestones, sandstones, and shales, ranging in age from Middle Cambrian to Quaternary, having a thickness of about 4500 feet, and presenting the general characteristics, thicknesses, and relations given on the columnar section sheet. The igneous rocks comprise several varieties which have been intruded among the sedimentary rocks at different horizons and are of early Tertiary age.

METAMORPHIC ROCKS.

Algonkian System.

In the Nigger Hill uplift there is exposed a small area of pre-Cambrian metamorphic schists, similar in most respects to those which outcrop in the central area of the Black Hills. A portion of them appear to be in place, upturned in the center of the uplift, but other portions are included in the younger igneous rocks which apparently completely surround them. These schists are penetrated by intrusive rocks of various kinds, including granites, amphibolites of Algonkian age, and other rocks. In the Bear Lodge uplift large masses of probable Algonkian granites are included in the trachytes. All these igneous rocks are described on a later page.

MICA-SCHIST.

Occurrence.—The schists of the Nigger Hill uplift occur in several irregular areas in the central part of the region. The largest mass extends in a rudely semicircular course from near bench mark 6238 westward around the head of Spottedtail Gulch and along the slopes west of that depression to a point north of Welcome. Other areas occur on the slopes and spurs about Bear Gulch, especially west and north of that place. The masses vary in size from a few feet to half a mile in width and most of them are inclosed in the younger igneous rocks. At the west end of Cement Ridge the schist is in place under the basal Cambrian sediments, and possibly at some other points the rock is connected with the main mass of schist, which is believed to be the floor under the younger igneous intrusions.

It is probable that the largest body of the schist was elevated en masse at the time of the syenite intrusion, and does not form an inclusion in the porphyry. Its elevated position, the fact that it partly encircles Mineral Hill, that it was not noted along Spottedtail Gulch, and that it is not exposed along Sand Creek (except as shown on the geologic map) would seem to indicate that this is the case and that if it is the floor of the laccolith, the latter is extremely uneven. Of the other schist areas some, perhaps all, are included in the porphyry. The larger areas along the bottom of Bear Gulch, however, may represent the irregular base on which the porphyry rests.

Description.—The schists are moderately dark-gray rocks, quite fissile when weathered, and consist essentially of quartz and biotite, or of quartz, orthoclase, and biotite, with a small proportion of magnetite. The biotite, which constitutes between a third and a half of the bulk of the rock, occurs in abundant small leaves arranged parallel to the plane of schistosity, the quartz and feldspar occurring in grains, some equidimensional, but most of them somewhat flattened. A few small, colorless garnets occur in some portions of the schist.

While it can not be positively stated, on the evidence of their mineralogic composition and general lithologic character alone, that these micaceous schists as a whole are metamorphosed pre-Cambrian sediments, it seems probable that this is the case, rather than that they have been derived from ancient igneous rocks.

SEDIMENTARY ROCKS.

Cambrian System.

DEADWOOD FORMATION.

General relations.—The Deadwood formation outcrops in the Nigger Hill, Bear Lodge, and Black Buttes laccolithic uplifts, and doubtless underlies most other portions of the quadrangle. Its rocks consist largely of sandstones, shales, limestones, and limestone breccias. The beds are not often exposed in regular order and in complete sequence from base to summit, owing to the very irregular manner in which they have been intruded by the igneous rocks. Cement Ridge, southwest of Welcome, presents a complete section ranging from Algonkian rocks to Whitewood limestone. Elsewhere the igneous rock is intruded at various horizons so as to split the strata into wedge-shaped masses from 25 to 200 feet in thickness, and some of these masses have been carried for considerable distances from their original positions.

Thickness and character.—The formation is about 300 feet thick and consists of a great mass of coarse sandstones with local conglomeratic beds at the base, sandstones and shales above, and local areas of limestone and limestone breccia near the top, the latter capped or replaced by a thin layer of sandstone, which immediately underlies the Whitewood limestone. The sandstones consist of quartz sand varying from brownish to pale reddish in color, and are usually only moderately thick-bedded. The basal beds nearly everywhere are conglomerates, the pebbles of which, in some districts, are one-half inch in diameter.

Shales occur at intervals in the formation. They are generally dark colored, greenish or dark gray, with a purplish cast, and are fine grained and compact. Some beds of shale on Little Spearfish Creek are bright red. The mineral glauconite, in its characteristic small bottle-green grains, occurs extensively in the sandstones and on the pebbles of the limestone conglomerates. This conglomerate is seen in the valley of Little Spearfish Creek, in Rudy Canyon, northwest of Sundance, and also near the saddle southwest of the Needles. It consists of flat pebbles or twisted and broken thin layers of gray to pinkish limestones in a limestone matrix, a characteristic occurrence in the Cambrian in various portions of the West.

Nigger Hill uplift.—The Deadwood formation appears in a nearly circular outcrop around the slopes of the Nigger Hill uplift. The principal plane of laccolithic intrusion is at or near the base of the formation, except for a short distance north of the Needles and at the east end of Cement Ridge, where the igneous rocks rise to a somewhat higher horizon. In portions of the area the formation is split by the igneous intrusions, but in the central and western portions of Cement Ridge all the beds appear in regular order. Much of this ridge is due to the basal conglomerates, which are known as "cement" by the miners. This rock consists mainly of quartz pebbles, but at some points near the basal contacts includes also pebbles and bowlders of dark-colored igneous rocks of Algonkian age. Most of the overlying beds are sandy shales and slabby brown sandstones, and masses of thin rocks, as well as of conglomerate, are included between some of the igneous bodies in the northwestern part of the uplift. The formation is extensively exposed in the slopes adjoining Beaver Creek north of Bear Gulch, and in the slopes south and southwest of Lytle Hill.

Sheep Mountain area.—The Deadwood formation appears prominently on the south slope of Sheep Mountain, brought up above the Minnekahta limestone by a local but profound fault. About 300 feet of beds are exposed, consisting of brown sandstones at the base, overlain by alternations of thin-bedded sandstones and shale of dirty-buff to greenish-buff color, a prominent ledge of brown, "worm-eaten" sandstone, and, at the top, 30 feet or more of grayish-green shale, as in the Deadwood region.

Bear Lodge area.—In most portions of the Bear Lodge Mountains the Deadwood formation is represented by a thick mass of gray to pinkish quartzite, or conglomerate, into which the igneous rocks have been intruded, and sometimes several such masses are found separated by layers of igneous rock. In some of these cases the quartzite appears to be at the top of the formation, and at one locality some of the top green shale appears. In Rudy Canyon, on the west side of the uplift, nearly 300 feet of Deadwood beds appear, owing to the igneous rock taking a lower plane of intrusion for some distance. The top member, under the Whitewood limestone, is 30 feet or more of green shale, as in Sheep Mountain; then there are 10 to 40 feet of purplish to gray quartzite, 40 feet of thin-bedded buff to purplish-gray sandstones and limestones with breccia and a small amount of flat-pebble limestone conglomerate, 200 feet of thin-bedded sandstone and sandy shale of buff and greenish-buff color with some reddish layers, and a 10- to 30-foot bed of quartzite lying on igneous rocks. About 200 feet farther east a thin mass of quartzite is included in the porphyry.

Black Buttes area.—The outcrop in the Black Buttes is near the north end of the igneous area, where the porphyry has been intruded at a lower horizon for a short distance, uplifting upper Deadwood beds. They consist of 40 to 50 feet of sandstones and sandy shales overlain by the regular succession of Ordovician and Carboniferous limestones.

Fossils and age.—Fossils occur in the Deadwood formation at most localities. The principal horizons are the lower sandstone and the upper shales, and the forms are regarded as Acadian (Middle Cambrian). The following species, in part from shales on the east slope of the Nigger Hill uplift, have been determined by Mr. Charles D. Walcott: *Dicellomus politus* Hall; *D. pectinoides* Whitfield; *Ptychoparia oweni* Hall; *Obolus* (*Lingulella*) *similis* Walcott; and *Obolus* (*Lingulepis*) *acuminatus* Conrad.

Ordovician System.

WHITEWOOD LIMESTONE.

Character and outcrops.—This formation is a hard, buff-colored limestone which outcrops in the Bear Lodge, Nigger Hill, and Black Buttes uplifts. Its thickness averages 70 feet, and, as it is thin and lies beneath a thick mass of limestone, it is usually hidden by talus from overlying beds. It extends partly around both of the larger uplifts, but in places the plane of igneous intrusion rises and cuts it out, this being the case at the east end of Cement Ridge, near the Needles, and at the heads of Lytle and Beaver creeks. The small area in Black Buttes is cut off at both ends by the porphyry. The rock, which is of uniform character throughout, is a hard, dirty, buff-colored, and mottled limestone, apparently of a fair degree of purity. It appears at intervals from Lytle Hill west and south to Cement Ridge, one conspicuous exposure appearing on the east side of Sand Creek. In Rudy Canyon it outcrops prominently in mottled gray and pinkish ledges, but is cut out by the igneous rock a short distance north of the canyon. The Whitewood limestone caps the south end of Sheep Mountain, where it is brought up by a fault, and rises in cliffs 30 feet high above the slopes of green shales at the top of the Deadwood formation. Here it is a dark, mottled, pink limestone about 60 feet thick, containing considerable sand.

Fossils.—The Whitewood limestone contains large Maclureas and a few other fossils of Ordovician age.

Carboniferous System.

ENGLEWOOD LIMESTONE.

Character and outcrops.—The basal member of the great series of Carboniferous limestones in the Black Hills has been separated as a formation known as the Englewood limestone. In its typical development it consists of rocks of pinkish color and moderately thin bedding, characters which distinguish it from the overlying massive gray limestone of the Pahasapa. Its thickness is about 50 feet. The formation is not so characteristic a feature in the Sundance quadrangle as in the region farther east, for its pink color and thin bedding are less pronounced. Its zone of outcrop extends around the Nigger Hill and Bear Lodge uplifts and it appears to a limited extent in the northern portion of Black Buttes. About the Needles, at the east end of Cement Ridge, and in part of the Bear Lodge uplift it is cut out by the porphyry. In the Bear Lodge Mountains the formation has not been distinguished, although it may be represented by 40 or 50 feet of dark-gray sandy limestones in the lower portion of the Pahasapa limestone.

Fossils.—In the region farther southeast the formation carries a few fossils of Mississippian age, believed to represent the horizon of the Chouteau limestone. The following forms have been reported: *Leptæna rhomboidalis*, *Chonetes ornatus?*, *Productus* aff. *P. mesialis*, *Spirifer striatiformis*, *Spirifer mysticensis*, *Spirifer peculiaris?*, *Camarotæchia metallica?*, *Pugnax* n. sp., *Pterinopecten* sp., *Platyceras* sp.

PAHASAPA LIMESTONE.

General relations.—The margin of the extensive limestone plateau of the northwestern Black Hills extends into the eastern edge of the Sundance quadrangle, but within a short distance to the west the dip increases rapidly and the Pahasapa limestone is soon carried beneath the Minnelusa formation. It is brought up again in nearly complete circular outcrops about the Nigger Hill and Bear Lodge uplifts and in Bald Mountain. Riflepit, Rattlesnake, and Sand Creek canyons expose the top of the formation for some distance. Several detached areas are exposed in Black Buttes, and on the northwest flank of Inyankara Mountain there is a small uplifted mass of it.

Thickness.—The complete thickness of the formation is exposed on the flanks of the Nigger Hill and Bear Lodge uplifts and in the northwest portion of the Black Buttes, and the amount is seen to average about 600 feet. At the east end of Cement Ridge the igneous rock cuts out the formation for some distance.

Character.—The Pahasapa limestone is a light-colored rock consisting of nearly pure carbonate of lime. It is massively bedded, weathers to a light dove color, is fine grained, and presents no notable variations in character in different parts. It appears to merge into the underlying Englewood limestone, but the transition takes place in a few inches. In its upper portion there is some uncertainty as to whether there should be included in the formation some light-colored limestones from 50 to 60 feet thick, which are separated from the main mass by 40 feet of sandy beds.

Physiographic features.—This limestone is a resistant rock, rising in high ridges or giving rise to cliffs and benches; consequently it usually is well exposed for observation in all parts of the region, except on some of the slopes where there is considerable soil covering. It outcrops in many bare ledges in the canyons in the Bear Lodge Mountains and the Nigger Hill uplift, and it appears extensively in the canyons of Little Spearfish Creek and the branches of Stockade Beaver Creek. In these canyons the rock presents steep walls of light-gray, massive limestone. Bald Mountain is an isolated outcrop of the limestone, due to a sharp upward flexure of the beds and the erosion of the overlying Minnelusa and younger formations.

Fossils.—Fossils occur in most parts of the Pahasapa limestone, but seldom in large numbers. The following are the principal forms which have been obtained: *Syringopora surcularia*, *Leptæna rhomboidalis*, *Schuchertella inæqualis*, *Chonetes gregarius?*, *Productus semireticulatus*, *Spirifer centronatus*, *Spirifer striatus* var. *madisonensis*, and *Syringothyris carteri*. These are of Mississippian age and represent approximately the fauna of the Madison limestone of Montana and the Little Horn limestone of the Bighorn Mountains.

MINNELUSA SANDSTONE.

Relations and distribution.—This formation consists mainly of light-colored sandstones, but some limestone beds are included and most of the sandstones have a calcareous cement in their unweathered condition. The upper member is characteristic, consisting of coarse-grained massive sandstone, mostly white, and often forming high cliffs. Softer, thinner-bedded sandstones, in part of red color, lie below. This lower series contains several beds of limestone and some sandy shales.

Part of the broad belt of outcrops of the Minnelusa formation which surrounds the Black Hills uplift extends across the east side of the Sundance quadrangle, and the formation also appears at the surface in the laccolithic uplifts marked by Bear Lodge, Inyankara, Green, and Strawberry mountains. Along Stockade Beaver Creek, where there are moderately steep and continuous dips to the west, the formation outcrops in a narrow zone deeply incised by canyons. Farther north the dips flatten, and in a low, broad anticline which extends from the Nigger Hill uplift through Bald Mountain the outcrop widens to 17 miles in a rough, wooded region of ridges and canyons. Soldier Creek and its branches have cut through the thin mantle of the Minnekahta and Opeche formations into the Minnelusa and afford extensive exposures of all these, and the Minnelusa beds are bared by numerous streams near the Black Buttes uplift. Northwest and north of the Nigger Hill uplift there is a broad outcrop belt of the Minnelusa, crossed by numerous deep canyons, along which the formation is bared for many miles, the intervening ridges being capped by Minnekahta limestone. Red Canyon and Sundance Creek and their branches also cut into it deeply. Strawberry and Green mountains expose a low dome of the upper beds of the formation. Inyankara Mountain brings up the Minnelusa along its northern side, and the Bear Lodge uplift presents it in an elliptical outcrop zone which extends entirely around Bear Lodge Mountains, in places split by igneous intrusions.

Thickness and local features.—The thickness of the formation appears to vary considerably, but in general it seems to become thinner to the northwest. In the deep well at Cambria, not far from the southern margin of the quadrangle, a thickness of 850 feet was found, consisting of fine-grained gray, buff, and brown sandstones, with a large proportion of calcareous cement. In Stockade Beaver Valley in the southeast corner of the quadrangle the thickness is about 500 feet, comprising 300 feet of lower beds of buff and gray sandstones, 30 to 40 feet of red sandstones, 50 feet of hard white sandstones, 80 feet of red brecciated sandstones, and the top bed of hard white sandstone, which is thin for a short distance but gradually thickens to the north. This top sandstone is over 100 feet thick on the slopes north of the Nigger Hill uplift, where it is a conspicuous feature and caps the walls of many deep canyons. Ordinarily it is coarse grained and cross-bedded. In Grand Canyon the formation consists mainly of three members—at the top white sandstone, 125 feet thick; next 50 feet, more or less, of soft sandstones, red in the upper part; and a basal series of thinner-bedded, buff sandstones with a few limy layers. On the west side of Inyankara Mountain the formation appears to have a thickness of only 350 feet, consisting mainly of gray and buff sandstone. On the east slopes of the Bear Lodge Mountains it is about 350 feet thick and on the west side it is about 300 feet thick, the upper white sandstone being its most characteristic feature.

Section of Minnelusa sandstone near the lower end of Sand Creek Canyon.

	Feet.
Opeche red sandstone.	
Buff sandstone, in beds of medium thickness, with abundant cherty concretions	10
White to buff, massive, coarse-grained sandstone in vertical walls	130
Yellowish to reddish limestone, moderately thin bedded	9
White to reddish, coarse-grained, massive sandstone	80
Gray to purplish and reddish impure limestone, moderately massive	12
White to red, coarse-grained, cross-bedded sandstone	8
Gray limestone, fine-grained, moderately thin bedded	25
White to buff, coarse-grained, cross-bedded, massive sandstone	20
Grayish, fine-grained, hard sandstone, thin-bedded	10
White, massive sandstone	22
Gray, fine-grained, impure limestone, irregularly bedded	3
White, massive sandstone	20
Pale-gray, fine-grained limestone, thick to thin bedded	20
Massive, white sandstone	5
Pale-gray, very fine-grained limestone, heavily bedded	75
Light-colored sandstone, stained more or less grayish, about	40
Pahasapa limestone.	
Total	489

Age.—No fossils were obtained in this formation in this area, but, from molluscan remains found in its upper beds in the southern Black Hills, the age of these beds at least is believed to be Pennsylvanian, though the lower beds may be Mississippian.

OPECHE FORMATION.

Character and outcrop.—This thin series of shales and sandstones lies next above the Minnelusa sandstone and is exposed mainly in slopes beneath the escarpment of overlying Minnekahta limestone. Its thickness averages from 60 to 80 feet, the amount decreasing gradually toward the northwest. Its outcrop area is a very irregular zone on the margin of the wide belt of the Minnelusa formation in the eastern part of the quadrangle, and around the uplifts of Bear Lodge, Green, Inyankara, and Strawberry mountains. The material consists of moderately soft, brownish-red sandstone, mainly in beds from 1 to 4 inches thick, and red sandy shales. At the top of the formation, for the first few feet below the Minnekahta limestone, there are shales which invariably have a deep purple color. The Opeche is exposed at numerous points, and from its relations to the Minnekahta limestone its identity can always be established.

Age.—The age of the Opeche formation has not yet been definitely determined, as it has yielded no fossils. From the fact that the overlying Minnekahta limestone contains Permian fossils and there are red deposits intercalated in the upper part of the Permian of Kansas and eastern Nebraska, it is provisionally assigned to that age.

MINNEKAHTA LIMESTONE.

Character and outcrop.—This formation, formerly known as the "Purple limestone," outcrops in a broad zone extending north and south across the Sundance quadrangle and caps the high ridges in the northeast corner of the area. Along the eastern margin of the Red Valley its westerly dip carries it beneath the Spearfish red beds, but it is brought up again by the dome-shaped uplifts of Bear Lodge, Green, Inyankara, and Strawberry mountains and Lime Buttes, a small knoll 4 miles south of Sundance Mountain. The rock is of light-gray color, but has a slight pinkish or purplish tinge, which suggested the name "Purple limestone." It is thin, averaging slightly less than 40 feet in thickness, but, owing to its hardness and flexibility, it usually forms prominent ridges with escarpments presenting nearly the entire thickness of the formation. Ordinarily the cliffs appear to consist of massively bedded rock, but on close examination it is seen that the layers are thin and clearly defined by slight differences in color. On weathering it breaks into slabs usually 2 to 3 inches in thickness. The Minnekahta limestone generally rises gradually from the Red Valley and extends far up declivities whose higher ridges expose the Minnelusa formation. In these long slopes it is often cut away by canyons and valleys, leaving it on ridges and outliers, such as the long, detached area extending southeastward from Henderson's ranch, which is cut off by Soldier Creek, and in the areas capping the ridge near Bentley's ranch, Manhattan, and north of the Nigger Hill uplift. In Canyon Springs Prairie and Williams Divide it is spread out widely with gentle slopes which are extensively farmed, but elsewhere its surface is mostly rocky and bears scattered bushes and occasional cedars or pines. In the smaller, dome-shaped uplifts the formation usually dips steeply away from the center and presents revetments extending part of the way up the slopes. This is especially noticeable in the beautiful low dome of Green Mountain (see fig. 4 on illustration sheet).

Composition.—The composition of the Minnekahta limestone varies somewhat, mainly in the admixture of carbonate of magnesia, which usually is present in considerable proportion, and in clay, which is a constant ingredient. In some of the layers flakes of clay or impure limestone give a mottled appearance to the weathered bedding planes of the rock.

Structure.—The Minnekahta exhibits more local variations in the amount and direction of its dips than other formations. This is due to its being a relatively hard bed of homogeneous rock lying between masses of soft beds, so that it has frequently been bent, the plasticity of the inclosing beds favoring local flexing and warping. The thin bedding planes are traversed by small faults and minute crumplings, but considering the large amount of deformation to which the formation has been subjected the flexures are rarely broken.

Age.—The limestone is classed in the Permian in the sense in which this term is used in the Mississippi Valley, the classification being based on fossils which it has yielded in the region west of Hot Springs.

Triassic (?) System.

SPEARFISH FORMATION.

Character and outcrop.—The Spearfish formation, known also as the "Red Beds," consists of red sandy shales with intercalated beds of gypsum and has a thickness of 500 to 600 feet. Its outcrop extends from north to south across the middle of the Sundance quadrangle in a broad, treeless, red valley, and usually presents wide, bare slopes and high buttes of bright-red clay with outcrops of snow-white gypsum in striking contrast. The sedimentary material is almost entirely sandy, red shale, generally thin bedded and without any special features except the gypsum, which occurs mainly at a horizon about 120 feet above the base of the formation and appears to extend continuously over the entire region, with a thickness of 20 to 30 feet in most cases.

A narrow zone of the formation also extends past the town of Sundance and along the west side of the Bear Lodge uplift. A small anticlinal area is exposed southwest of Sundance, and the formation extends for some distance along Inyankara Creek and up some of its branches, owing to a low anticline. It is faulted out for a short distance along the west side of Inyankara Mountain. Outlying remnants of the Spearfish formation occur at various points on the Minnekahta limestone plateaus, notably about Boyd and north of Inyankara.

Gypsum.—The outcrop of the gypsum bed extends southward from Rocky Ford, a short distance west of the foot of the slopes of the Minnekahta limestone, usually having a width of several hundred yards, but at some localities where the dips are low it is spread out more widely. It passes around the west side of Green Mountain, caps some of the high points west of Horton, extends down Oil Creek to a point 5 miles above T E ranch, and thence east and south. In this region a thick bed of gypsum begins at the top of the formation and becomes a conspicuous feature in the mountain slopes in range 61, township 47, where its thickness is 25 feet in most places. One of its most interesting exposures is at Red Butte, which it caps (see fig. 8 on illustration sheet). In the southeast corner of the quadrangle there is also a thin layer of gypsum lying on the Minnekahta limestone at the base of the formation. Four miles north by west from Inyankara Mountain a bed of gypsum appears near the top of the formation for some distance, and in the vicinity of Sundance it is 8 feet below the top and 4 feet in thickness. The gypsum forms both ridges and sinks, the latter where there is underground seepage on the slopes, the former on many of the smaller divides. One of the most remarkable sinks is on the east side of the main road 3 miles east of the center of Green Mountain. It is 30 feet in diameter and 25 feet or more deep, and has a rim of red shales. Numerous small sinks were observed southwest of Black Buttes. A circle of gypsum ridges surrounds Green Mountain and the limestone dome south of Sundance Mountain, and extends partly around Inyankara and Strawberry mountains. A local dome, known as Gypsum Buttes, on the northeast side of Black Flat, is marked by a rim of gypsum ridges with revetments. It is a miniature reproduction of Green Mountain and of the limestone dome just north, but was not uplifted sufficiently for erosion to expose the underlying limestone.

Age.—The Spearfish deposits are distinctly separated from the Minnekahta limestone below by an abrupt change of materials. No fossils have been discovered in the Spearfish formation and its precise age is unknown. From the fact that it lies between the Permian below and the marine Jurassic above, it has been regarded as Triassic in age, but it may prove to be Permian. It is separated from the Sundance formation by a planation unconformity representing all of earlier Jurassic and probably part at least of Triassic time.

Jurassic System.

SUNDANCE FORMATION.

Outcrops.—The outcrop of the Sundance formation extends diagonally from southeast to northwest across the western half of the Sundance quadrangle, and varies in width from one-half mile to 7 miles. There is an extensive outlier in the Mount Pisgah Range and two very small outliers of lower beds found on the east side of Bear Lodge Mountains, 3 miles northeast of Sundance. In greater part it extends along the slopes which rise to the ridges and mesas capped by Lakota sandstone, where it is often overlain by a considerable amount of sandstone talus. Exposures are extensive and the formation everywhere presents characteristic features.

Character.—The formation consists of shales and sandstones in a series which, in the main, is regular. Its thickness is about 325 feet, and it appears not to vary greatly from place to place. At the base there are dark shales, although at some localities these are underlain by a local thin bed of sandstone. Their thickness averages from 20 to 50 feet, the amount increasing gradually toward the south. Four miles south of Sundance the basal shale is 30 feet thick and lies on a 3-foot bed of red sandstone at the top of the Spearfish formation. In the small outlier northeast of Sundance the basal bed is 8 feet of light-colored, soft, sandy shales and sandstone overlain by 30 feet of green shale capped by the usual buff, massive sandstone. Next above the lower shales is a series of buff, fine-grained sandstones, in part massively bedded and having a thickness of 30 to 40 feet, constituting a characteristic and persistent member of the formation and one of the most prominent features. It usually outcrops as a distinct bench with precipitous ledges in the general shaly slope. It often gives rise to terraces and low buttes. The upper part of the sandstone member merges into sandy shales of buff to gray color and these into soft, impure sandstones of a distinctly reddish tint, having a thickness of 40 to 60 feet. Above are dark-gray and greenish-gray shales about 150 feet thick, containing thin layers of fossiliferous limestone.

Relations at top.—At the top of the formation the shales give place to a thin mass of yellowish sandstone which lies directly below the Morrison shales and may possibly represent the Unkpapa sandstone. There is no evidence of unconformity at the top of the formation, but the next succeeding deposit begins very abruptly. Absence of the Unkpapa sandstone would indicate a time break of considerable length between Sundance and Morrison deposition.

Fossils.—Fossils are particularly abundant in the slopes west and southwest of Sundance, but are plentiful in all the exposures. One of the most conspicuous and abundant fossils is *Belemnites densus*, a cigar-shaped form of heavy, hard carbonate of lime, smooth on the outside but having a radiated structure within. They occur mostly in sandy layers in the upper shale series and often weather out on the surface in such numbers as to be a notable feature in most of the outcrops. In the upper shales there also occur the following species:

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

In the northwest portion of the area occasional layers of fossiliferous limestone occur in the lower shales. The forms reported are as follows:

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

All of these species are of upper and middle Jurassic age.

The Sundance formation is believed to be equivalent to the Ellis formation of Montana and the Yellowstone Park region.

Cretaceous System.

MORRISON SHALE.

Character and outcrops.—The Morrison shale consists of a sheet of massive shale or clay, usually of light-gray or greenish-gray color, merging into maroon, buff, and purple tints. It includes some thin beds of fine-grained gray sandstones and an occasional layer of limestone. It averages about 150 feet in thickness and outcrops below escarpments of Lakota sandstone in a zone extending across the western and southwestern parts of the quadrangle. In this zone it is in some places deeply covered by talus from the cliffs above, but there are many exposures. Owing to the low dips and deep erosion by streams which flow eastward across the western slope of the Black Hills, the formation has been removed in such manner that many outliers remain in ridges of irregular outline.

The deposits of this formation are distinguished from those of the Sundance in most cases by color and by the massive texture of the shale. The most extensive exposures are to be seen in the ridges adjoining Beaver Creek, along Mason Creek near the county line, in Skull Creek Valley north and northwest of the Holwell ranch, in Black Canyon, along Oil Creek, and in the ridges farther east. The formation contains much white sandstone in Oil Creek Valley, especially west of the T E ranch.

Age.—The Morrison formation contains fossil bones of saurians, which have usually been regarded as late Jurassic in age, but some eminent authorities now believe that they are earlier Cretaceous, and as its stratigraphic relations in Colorado and elsewhere sustain this view in some measure it is here assigned to the Cretaceous.

LAKOTA SANDSTONE.

Occurrence.—The Lakota sandstone is a conspicuous feature in the western and southwestern portions of the Sundance quadrangle, rising in prominent cliffs above slopes of the underlying shales, both in the plateau which here represents the hogback range and in numerous outlying mesas to the east. Owing to the low dip and numerous deep canyons which traverse the sandstone its boundary is exceedingly irregular.

Character.—The rocks consist mainly of gray to buff, coarse-grained, massive-bedded sandstone, usually of considerable hardness and having a thickness of 150 to 300 feet. It is very thin locally near T E ranch, on the west side of Oil Creek Valley. Its basal beds are often conglomeratic, and thin streaks of conglomerate occur higher in the formation.

Coal beds.—At or near its base it often contains coal in lens-shaped deposits, or possibly channels, of considerable extent. These coal beds vary in thickness, reaching a maximum of 9 feet in the ridge west of Inyankara Mountain, where they consist of mixed coal and carbonaceous shale. Owing to the mantle of talus from the cliffs above and to the disintegration and burning out of the coal, it is exceedingly difficult to explore the horizon without extensive digging. Local coal basins have been found in the ridge southeast and south of Holwell ranch, on the ridge west of Inyankara Mountain, and west and southwest of Sundance.

Age.—From extensive collections of plants which have been made in the Lakota formation in the Black Hills, its age is known to be Lower Cretaceous.

FUSON FORMATION.

Character and outcrops.—Lying between the massive sandstones of the Lakota and Dakota formations, there is a thin series of shales and thin-bedded sandstones which have been designated the Fuson formation. The shales are in places red or maroon colored, but in others are gray and buff. They merge into sandstones that are mostly thin bedded and contain shaly partings. Possibly in some locations the formation is absent, but in nearly all clear exposures it appears to be separable from the adjoining beds. Its thickness varies from 10 and 15 feet to 40 feet in exceptional cases, but it is so often obscured by talus from the sandstones above that good exposures are rare. On the west side of Oil Creek, near T E ranch, the formation consists of 20 feet of dark-gray shale and sandy shale overlain by 6 feet of thin-bedded buff sandstone. Its outcrop extends across the southwest corner of the quadrangle and exposures may be seen occasionally along the west side of the North Fork of Mason Creek, on Skull Creek, in Black Canyon, and under the outliers of Dakota sandstone along the lower part of Oil Creek.

Fossils.—The formation has not been examined for fossils in this area, but in the Hay Creek coal field, farther north, it constitutes part of "Bed No. 2 of the Dakota group," from which large numbers of plants of earlier Cretaceous age were collected by Prof. W. P. Jenney, and it is therefore placed in the Lower Cretaceous.

DAKOTA SANDSTONE.

Outcrop and character.—This formation caps the plateau west of the North Fork of Mason Creek and west of Skull Creek, and it occurs in outliers also on the ridges between Skull Creek and the headwaters of the branches of Plum Creek southwest of T E ranch. Some other outlying areas occur north of Mason Creek, in range 63. Mason Creek crosses the formation in a valley which presents numerous exposures.

The Dakota sandstone is a coarse-grained, buff-colored rock, often massively bedded and cross-bedded, which merges into a thinner-bedded variety, especially in its upper portion. Its thickness ordinarily is less than 100 feet, and in the ridges west of Mason and Skull creeks from 40 to 60 feet are usually found. The massive lower member generally forms cliffs of reddish color, often with a characteristic rude columnar structure. The Dakota sandstone contains considerable iron, to which is due the reddish-brown color of the rocks when weathered, and much of which occurs also as small concretions of ironstone or sand cemented by oxide of iron.

Age.—From plants collected in other parts of the Black Hills the Dakota sandstone is classed as Upper Cretaceous.

GRANEROS SHALE.

The southwest corner of the Sundance quadrangle is occupied in greater part by the Graneros shale, the lowest division of the Benton group. It consists of fissile shales, mostly of dark color, having an aggregate thickness of about 1000 feet. It extends far up the slopes of the plateau, which in this part of the Black Hills represents the hog-back range, reaching nearly to its edge west of Skull Creek, southeast of Holwell ranch. Within about 200 feet of its base the formation contains a conspicuous series of harder shales and thin-bedded, fine-grained sandstones which weather to a light-gray color and, owing to their hardness, form a line of knobs and ridges that rise slightly above the main shale slope. The ridge due to this member is prominent on the west side of Dry and Turner creeks, and it usually bears a sparse growth of pine trees, from which is derived the local name, Piney Ridge. This member is an extension of the Mowry beds of the Bighorn Mountains and adjoining region.

In its upper portion the Graneros shale contains a thin bed of a deposit known as bentonite, a light-colored, massive, soft rock or hard clay, from 3 to 5 feet thick, which is conspicuous in a series of slopes and knobs just north of the railroad east of Iron Creek. It has been mined to some extent at this place and, owing to the low dip of the beds, is spread out widely so that it is readily accessible. It has great capacity for absorbing water and in some portions of its area, where the drainage is imperfect, the bentonite is softened into "soap holes," or deep, miry spots in which cattle are occasionally lost.

At the top of the Graneros formation are gray shales containing hard, calcareous concretions which give rise to knobs and low ridges lying about 1½ miles southwest of the railroad.

The Graneros shale contains very few fossils except fish scales, which are very numerous in the beds constituting Piney Ridge.

GREENHORN LIMESTONE.

One of the most prominent features in the plains immediately adjoining the Black Hills is a low but distinct escarpment due to the hard Greenhorn limestone in the middle of the Benton group. It crosses the southwest corner of the Sundance quadrangle, rising in a ridge facing northwest, about 2 miles southwest of the railroad.

The limestone is thin-bedded and is characterized by a large number of impressions of *Inoceramus labiatus* (see fig. 9B on illustration sheet), a fossil which is of infrequent occurrence in the adjoining formations. It contains a considerable amount of clay and some sand, and on hardening by exposure breaks into thin, pale-buff slabs exhibiting impressions of the distinctive fossils. Its thickness averages about 40 feet, including some shaly beds in its upper portion, and it dips gently to the southeast. At its base it is distinctly separated from the black shales of the Graneros formation, and its upper part grades into the Carlile shales with 6 or 8 feet of passage beds.

CARLILE FORMATION.

The Carlile formation occupies a very small area in the extreme southwest corner of the quadrangle. It consists of an alternation of shales and sandstones of light-brown color, the latter rising in low ridges on the shale slopes. The thickness of the entire formation averages about 700 feet, but only its lower half is found in this quadrangle.

Tertiary System.

SAND, GRAVEL, AND CONGLOMERATE.

General relations.—In the Sundance quadrangle there remain several small outliers of Tertiary deposits, which are believed to belong to the White River group, but whether they represent the Chadron sand, the Brule clay, or even the higher Arikaree beds of the Miocene, is not known. The materials comprise impure fuller's earth, gravels, sand, and conglomerates. They lie far above the level of recent alluvial deposits and seem to be much older than any of the Quaternary beds known in the vicinity of the Black Hills.

Local features.—On the northeast side of the Bear Lodge Mountains there is an extensive deposit, over 100 feet thick, of Tertiary gravels and conglomerates, interstratified with fine sand, sandy clays, and impure fuller's earth, reaching altitudes of 5800 to 6000 feet, and constituting a plateau which extends far northward along the extension of the Bear Lodge Mountains. The conglomerate contains numerous pebbles and bowlders, derived from the adjacent formations, including many of the igneous rocks from the Bear Lodge Mountains. This deposit extends southward along the east slope of the mountain east of Warren Peaks, at altitudes ranging from 5800 to 6050 feet, and constitutes a distinct bench or terrace, in places over one-half mile in width, abutting against the higher slopes of the mountain. One of these terraces forms the divide between the headwaters of North Redwater and Beaver creeks. The deposits are fully 100 feet thick and they dip northward at the rate of about 100 feet per mile. A somewhat similar material caps small outlying areas of the Spearfish formation on the narrow ridges on the northern margin of the quadrangle, near the State line, at an altitude of 4100 feet. Six miles farther south, just north of Lytle Hill, small areas of apparently the same formation occur at an altitude of 5100 to 5200 feet. Deposits of fuller's earth and overlying bowlders occur at the head of the east fork of Hewston Creek, near the foot of the Bear Lodge Mountains, at an altitude of 5800 feet, apparently having a thickness of 100 feet. Another deposit extends along the ridge followed by the road east of Miller Creek, and slopes upward from an altitude of 5300 feet at the south to 5800 feet at the north. On the divide in the southeast corner of township 49, range 64, a deposit consisting of about 50 feet of soft, buff sand, with some darker clayey sand, caps small outlying areas of Graneros shale at an altitude of 4750 feet. Doubtless there are small areas of Tertiary deposits in other parts of the region, for they lie in out-of-the-way places and are not always discernible.

Original extent.—These scattered outcrops indicate that the slopes of the Black Hills were originally covered by an extensive deposit of Tertiary materials which have been removed by the widespread erosion of later Tertiary and Quaternary times.

Quaternary System.

The Quaternary formations of the Sundance quadrangle comprise recent alluvial deposits along the stream valleys and upland gravels and sands that occupy old terraces which are remnants of a previous epoch of topographic development.

Older terrace deposits.—The largest of the older terrace deposits occurs in the Red Valley between Inyankara and the canyon of Stockade Beaver Creek. Other areas occur on the south side of Inyankara Creek, on terraces west of Sundance, on the divides between Sundance Creek and Rocky Ford Creek, on the ridge north of Rocky Ford Creek, on the divide between Skull Creek and Turner Creek, and along an old stream channel extending southward through the depression in the divide between Beaver and Mason creeks in range 63. These deposits usually lie on well-marked terraces that are elevated considerably above the present stream bottoms and consist largely of sand, pebbles, and bowlders of various kinds. The largest deposit occupies a broad terrace level south of Boyd, where it lies mainly on a thin mass of Spearfish red shales, and other portions are found north and northwest of Boyd, capping several ridges. The materials here are sands and loams containing many pebbles and bowlders derived from the Minnekahta, Minnelusa, and Pahasapa formations, and, just south of Boyd, they contain many lens-shaped siliceous concretions from the top of the Pahasapa formation. About Inyankara there are terraces thinly capped by sands containing pebbles brought from various local sources. In the Sundance region and farther northeast extensive thin sheets of sands and gravels cap wide terraces. West of Inyankara, on both sides of Inyankara Creek, there are well-marked terraces with a covering of gravel, sand, and loam, evidently deposited by a predecessor of the present creek. At the gap in the ridge in the west-central portion of township 50, range 63, there is a deposit of gravel and sand that was left by a stream which flowed southward. This is known by the fact that there are numerous remnants of terraces extending in that direction and sloping down part of the way to the level of Inyankara Creek. On the next divide south, where the road crosses the ridge, there is an extensive flat covered with gravels and sand, possibly representing the ancient course of Dry Creek flowing into Inyankara Creek. Gravel deposits begin on the ridge west of Skull Creek at a point 2 miles west-southwest of Holwell ranch and extend at intervals to the southern margin of the quadrangle, probably representing a predecessor of the present Skull Creek.

The gravel deposit overlying the supposed Tertiary formation west of the North Fork of Mason Creek, in township 49, may possibly belong to the Quaternary and be related to the early system of the drainage above described, but apparently it belongs to a still earlier one. It contains fragments of Minnekahta limestone and *Belemnites densus*. A small cap of bowlders of early Quaternary age lies on the Sundance formation in the small butte 4 miles southeast of Sundance.

Alluvium.—The principal alluvial deposits are in the valleys of the larger streams in the western half of the quadrangle, but they are so narrow and discontinuous that their representation on the map is not desirable. The most extensive ones are along Sundance Creek for 8 or 10 miles below Sundance, along Beaver Creek from Black Flat to its mouth, on Inyankara Creek below Inyankara, on Mason Creek, Skull Creek, and on Oil Creek in the vicinity of T E ranch. Soldier, Cold Springs, and Little Spearfish creeks run in narrow valleys that contain more or less alluvium and local wash. The alluvium consists mainly of local materials and varies in thickness from thin soils to deposits 20 or 30 feet thick in some of the deeper valleys, such as Beaver or Inyankara. Many of the creeks cut through their valley floors into the underlying deposit, and all alluvium merges into local talus on the slopes adjoining the valleys.

IGNEOUS ROCKS.

By W. S. Tangier Smith.

General statement.—The igneous rocks of the Sundance quadrangle belong to two widely separated periods of time, the first pre-Cambrian (Algonkian?), the second probably post-Cretaceous (early Eocene?) To the earlier period belong the granites and the metamorphic amphibolites of the Nigger Hill laccolith, and probably the granite of the Bear Lodge uplift. The Eocene (?) igneous rocks form an interesting group of closely related types, all of which have probably been derived by differentiation from a magma rich in sodium. They form laccolithic masses and associated minor intrusions. The rock types of the principal laccoliths are few, comprising monzonite- and syenite-porphyries and a phonolitic rock which here, as elsewhere in the Black Hills, is apparently of later age than the other porphyries. Rocks of identical type but from different laccoliths are distinguishable by slight but characteristic differences. Very few chemical analyses have been made of these rocks, consequently the rock names here used are provisional.

Algonkian (?) Intrusive Rocks.

AMPHIBOLITE-SCHIST.

Basic dikes, metamorphosed to tough, fine-grained, greenish, and usually schistose rocks, are common in the mica-schists of the Nigger Hill uplift. They are composed of green hornblende with minor proportions of orthoclase, quartz, and a sodic plagioclase. Biotite, in small scales, with apatite, ilmenite, and granular titanite, the last apparently secondary after ilmenite, are common accessory minerals.

GRANITE AND PEGMATITE.

Granitic rocks of supposed pre-Cambrian age are present in both the Nigger Hill and Bear Lodge uplifts. In the former they cut the mica-schist as dikes. In the latter they occur only as inclusions, with blocks of schist, in the porphyry of the laccolith.

NIGGER HILL LACCOLITH.

Relations.—The numerous dikes of the Nigger Hill region range from 1 foot to 50 feet in width. Most of them have a northerly or northwesterly trend that follows the cleavage of the schist. In an included mass of schist, on one of the spurs of Cement Ridge southwest of Mineral Hill, seven dikes were noted within a distance of a little over 400 feet. Occasionally, however, they cut across the schist, as, for example, north of Mineral Hill, on Sand Creek, where at one point the schists, which strike N. 5° E., are cut by a dike trending N. 72° E. No well-defined inclusions of either schist or granite were seen in the nepheline-syenite (foyaite) of Mineral Hill, although some granite occurs near the eastern base of this hill, just south of Welcome, and, as loose blocks, at a point on the northeast spur of the same hill north of Welcome. The granite dikes occasionally show partings parallel to their walls. At one point in the schist area southwest of Mineral Hill, granite cements brecciated schist.

Description.—The granites of the Nigger Hill uplift are very light gray, frequently yellowish when weathered, and range from a moderately fine-granular rock to one whose individual constituents reach a diameter of 15 cm. The grain is variable, a single hand specimen usually showing both sodium and fine-grained areas. Feldspars, comprising orthoclase, microcline, and albite, predominate over the quartz. These three species may be present in various proportions, although albite is rarely dominant. Micrographic intergrowths of feldspar and quartz are rare. In some of the dikes a silvery white mica is fairly abundant, though many of them are free from mica. Tourmaline is a minor constituent of some of the dikes in the schist area west of Sand Creek. In many of the granite dikes about Tinton cassiterite, in grains of various sizes, is irregularly disseminated.

Pegmatitic facies.—While some of the dikes of the Nigger Hill region are typical granites, others have the character of pegmatites, with the coarse texture and graphic intergrowth of quartz and feldspar characteristic of these rocks. This texture, however, has been obscured or obliterated by the crushing of the rocks during the later igneous intrusions, and the grain has been so reduced as to resemble, under the microscope, that of fine-grained granite.

Metamorphism.—All of the granite when examined under the microscope shows a cataclastic structure due to squeezing. The quartz and feldspar are deformed or granulated, and are in part cemented by secondary quartz, feldspar, and muscovite. In some places the cementing minerals have partially replaced the original crushed minerals. This is especially noticeable in some of the Tinton rocks, in which also cassiterite seems to have formed metasomatically at the expense of the granulated primary constituents. Cassiterite has been found only in the granite of the central part of the laccolith, where this rock forms inclusions in the porphyry.

Veins.—Occasional quartz veins carrying fragmental black tourmaline (deep blue in thin section) are associated with the granite dikes in the schist area west of Sand Creek. One of them shows under the microscope a small amount of feldspar, its manner of occurrence being such as to suggest the nearly complete replacement of an original granitic dike by secondary minerals, largely quartz.

BEAR LODGE MOUNTAINS.

Relations.—In the Bear Lodge Mountains, in the northwest corner of the quadrangle, granites occur within the main igneous area of the uplift and to a slight extent at several points outside of this area. All of the masses shown on the map, notwithstanding the dike-like form of some of them, are probably inclusions in later igneous rocks. This interpretation is the more probable as none of the granitic rocks of other parts of the Black Hills are known to be of post-Cambrian age. Smaller granitic inclusions within the main intrusives of the laccolith are common, and the granitic fragments are abundant in the igneous breccias described on page 8.

The inclusions vary greatly in size, ranging from microscopic fragments of the different minerals composing the granite to the body of granite extending for more than 3 miles along the eastern side of the laccolith, on the headwaters of Beaver and Redwater creeks, with a width, east of Warren Peaks, of about three-eighths of a mile. This body lies roughly parallel to the Cambrian beds just east of it, and was probably never entirely enveloped by the monzonitic magma by which it was uplifted. For the greater part of its course it is overlain by a thin bed of quartzite that forms the base of the Deadwood formation. This bed, however, is separated from the succession of sedimentary rocks to the east by porphyry sheets. The granite mass may be an upraised sill originally intruded beneath the Cambrian rocks, or it may be part of the pre-Cambrian formation upon which these sediments were laid down.

Outside the main laccolith small, scattered inclusions of fine-grained biotite-granite occur in the phonolite on the round knob south of the head of North Miller Creek. Inclusions of medium-grained granite, up to 18 inches long, are numerous, with fragments of other rocks in a sill of porphyry near the head of the east fork of Blacktail Creek, about 1½ miles north of the Sundance quadrangle. Granite of various types, in blocks and smaller fragments, all more or less rounded, is present in an agglomerate occupying a shallow saddle at the western base of a knob of phonolite a little over 5 miles east of north of Sundance. Similar agglomerates have been described by Jaggar at the Devils Tower and the Little Missouri Buttes, in the Devils Tower quadrangle, northwest of the Sundance quadrangle.

Description.—The Bear Lodge granites are aggregates of quartz with one or more species of feldspar. Magnetite, apatite, and zircon are the usual accessories. Mica is absent as a rule, or present only as an accessory. At one point, however, near the eastern edge of the large granitic area referred to above, biotite is so abundant as to be a prominent constituent.

Orthoclase or microcline is usually the dominant feldspar, with microperthite, albite, and oligoclase in various minor proportions. Very rarely albite is the principal feldspar. Quartz is usually abundant.

These granites differ both in grain and in mineral composition from those of Nigger Hill. Moreover, they seldom show the crushing, cementation, and metasomatic replacement so common in the rocks of the other uplift. Neither tourmaline nor cassiterite has been noted in the granites of the Bear Lodge uplift. Though not usually porphyritic there are sometimes more or less tabular feldspar phenocrysts reaching a maximum length of between 3 and 4 cm. The rocks, on the whole, are much finer grained than those of Nigger Hill, and are more nearly uniform in texture. A porphyritic texture is occasionally present, due to the development of tabular phenocrysts of feldspar to lengths of 1 or 2 inches.

In most of the granite the individual crystal grains or andedra reach a maximum length of between one-half and 1 cm., the average diameter being usually in the neighbornood of 2 mm. Rarely the granite is much finer grained, as, for example, toward the north end of the large mass near the east margin of the laccolith. The general fineness of the grain, together with the poverty in mica, allies these rocks with the aplites rather than with the typical granites.

Tertiary Intrusive Rocks.

PETROGRAPHY.

MONZONITE- AND SYENITE-PORPHYRIES.

General character.—The principal rock at each of the centers of intrusion shown on the geologic map belongs to a group prominent elsewhere in the Black Hills and indeed throughout the Rocky Mountains. In general these rocks are distinctly porphyritic and are characterized by many phenocrysts of feldspar and hornblende in a light-gray, aphanitic, but microcrystalline groundmass. While soda-lime feldspars predominate among the phenocrysts, potash feldspar is the chief constituent of the groundmass. Quartz is quite subordinate or is absent. The ratio between the potassium and the sodium-calcium feldspars is variable but on the whole is near unity, and most of the rocks belong in the monzonite group. Some of them, however, would more properly be designated as syenite-porphyry, if a sharp distinction were desirable or practicable.

Nigger Hill laccolith.—The monzonite-porphyry of the Nigger Hill laccolith and associated sheets and dikes is a light-gray rock with abundant phenocrysts of oligoclase-andesine and of common hornblende. Biotite phenocrysts are rare.

The phenocrysts range from 0.5 to 5.5 mm. in length, the average being about 1 mm. They usually constitute about one-fourth of the rock by volume, the hornblende being generally subordinate to the other phenocrysts in total bulk.

The groundmass is always holocrystalline and consists mainly of orthoclase, with subordinate magnetite, plagioclase, and quartz, the last being probably in part secondary, and a little apatite and titanite. The texture of the groundmass is granular or trachytic. The average diameter of the groundmass constituents ranges from 0.02 mm. to about 0.06 mm. Micropoikilitic and fluidal textures are occasionally developed.

The grain of the dike and sill rocks is but slightly finer than in the porphyry of the largest mass. In two sills near the northern margin of the uplift hornblende is so abundant as to render the rock unusually dark.

The hornblende of the porphyry alters into chlorite and calcite with a minor proportion of epidote and occasionally of a colorless mica. The chief products of the weathering of the feldspars are sericite, calcite, and kaolin.

Black Buttes.—The monzonite-porphyry of the Black Buttes is similar to that of Nigger Hill, but has certain peculiar features worthy of note. The rock is on the whole probably more alkalic than that of Nigger Hill, as indicated by the prevalence of alkali-feldspar phenocrysts. The Black Buttes porphyry occurs as a single mass associated with minor bodies of phonolite and bostonite and of itself. Within this mass the rock presents two facies, distinguishable by the character of their larger feldspar phenocrysts. North of the road which crosses the buttes from east to west, the larger feldspars are roughly equidimensional, with a maximum diameter of about 1½ cm. South of the road the phenocrysts are prismatic or tabular, with a maximum length of 3 cm. Of the two the northern facies more nearly resembles the Nigger Hill rock, the only essential difference being in the greater number and different character of the phenocrysts of the Black Buttes rock. In addition to the large, scattered crystals of orthoclase just referred to, smaller phenocrysts of orthoclase, oligoclase, and pyroxene, the last completely altered in all surface exposures, occur. Oligoclase is the dominant feldspar and sometimes has a narrow border of orthoclase. There is probably also a little anorthoclase present.

The large, scattered, tabular phenocrysts of the southern facies are sanidine. Unaltered ferromagnesian minerals, comprising augite and ægirite-augite, derived in part from brown amphibole by resorption with occasionally a little unchanged amphibole, are common as subordinate phenocrysts, and are sparingly present in the groundmass, which is generally coarser grained than in the other facies. It consists chiefly of orthoclase with a very little plagioclase, and has a trachytoidal texture. Some marginal phases, however, have a trachytic groundmass of even finer grain than that of the northern facies.

The two general facies just described grade one into the other and clearly belong to one igneous mass.

Inyankara Mountain.—The porphyry of Inyankara Mountain has fewer phenocrysts than that of Nigger Hill, the ratio of phenocrysts to groundmass ranging from 1.4 to 1.7. Oligoclase forms the principal phenocrysts, but there is a minor amount of orthoclase which often appears as a border about the oligoclase. Augite and ægirite-augite are the chief ferromagnesian minerals. They are associated with a little brown hornblende showing partial resorption.

The groundmass of the Inyankara porphyry varies in texture from microgranular to trachytic, the latter being more common near the borders of the mass. The groundmass of the central part of the intrusion is coarser grained than that of most of the Nigger Hill porphyry, and contains in addition to orthoclase and magnetite a considerable amount of augite. The Inyankara porphyry seems richer in alkalies than the Nigger Hill rock, and is a syenite-porphyry rather than a monzonite-porphyry.

At three points on the rim of the laccolith, situated respectively south, east, and northeast of the main peak of the mountain, an exceptionally alkalic facies of porphyry is found. This is almost free from ferromagnesian minerals and consists essentially of alkali feldspar with a small proportion of magnetite and a little interstitial quartz. It contains a few scattered orthoclase and anorthoclase phenocrysts, comparable in size to those of the common facies of this porphyry, and is characterized by an abundant generation of anorthoclase crystals intermediate in size between these large crystals and the laths and grains of the groundmass, and averaging about 0.15 mm. in length.

Sundance Mountain.—The rock of Sundance Mountain is a syenite-porphyry showing a few small scattered phenocrysts of oligoclase, with only an occasional prism of brown or green amphibole. The mass of the rock is composed essentially of a fine-grained aggregate of two species of feldspar. One, occurring chiefly in numerous laths, is probably oligoclase. The other, which forms the larger part of the rock, is microgranular and is probably orthoclase.

The rock as a whole is uniform in petrographic character, but at one point on the northern face of the mountain, a little east of south of Sundance, at an altitude of 5400 feet, it is banded with narrow stripes of lighter and darker gray.

Bear Lodge Mountains.—The principal laccolith of the Bear Lodge Mountains and most of the associated smaller masses about the flanks of the uplift consist of porphyry which is so much richer in orthoclase than that of Nigger Hill that it may appropriately be termed syenite-porphyry. There is, however, much variation among the Bear Lodge porphyries, which show both monzonitic and trachytic facies.

These rocks have a yellowish, reddish, or grayish color, and are in general greatly altered, usually containing minute cavities due to the decay or solution of some of the minerals of the rock. Comparatively fresh porphyry occurs as intrusive sheets on the northwest flanks of the laccolith, and also within the main igneous mass in the low area south and southeast of Warren Peaks.

This fresher porphyry, which is not typical of the laccolith as a whole, resembles some of the porphyry of the Black Buttes. The groundmass, however, is on the whole finer grained, and ferromagnesian minerals are more abundant, in places even in excess of the feldspar phenocrysts. They comprise one or more of the following: A pale-green augite—in one instance associated with a little ægirite-augite, brown to green amphibole, and biotite, the last not found in the Black Buttes porphyry. Any one of these except the ægirite-augite may be the dominant ferromagnesian mineral, though as a rule the biotite is subordinate when found with the augite or amphibole. The feldspar is usually oligoclase, occasionally with a narrow orthoclase rim; in one occurrence, however, northwest of the main laccolith, the feldspar is sanidine, with only a small proportion of oligoclase. The groundmass of this porphyry is composed chiefly of a very fine-grained trachytic felt of orthoclase, with occasionally subordinate augite, as in some of the Black Buttes porphyry. Micropoikilitic texture is common in the groundmass of some specimens.

The weathered and more typical porphyry of the Bear Lodge Mountains differs considerably from that just described. It is characterized by unusual variability both in grain and in the kind, size, and abundance of its phenocrysts, the variations occurring sometimes even within a few yards. The rock is nearly always porphyritic. Phenocrysts are sometimes abundant, sometimes rare. They consist of feldspar, as the few ferromagnesian minerals which were originally present in most of these rocks have been weathered out. Oligoclase is the dominant feldspar, the crystals frequently having rims of orthoclase or sanidine. The groundmass of these rocks, though sometimes granular or trachytic-granular, is typically a fine-grained trachytic felt of orthoclase. The chief products of the weathering of these porphyries are muscovite, kaolin, and limonite.

A coarser-grained syenite-porphyry occurs sporadically in small masses within the main laccolith. This is, so far as known, the most coarsely crystalline porphyry of the quadrangle. The largest occurrence noted was east of the summit road, near the southern margin of the laccolith, where there appears to be a considerable body of this rock extending for nearly a mile along the ridge.

No satisfactory exposures of syenite-porphyry were seen in the field, and its relation to the typical porphyry is obscure. In most places there appears to be an abrupt change to the finer-grained rock, although southwest of Warren Peaks toward the margin of the laccolith, one grades into the other.

Some specimens of the coarse facies, when broken, have a pronounced fetid odor, which was noted especially in the rocks near the southern margin of the laccolith. Like most of the other rocks of the area, the syenite-porphyry is considerably weathered and at only one place noted within the main laccolith did it contain any unaltered ferromagnesian minerals, in this case augite. This facies differs from the typical porphyry mainly in the coarser grain of the groundmass, although it is also somewhat more alkalic than much of the finer-grained porphyry. The phenocrysts, which are usually well differentiated from the groundmass, consist of orthoclase and sometimes a little oligoclase, which occasionally occurs as a core to the orthoclase. The groundmass, like that of the typical porphyry, is trachytic in texture, and in this facies the average diameter of the grains is between 0.2 and 0.3 mm. The groundmass is composed of orthoclase, with usually a minor proportion of albite.

Outside of the main igneous area of the Bear Lodge Mountains syenite-porphyry, with relatively coarse-grained groundmass, has been noted in one of the minor intrusives on Lytle Creek; also as a dike of comparatively fresh rock north of a laccolith situated nearly 3 miles beyond the northern boundary of the quadrangle.

NEPHELINE-SYENITE.

Occurrence.—Nepheline-syenite of the foyaite type is known to occur within the quadrangle in the Nigger Hill uplift only. With minor masses of allied rocks it entirely surrounds Mineral Hill, inclosing the central core of pseudoleucite-porphyry. On the west, south, and north the foyaite zone has an average width of nearly half a mile, but it is much narrower on the east. On the summits of the long northern spurs of Mineral Hill foyaite occurs only locally and in subordinate amount, the rocks here, south of the mica-schist and monzonite-porphyry, consisting for the most part of basic differentiation products of the Mineral Hill magma.

Description.—The nepheline-syenite is a dark-gray, fine-granular rock, with generally trachytoid texture. It is occasionally porphyritic, orthoclase occurring in two generations. The chief constituents of the rock are orthoclase, nepheline, pyroxene, and magnetite. Oligoclase is occasionally present and rarely it is an essential constituent. Nepheline is generally abundant, but it is occasionally scarce, and the rock passes locally into pulaskite. In some parts of the rock mass the nepheline is represented only by alteration products. A second feldspathoid, usually anhedral, though occasionally in sharp crystals with clear margins and clouded centers, was noted in some specimens. It is apparently noselite. Pyroxene is as a rule the dominant ferromagnesian mineral, though in one variety or facies biotite is the only dark mineral present. The pyroxene is usually a pale-green augite, sometimes accompanied by ægirite-augite. In some facies ægirite-augite is the only pyroxene present. Brown amphibole, sometimes intergrown with augite, biotite, and pleochroic apatite, are common accessory minerals. Titanite and melanite are less common, although the latter in two places is an important constituent of the rock.

White, fine-granular, aplitic dikes, consisting essentially of the dominant light-colored constituents of the nepheline-syenite, are in places abundant in the nepheline-syenite area.

Associated pyroxenite.—Angular fragments of pyroxenite are included in the nepheline-syenite at several places, particularly near its borders. In some localities the nepheline-syenite, crowded with these inclusions, seems to grade into pyroxenite as a basic contact facies.

The pyroxenites are nearly black, medium- to fine-granular rocks, composed of augite, magnetite, and apatite, usually with scattered flakes of biotite. The augite, which is pale green and slightly pleochroic in thin section, constitutes the bulk of the rock, magnetite forming from one-fourth to one-third. Apatite is common and is more abundant in the coarser-grained varieties of the rock. One of these, from near the western base of Mineral Hill, contains in places 10 per cent of apatite. This coarse-grained rock differs from most of the pyroxenites at other points in containing a very little partly decomposed orthoclase and the decomposition products of what was probably nepheline.

PSEUDOLEUCITE-PORPHYRY.

Occurrence.—The pseudoleucite rocks of the quadrangle are limited to Mineral Hill and its vicinity. The only body of them represented on the map is that which, surrounded by nepheline-syenite, forms the mass of Mineral Hill. The pseudoleucite-porphyry is usually gray but is occasionally yellowish or reddish. Though the rock is sometimes without noticeable phenocrysts, light-gray or nearly white porphyritic pseudomorphs after leucite (pseudoleucite) up to 5 cm. in diameter are common. The porphyry is everywhere greatly weathered and generally contains numerous small or minute cavities due to the partial or complete leaching out of some of the minerals.

In its original condition the rock was apparently fine grained, holocrystalline, and porphyritic, with phenocrysts of leucite and accessory magnetite and apatite. The groundmass appears to have been originally granular, and it, also, probably consisted largely of leucite. Other probable constituents were nepheline, pyroxene, and garnet. Owing to their altered condition these rocks seldom show any of the minerals originally contained in them except occasionally apatite and perhaps a little magnetite. The rock now consists essentially of three secondary minerals—orthoclase, a colorless mica (presumably muscovite), and limonite. Orthoclase, the chief constituent of the rock, occurs generally as a granular mosaic, through which the mica is scattered in microscopic scales or aggregates. The form and mode of occurrence of these aggregates suggest in many cases the replacement of some feldspathoid, possibly nepheline. This is rendered more probable by the fact that this mica is a common alteration product of nepheline in the rocks of this region. The limonite, though sometimes associated with the mica, occurs plainly in patches, sometimes with hexagonal outline. The numerous small cavities in the rock are usually lined with limonite or with opaline or chalcedonic silica.

The pseudoleucite phenocrysts are aggregates of orthoclase and muscovite which are quite distinct in the hand specimen, but differ microscopically from the rest of the rock only in their freedom from limonite (or magnetite) and in a coarser crystallization of the feldspar. That pyroxene and feldspar were originally present in small amount in the rock is suggested by the forms of some of the cavities, and some weathered pyroxene crystals were identified in one thin section. The occurrence of original magnetite and garnet in the groundmass of the rock is suggested by the forms of some of the limonite. Occasionally the feldspar of the groundmass has a parallel or trachytic arrangement and may be original; whereas, the granular feldspar has probably all been formed by a recrystallization of the rock.

Other pseudoleucite rocks in bodies too small to map occur within the nepheline-syenite mass. One of these is a pseudoleucite-syenite, which is known in place only at one point, nearly half a mile west of south of Welcome, just south of the fork in the road and near the margin of the foyaite area. Bowlders of the same rock, however, are common in the gravels of Sand Creek for some distance south of the mouth of Mallory Gulch. The source of this rolled material was not determined. It may come from some of the densely wooded western slopes along Sand Creek north of Welcome.

The pseudoleucite-syenite is dark gray and is characterized by many pseudophenocrysts having the distinctive form of leucite. Some of these are light gray and small; others are larger, with a maximum diameter of 1.5 cm., and have a reddish tinge. Occasionally they show zones due apparently to the arrangement of included pyroxene.

As shown by the microscope, the pseudoleucites are composed of nephelite, or its alteration products, and orthoclase, and lie in a matrix composed essentially of pyroxene-nephelite, magnetite, some orthoclase, and usually garnet. The pyroxene is ægirite-augite, usually with more or less augite. Apatite, titanite, zircon, biotite, and rarely a small flake of muscovite occur as accessories. This rock differs from the pseudoleucite-porphyry in the absence of a porphyritic texture, although a porphyritic appearance is given to it in some cases by the great variation in the size of the pseudoleucites.

Pseudoleucite rocks occur within the nepheline-syenite as dikes. These are usually medium- to dark-gray porphyritic rocks, with very fine-grained to aphanitic groundmass. They are similar, on the whole, to the pseudoleucite-porphyry of Mineral Hill, although some of them are much less weathered.

Relations of pseudoleucite-porphyry and nepheline-syenite.—Although the nepheline-syenitic area practically surrounds Mineral Hill, nepheline-syenite is absent, as has already been stated, in a part of this annular area, on the northern spur of the hill northwest of Welcome, although the rocks here consist chiefly of differentiation products of the nepheline-syenite magma. Mineral Hill is asymmetrically placed within the nepheline-syenite area, which is much narrower on the east than on the west.

It is possible that the nepheline-syenite and pseudoleucite-porphyry together form a minor laccolith within the larger Nigger Hill uplift, resting, as does the latter, on an irregular floor of pre-Cambrian rocks. The mutual relations of the rock masses, however, as well as their general form and structure, which are shown on the map, indicate that the nepheline-syenite and pseudoleucite-porphyry form a stock that is intrusive into the monzonite-porphyry of Nigger Hill and they are so represented in the accompanying cross sections of the uplift (see figs. 1 and 2). It is probable also that these two rocks, although they were derived from the same magma, were not simultaneously intruded, but that they resulted from two eruptions that were separated by a comparatively short interval of time. The strongest evidence in support of this view is the fact that the rocks of the two areas do not grade into each other, but, though subject to some local variation within their own boundaries, retain their distinctive characters throughout their respective areas. Additional evidence is furnished by the asymmetric position of the pseudoleucite-porphyry within the nepheline-syenite area and by the existence of dikes of pseudoleucite-porphyry within the nepheline-syenite west of Mineral Hill.

While both of the rock masses, as shown by their mineralogical compositions, are comparatively rich in alkalies, the pseudoleucite-porphyry seems relatively richer in potash, and the nepheline-syenite in soda. The porphyry also appears to have a higher content of silica and alumina, but is somewhat poorer in lime, iron, and magnesia than the nepheline-syenite.

PHONOLITE.

Occurrence.—Phonolitic rocks occur in the Bear Lodge Mountains, Black Buttes, and very subordinately in the Nigger Hill uplift. They include both nephelinitoid and trachytoid types, together with tinguaite and nepheline-syenite-porphyry. These rocks do not form large laccolithic masses within this quadrangle, but occur only as dikes, sheets, and subordinate laccolithic intrusions within or on the flanks of the larger uplift.

Bear Lodge Mountains.—Phonolite occurs in the Bear Lodge Mountains as dikes or small masses within the main laccolith; also as sheets, minor laccoliths, and dikes on the flanks of the uplift. The tinguaite forms dikes or small bodies within the main porphyry mass.

The phonolites are light to dark gray, usually with a greenish tinge. In general they are without noticeable cleavage or parting, though in one instance they are almost slaty. They are mostly of the trachytoid variety, although there are some nephelinitoid phonolites, and locally the rock of the long, narrow mass east of Miller Creek approaches nepheline-syenite-porphyry in texture and composition.

These rocks are always porphyritic, and frequently contain numerous coarse, tabular, sanidine crystals having a maximum length of 3 cm. or more. The phenocrysts include the following minerals: Sanidine (or perhaps soda-orthoclase), anorthoclase, ægirite-augite (sometimes with augite centers or ægirite rims or both), one or more feldspathoids, melanite garnet, magnetite, titanite, apatite, and rarely zircon. Feldspar or a feldspathoid is usually dominant, though sometimes ægirite-augite preponderates. Brownish or brownish-yellow melanite is occasionally common. Titanite and apatite are common accessories in most of the rocks, but magnetite is seldom abundant.

The feldspathoids are altered to aggregates of analcite, natrolite, calcite, mica (muscovite?), and probably other minerals. The original mineral was probably in most cases nepheline, although the presence of sodalite or noselite in some of the varieties is inferred from the isotropy of unaltered crystal grains and the outlines of the pseudomorphs. That the feldspathoid is in some instances altered nephelite is suggested by the following analysis of a trachytoid phonolite from Warren Peaks. In this rock only one feldspathoid was noted, a brownish mineral showing frequent hexagonal sections, which is common as a phenocryst. The analysis shows only traces of chlorine and little sulphuric acid, while the calculated norm of the rock gives 8.5 per cent of nephelite. In drawing conclusions, however, the fact that sodalite and noselite give rise on weathering to alteration products free from chlorine and sulphuric acid must not be overlooked.

The following analysis of trachytoid phonolite (pulaskose) from Warren Peaks was made by George Steiger in the laboratory of the United States Geological Survey. The rock was called syenite-porphyry in Bulletin No. 228 of the Survey (p. 102).

Analysis of trachytoid phonolite from Warren Peaks, Wyoming.

	Per cent.
SiO_2	55.14
Al_2O_3	18.98
Fe_2O_3	2.60
FeO	1.62
MgO	.32
CaO	3.96
Na_2O	5.38
K_2O	6.64
H_2O-	.63
H_2O+	3.70
TiO_2	.50
CO_2	None.
P_2O_5	.17
SO_3	.10
Cl	Trace.
S	.03
MnO	Trace.
BaO	......
Total	99.77
Less O	.01
	99.76

In only one place—the long, narrow area east of Miller Creek—was any unaltered nepheline seen among the phenocrysts of the phonolite.

The groundmass of the phonolites is always fine grained, sometimes granular, more often trachytic, and usually shows flow structure. It is composed mainly of alkali-feldspar laths with ægirite or ægirite-augite or both, sometimes augite, one or more feldspathoids, frequently a small amount of magnetite, and rarely a little garnet. Generally only one feldspathoid is present, usually the same species that occurs among the phenocrysts. Nepheline in clear, colorless, short, hexagonal prisms is occasionally abundant in the groundmass of some of the rocks.

The tinguaites of the Bear Lodge uplift, as distinguished from the phonolites just described, are characterized chiefly by their decided green color, due to the abundance of ægirite needles contained in the groundmass. They have, on the whole, fewer phenocrysts than the phonolites, and these are generally small. In most cases pseudomorphs, apparently after nepheline, are the most abundant phenocrysts, though sometimes sanidine, in small lath-like forms, is dominant. In some varieties no feldspar at all is present. Ægirite-augite sometimes occurs, occasionally with pale augite centers and margins of ægirite, as in the phonolites, and melanite, though rare, is occasionally an important phenocryst. Biotite, not seen in the phonolite, occurs sparingly in one of these rocks. Apatite and magnetite are the usual accessory minerals.

The groundmass is usually very fine-grained, frequently with pronounced flow structure. It consists of a felt of fine ægirite needles, with minute laths of feldspar. In some of these rocks nepheline is abundant in the groundmass; in others an isotropic feldspathoid, not seen in well-defined forms, is moderately common. In one rock a very little fluorite was noted as a secondary product.

Black Buttes.—The southern and largest mass of phonolitic rocks in the Black Buttes consists of nepheline-syenite-porphyry. Some of this rock occurs also in the eastern part of the northern area of phonolite. The rest of the mass, however, with a little intrusion shown on the map between the two larger areas, consists of phonolite and a rock intermediate between phonolite and monzonite-porphyry.

The Black Buttes phonolites are gray or nearly black rocks, with generally abundant phenocrysts of moderate size. These consist chiefly of alkali feldspar and pyroxene, the former predominating. A feldspathoid which is probably either sodalite or noselite is always present in subordinate amount among the phenocrysts. Among the minor constituents, yellowish-brown melanite is sometimes common, and brown amphibole, not noted in the Bear Lodge phonolite, is occasionally present. The feldspar is mainly orthoclase, although sanidine, soda orthoclase, and a little oligoclase, frequently mantled or intergrown with orthoclase, are present in some of the rocks. As in the Bear Lodge rocks, the pyroxene is generally ægirite-augite, sometimes with light augite centers. Ægirite was noted only in one rock from near the center of the buttes.

In the general texture and composition of the groundmass these rocks resemble the Bear Lodge phonolites. A second generation of the same feldspathoid found among the phenocrysts usually, occurs as a minor constituent of the groundmass. No other feldspathoid was identified in these rocks, although some of the phonolite from near the center of the Black Buttes contains analcite, which was probably derived from nepheline. The accompanying analysis, however, of one of the phonolites (No. 1) from the Black Buttes indicates that nepheline, sodalite, and noselite are all present.

The following analyses of phonolitic rocks from the Black Buttes were made by George Steiger in the laboratory of the United States Geological Survey.

The rocks of intermediate character previously referred to, which have been mapped with the phonolite on account of close field association with this rock, are exposed near the road running north from the center of the Black Buttes, where they occur along the western margin of the narrow strip of phonolite, and also near the road which runs southwest from the center of the buttes. These rocks megascopically resemble some of the phonolite just described, but microscopically are more closely allied to the monzonite-porphyry. They are less alkalic than the phonolite, oligoclase is more abundant and is usually the dominant feldspar, and the ægirite-augite contains less of the ægirite molecule. No feldspathoids have been recognized in any of these rocks. More or less brown hornblende and biotite occur as phenocrysts. The apatite of most of these rocks is pleochroic.

Analyses of phonolitic rocks from Black Buttes, Wyoming.

	No. 1. Per cent.	No. 2. Per cent.
SiO_2	57.46	58.08
Al_2O_3	18.41	18.38
Fe_2O_3	2.40	3.02
FeO	1.28	1.42
MgO	None.	.96
CaO	4.02	3.85
Na_2O	9.23	6.22
K_2O	4.93	5.11
H_2O-	.45	.37
H_2O+	1.12	1.55
TiO_2	.42	.58
CO_2	None.	None.
P_2O_5	.11	.21
SO_3	.50	.07
Cl	.23	Trace.
S	.05	None.
MnO	.11	.10
BaO	None.	None.
Total	100.72	99.92
Less O	.08	
	100.64	

No. 1. Phonolite (laurdalose) from a point near the center of the Black Buttes.

No. 2. Trachytoid phonolite (akerose) from a place just north of the road near the western margin of the Black Buttes igneous area.

In Bulletin No. 228 of the United States Geological Survey, page 102, No. 1 was called essexite-porphyry (essexose), and No. 2, syenite-porphyry (akerose-laurvikose).

The nepheline-syenite-porphyry of the large phonolitic mass near the southern margin of the buttes apparently forms a subsidiary laccolith of the Black Buttes uplift and is very different, both megascopically and microscopically, from the phonolitic rocks previously described. It is light gray, often with a reddish tinge, and is frequently spotted with brownish-red or yellow phenocrysts of weathered nepheline. The rock shows a marked tendency to split into thin plates. It is holocrystalline and somewhat porphyritic, with phenocrysts of nepheline (elæolite), ægirite, feldspar, and sometimes a little magnetite. Nepheline forms the largest phenocrysts, the average diameter of the sections being a little less than 1 mm. On weathering it develops a prismatic cleavage and gradually alters to colorless or yellowish analcite. The feldspar is microperthite or cryptoperthite.

The groundmass, which constitutes the bulk of the rock, is coarser grained than in the other phonolitic rocks of the Black Buttes. It consists chiefly of microperthite and cryptoperthite and has a trachytic, or, less commonly, a granular texture. A grayish, weathered feldspathoid, either sodalite or noselite, occurs in the groundmass in minute crystals up to 0.1 mm. in diameter, and there is occasionally a little ægirite present.

The nepheline-syenite-porphyry of the northern phonolitic intrusion differs from that just described in that the nepheline is confined to the groundmass and the scattered phenocrysts consist of orthoclase with subordinate ægirite-augite.

BOSTONITE.

Bostonite forms three sharp-pointed hills in the western part of Black Buttes. The rock is light gray, holocrystalline, and porphyritic, with fine-grained groundmass, and consists essentially of feldspar with accessory magnetite, apatite, and titanite. No ferromagnesian minerals were seen. The feldspars include orthoclase, anorthoclase, and oligoclase and occur in various proportions in the different masses. The phenocrysts are orthoclase or anorthoclase and lie in a trachytic groundmass composed mainly of the same species.

DIKES AND SHEETS.

Occurrence.—In the Nigger Hill uplift are numerous dikes, sheets, and small masses, which occur principally in or near the nepheline-syenite or pseudoleucite-porphyry, especially on the northern spurs of Mineral Hill, and also in the schist. Only two intrusions belonging to this group are known in the monzonite-porphyry of Nigger Hill. These rocks are also intruded in the Carboniferous rocks at three places—near the southeastern margin of the uplift, near its southwestern margin, and in Grand Canyon about 5 miles northwest of Mineral Hill. Many of the dikes in the nepheline-syenite and in the pseudoleucite-porphyry are not shown on the geologic map. Most of the others are represented by a single color under the head "Dikes and sheets."

Character.—The rocks of these minor bodies range from extremely basic pyroxenites to light-colored aplites. Their peculiar character and, to some extent, their complementary composition, together with the areal relations of some of them to the nepheline-syenite and pseudoleucite-porphyry, are grounds for considering these small masses as differentiation products of the same magma which solidified as the nepheline-syenite and pseudoleucite-porphyry of Mineral Hill. The pseudoleucite-porphyry itself, as has been shown, may have been a differentiation product of this general magma which probably had an average composition near that of the nepheline-syenite. Judged by the exposures within the nepheline-syenite area this magma was particularly subject to differentiation. This is shown not only by the variations of its nepheline content, but especially in the varying proportions of its dark minerals, in the common local segregations of pyroxenite, and in the occasional occurrence of aplitic veins almost free from dark minerals.

In the process of differentiation the iron oxides, magnesia, and lime have segregated in one direction, as is seen in the rocks rich in ferromagnesian minerals, and the alumina and alkalies in another, as is exemplified in the dike rocks with abundant feldspars or nepheline and scanty ferromagnesian constituents. The Mineral Hill magma was comparatively rich in phosphoric acid, and this was concentrated in the first group of oxides, yielding at the basic end of the rock series a pyroxenite rich in apatite. The rock types produced are the following: Pyroxenite, ijolite, nephelinite, fourchite, camptonite, vogesite, garnet-nepheline rocks, pseudoleucite-porphyry, phonolite, monzonite-porphyry, syenite-porphyry, syenite (including nepheline-syenite), and alkali-granite-porphyry. Light- and dark-colored rocks are about equally abundant. A large part of the leucocratic, or light-colored members of the group occur between Spottedtail and Sand Creek gulches, not far from the margins of the nepheline-syenite and pseudoleucite-porphyry. On the northern spurs of Mineral Hill the leucocratic rocks are closely associated with melanocratic, or dark-colored types, the outcrops along the ridges within the area colored as nepheline-syenite on the map showing alternating light and dark rocks. The dark rocks, which seem here to be on the whole more abundant, form considerable masses in which the light-colored rocks occur as dikes. Nearly all the rocks of this group which are noted in the pseudoleucite-porphyry area occur in the northwestern part. They are chiefly leucocratic, the only distinctly melanocratic rock seen being pyroxenite, which is found near the western base of Mineral Hill.

Among the light-colored rocks of the group are syenite-porphyry and monzonite-porphyry, some of the latter resembling the laccolith porphyry of Nigger Hill. It is possible that some of the monzonite-porphyry dikes, especially those outside of Mineral Hill, are derived from the Nigger Hill magma, but their general distribution and their close association with dikes evidently related genetically to the nepheline-syenite magma indicate their derivation from the Mineral Hill center.

Ijolite.—The igneous sheet in the Minnelusa formation in Grand Canyon, northwest of Mineral Hill, is probably a somewhat altered ijolite. The bottom of the sheet is 60 feet above the floor of the valley, and its thickness is 10 or 11 feet. The rock is dark gray and fine granular except close to the contacts, where it contains minute light-colored phenocrysts in an aphanitic groundmass. The sedimentary rocks are hardened near the intrusion.

The sheet is essentially a hypidiomorphic-granular aggregate of altered nepheline, ægirite-augite, and melanite, the nepheline being in excess of the dark minerals. There is in places a little untwinned feldspar, and apatite and magnetite occur as accessories. Marginal facies of the rock, which are much weathered, contain very many minute porphyritic crystals of pseudoleucite, many small garnets, a small amount of magnetite, and in the rock from the lower contact an undetermined feldspathoid (?).

Nephelinite.—The thin sheet intruded in the Pahasapa formation north of the head of Rattlesnake Canyon is a dark-gray, porphyritic nephelinite, consisting of numerous phenocrysts of pale-green, slightly pleochroic augite, magnetite, and apatite in a gray matrix made up mainly of what are apparently alteration products of nepheline with a considerable amount of calcite. This rock gelatinizes readily in hydrochloric acid, and a drop of the solution yields on evaporation abundant cubes of sodium chloride. Much altered rock, probably nephelinite, occurs on the northern spur of Mineral Hill, a little south of the monzonite-porphyry contact.

Augite-fourchite.—This rock occurs as dikes in the monzonite-porphyry on the east side of Beaver Creek, near the southern margin of the Nigger Hill laccolith, and in the small southernmost area of schist on the west side of Beaver Creek. It is a dark-gray, dense rock, consisting of numerous augite prisms and magnetite grains in a brown to nearly colorless isotropic base containing abundant augite microlites and occasionally a little spherulitic feldspar. The rock on the east side of Beaver Creek contains abundant little spheroids up to half an inch in diameter, which weather out of the mass. The spheroids differ from the rest of the rock in containing comparatively little isotropic base. The groundmass consists largely of albite in long laths and needles, having a tendency to form fan-shaped aggregates, and of orthoclase in small xenomorphic grains. The spheroids are separated from the rest of the rock by broad, brownish, glassy bands.

Another rock, provisionally classed as a fourchite, forms a dike cutting the Carboniferous rocks south of the Nigger Hill porphyry area. This dike has a trend S. 78° E., an exposed length of about 250 feet, and a width of between 50 and 75 feet. It shows a more or less well-developed, horizontal columnar structure. The rock of this dike differs considerably from the fourchites already described. It is dark gray, almost black, very fine grained, and porphyritic, the phenocrysts, which are small and scattered, being slightly pleochroic augite, magnetite, some apatite, and an occasional andesine feldspar. The matrix in which these minerals occur is pale gray to nearly colorless, and for the most part is isotropic or nearly so. It consists largely of clear and almost colorless minute grains, averaging between 0.02 and 0.03 mm. in diameter. These resemble leucite in form, though having no distinct boundaries, and usually contain numerous inclusions of augite and magnetite microlites, zonally arranged. The optical characters of these grains and chemical tests indicate that the light-colored portions of the groundmass probably consist in large part of analcite, either as an original mineral or as a pseudomorph after leucite. In addition to the minerals mentioned the groundmass contains a variable but generally small proportion of feldspar in untwinned or simply twinned laths, or in small micropoikilitic areas. Calcite occurs in small amount as a secondary mineral.

Augite-camptonite.—Intruded in the pre-Cambrian schists in Bear Gulch, between 300 and 400 yards south of the settlement of that name, are two narrow dikes of what is here called augite-camptonite, though the rocks, strictly speaking, are intermediate in character between camptonite and fourchite. They are dark gray and porphyritic, with compact groundmass, and the dark minerals are more abundant than the light-colored ones. The phenocrysts are augite and magnetite, with accessory apatite and small biotite crystals. In one dike the light-colored part of the groundmass consists of feebly polarizing feldspar and a minor proportion of isotropic material. In the other the matrix is mostly isotropic, with little feldspar. The feldspar consists of both orthoclase and oligoclase in nearly equal amounts. The isotropic mineral is somewhat brownish and is probably analcite. Both rocks gelatinize with hydrochloric acid, and cubes of sodium chloride form on evaporation of the solution.

Augite-vogesite.—Augite-vogesite is by far the most abundant dark rock on the northern spurs of Mineral Hill, where it forms a considerable mass. It occurs also as a dike, 1 foot wide, in the schist on the north side of Sand Creek a short distance below the mouth of Spottedtail Gulch. Vogesite is dark gray, often nearly black, porphyritic, holocrystalline, and usually very fine grained. The dark-colored minerals are as a rule the more abundant. Phenocrysts are common, and consist chiefly of augite and magnetite, the former predominating, together with accessory apatite, biotite, and, rarely, plagioclase feldspars. Most of these rocks, like many others of the group, are fairly rich in accessory apatite, as is indicated for one of them by the comparatively large amount of phosphoric acid shown in its analysis, which is given below. In addition to these minerals, brown amphibole is common as a phenocryst in one facies of the vogesite.

The groundmass, which is often crowded with dark-colored constituents, consists of augite, magnetite, a variable amount of biotite, feldspar, altered nepheline, and, locally, brown hornblende. Orthoclase and andesine, the former usually dominant, are the principal light-colored constituents of the groundmass. In the facies analyzed there are occasional crystals of a considerably altered colorless mineral which is probably noselite. The mineral is roughly hexagonal in outline and contains numerous microscopic inclusions of magnetite centrally massed. These rocks gelatinize with acid.

The following analysis of nepheline-bearing augite-vogesite (kentallenose), from the summit of the northern spur of Mineral Hill, was made by George Steiger in the laboratory of the United States Geological Survey:

Analysis of augite-vogesite from Mineral Hill, Wyoming.

	Per cent.
SiO_2	42.95
Al_2O_3	12.44
Fe_2O_3	10.16
FeO	5.18
MgO	5.82
CaO	13.11
Na_2O	2.10
K_2O	2.29
H_2O-	.91
H_2O+	1.98
TiO_2	1.34
CO_2	None.
P_2O_5	1.37
SO_3	.15
Cl	.07
S	None.
MnO	.29
BaO	None.
Total	100.16
Less O	.02
	100.14

Garnet-nepheline rocks.—At two points on the northwest slopes of Mineral Hill occur rocks characterized by abundant minute garnets. One of the rocks is very fine grained, and, though dark in color, consists largely of light-colored minerals. The dark minerals are mainly brown garnet and biotite, with a minor proportion of ægirite-augite. The light-colored matrix is granular and consists of more or less altered nepheline and orthoclase (?). The other rock, which is porphyritic, with the light and dark minerals nearly evenly divided, is considerably altered. The phenocrysts are brown garnet, augite, magnetite, and a probable feldspathoid altered to analcite with apatite as an accessory. The groundmass consists of the same secondary analcite with abundant small garnets, some magnetite, very much pyroxene, and a very little feldspar, perhaps secondary.

Phonolite.—Near the end of the west fork of the northern spur of Mineral Hill occurs a dark-greenish-gray trachytoid, tephritic phonolite, with numerous phenocrysts of feldspar-augite, brown amphibole, magnetite, and a much altered isotropic feldspathoid in a dense groundmass. The feldspars are orthoclase and oligoclase, the former occurring largely as a mantle to the latter. The original feldspathoid was probably nepheline. Titanite and apatite occur as accessories. The groundmass consists mainly of weathered feldspar laths with microscopic grains of magnetite.

Monzonite-porphyry and syenite-porphyry.—These porphyries are especially common northwest and north of Mineral Hill, within the pseudoleucite-porphyry area. But they also occur on the northern spur of Mineral Hill north of the pseudoleucite-porphyry area, in the schist on Sand Creek below the mouth of Spottedtail Gulch, in the schist a short distance south of the settlement of Bear Gulch, and within the Nigger Hill porphyry area.

Most of these dikes and sheet rocks do not differ essentially from the monzonite- and syenite-porphyries of the Nigger Hill and Bear Lodge laccoliths. They are usually light gray, and, like most of the light-colored rocks of the quadrangle, are generally much weathered. They vary in texture from facies similar to the coarser-grained syenite-porphyry of the Bear Lodge Mountains to facies having very fine-grained groundmass and well-defined phenocrysts. Unlike the Nigger Hill porphyry, most of these rocks contain orthoclase phenocrysts, the porphyritic feldspars being usually orthoclase, or orthoclase and oligoclase. Ferromagnesian minerals are abundant in some of these, but nearly absent from others. They comprise biotite and hornblende. The groundmass, which is trachytic or granular, consists, as in most of the porphyries of the quadrangle, essentially of orthoclase.

One of the more important of the light-colored rocks of the group, probably a nepheline-syenite-porphyry, forms a broad dike-like mass on the west and northwest slopes of Mineral Hill, between 200 and 300 feet above Spottedtail Creek. This mass appears to continue unbroken for half a mile or more. The rock is grayish and more or less yellowish in color, and is composed largely of a trachytic aggregate of thin, tabular orthoclase phenocrysts, elongated parallel to the axis and usually simply twinned. These feldspars have an average length of between 1 and 2 cm. They contain frequent small inclusions, probably altered nepheline, often hexagonal, squarish, or more or less rounded in form and composed mainly of aggregates of secondary muscovite in microscopic flakes and of limonite. In the angular spaces between the feldspars is a considerable amount of interstitial matter of greenish- or yellowish-gray color, composed largely of the same altered nepheline (?) and tabular orthoclase. Magnetite and apatite are occasionally present, and small cavities probably due to the weathering out of some minor ferromagnesian constituent are moderately common within these areas.

Syenite.—On the northern spur of Mineral Hill are five dikes and one larger mass, 400 feet wide and several hundred yards long, of syenitic rocks. One of the dikes is nepheline-syenite with abundant altered nepheline, having brown amphibole and augite as its ferromagnesian constituents. The others, which are considerably altered, appear to have contained little or no nepheline.

Alkali-granite-porphyry.—This rock occurs at the Interocean mine, west of Welcome. It is light gray, porphyritic, and fine grained. Phenocrysts are numerous, and consist of feldspar with a minor and sometimes insignificant proportion of biotite. Magnetite is never more than an accessory. The feldspar is sometimes orthoclase and microperthite with a minor proportion of oligoclase. Sometimes the oligoclase is the chief phenocryst, with smaller amounts of orthoclase and very little microperthite, the last two occurring in part as a mantle to the oligoclase. The groundmass is holocrystalline-granular and consists of feldspar and quartz. The feldspars are orthoclase and microperthite, with sometimes one and sometimes the other in excess. The quartz is abundant and frequently occurs in micropoikilitic areas.

IGNEOUS BRECCIA.

Many of the fissures through which the porphyries were intruded must have contained more or less broken rock. The intrusion itself undoubtedly in many instances brecciated the fissure walls, and where there were successive intrusions the brecciation involved previously intruded porphyry as well as older igneous or sedimentary rocks. Such breccias, of which the intruding rock forms the matrix, are commonly associated with the intrusive eruptions of the northern Black Hills and are found most often along the margin of the invading mass. In the Sundance quadrangle they occur in the Bear Lodge Mountains, in the Black Buttes, and in connection with several of the minor intrusives on the east side of the Bear Lodge uplift.

The breccias of the Bear Lodge laccolith were noted on and in the vicinity of the two highest peaks of the Warren Peaks group; on the ridge and slopes west of the road, near and north of the northern boundary of the quadrangle; on the spur south of Beaver Creek, just west of the granite; and at several points about 2 miles southeast of the highest of the Warren Peaks. These Bear Lodge breccias contain abundant fragments of granite and of various facies of the Bear Lodge porphyries, together with numerous fragments of minerals from the coarser-grained rocks, especially granite, all embedded in a reddish, yellowish, brownish, or grayish matrix, which as a rule constitutes but a small part of the rock. The rock is always greatly weathered, and minute cavities, due to the leaching out of minerals, especially the ferromagnesian constituents, are common both in the matrix and in many of the included rock fragments. The matrix usually contains abundant microscopic grains of red or yellow iron oxide, sometimes so numerous as to render it almost opaque. The clearer parts, as seen with a high power, show a faintly polarizing granular or somewhat felted feldspar aggregate.

The igneous breccias of the Black Buttes porphyry area (mentioned above) are similar to those just described, except that they contain no granitic material.

The sheet of phonolite in the Minnelusa formation north of Sundance and near the northern margin of the quadrangle is intruded in what appears to be a bed of shale belonging to this formation and is associated with a breccia consisting of sandstone, sand grains, shale, and porphyry, in a small proportion of cement which is apparently igneous.

Another breccia, also associated with an abundance of shale, is found nearly 1½ miles southeast of this occurrence, along the northwestern base of the small body of phonolite which occurs at this point. The breccia includes shale, limestone, dark-gray, fine-grained quartzite, and various types of granite and gneiss, besides mineral fragments from the granular rocks. The cement of this agglomerate appears to have been weathered out for the most part, leaving the loose, fragmental material, much of which, however, still retains a coating of the matrix with its abundant smaller inclusions. This matrix does not differ essentially from that of the other breccias described. The granite of this breccia is undoubtedly pre-Cambrian and is like that of the Devils Tower agglomerate, about 25 miles northwest of this area, described by Jaggar in his account of the laccoliths of the Black Hills (Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 3, p. 263). It resembles the Archean granite of the Rocky Mountains, rather than the granite of other parts of the Black Hills. Two varieties of shale are found in this breccia, one nearly black and occurring in thin flakes, the other very dark gray and breaking into small angular fragments. These shales are probably derived, in part at least, from the Minnelusa formation.

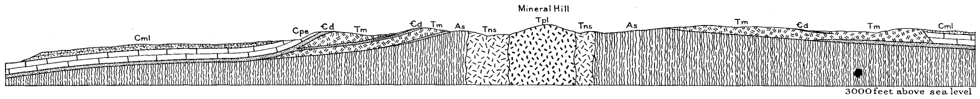


FIG. 1.—Northwest-southeast section through Nigger Hill laccolith along line G–G on structure-section sheet.
As, Mica-schist; Cd, Deadwood formation; Cpe, Pahasapa and Englewood limestones; Cml, Minnelusa sandstone; Tm, monzonite- and syenite-porphyries; Tns, nepheline-syenite; Tpl, pseudoleucite-porphyry.
Horizontal and vertical scales: 1 inch=1 mile.

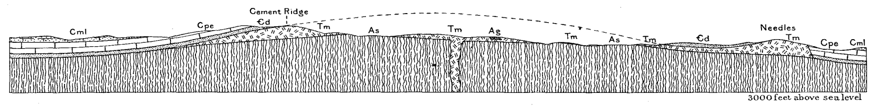


FIG. 2.—Southwest-northeast section through Nigger Hill laccolith along line H–H on structure-section sheet.
As, Mica-schist; Ag, granite and pegmatite; Cd, Deadwood formation; Cpe, Pahasapa and Englewood limestones; Cml, Minnelusa sandstone; Tm, monzonite- and syenite-porphyries.
Horizontal and vertical scales: 1 inch=1 mile.

In addition to the occurrences described above, there is a considerable body of breccia in the igneous area a little over a mile northeast of Sundance. The breccia is found here just northwest of the phonolite and forms most of the northwestern portion of the area. It is well exposed in the northern part of the area, close to the phonolite, and here the material occurs in layers which vary from coarse to fine grained, but are without sharp division lines. These layers strike N. 40° E. and dip northwest at 38°. They lie parallel to the plane of contact with the phonolite. These breccias are characterized by their light-gray color and, unlike those last described, appear to consist wholly of igneous material (phonolite and syenite-porphyry, with scattered fragments of feldspar, augite, hornblende, and magnetite), derived, so far as could be determined, from the intrusive rocks which form the southeastern portion of this area. There is comparatively little matrix, often little more than a film between the closely packed fragments of rock. This matrix is similar in general microscopic character to that of the breccias previously described.

GEOLOGIC RELATIONS.

General statement.—The most striking and important form taken by the Tertiary igneous rocks of the Sundance quadrangle is the laccolith. This consists in some instances of a single intrusion of one general rock type, as at Sundance Mountain and perhaps at Inyankara Mountain. In other cases, as in the Bear Lodge and Nigger Hill uplifts, while the main laccolithic mass consists of a single undifferentiated or but slightly differentiated type, it is associated with intrusions of other rocks. Some of the laccoliths include subsidiary laccolithic masses within the main area or about its borders, as in the case of the Needles in the Nigger Hill uplift. This is especially true of the Bear Lodge uplift. The Black Buttes differ somewhat from these in having been formed by several intruded masses of more nearly equal importance. It is a laccolithic aggregate. The principal laccoliths, as has appeared from the preceding petrographic descriptions, are those of Nigger Hill, Bear Lodge Mountains, Black Buttes, Inyankara Mountain, and Sundance Mountain. The general geologic relations of the Tertiary igneous rocks at each of these eruptive centers or uplifts will now be briefly reviewed.

Nigger Hill uplift.—The igneous rocks of the Nigger Hill uplift consist of pre-Cambrian granite and of Tertiary nepheline-syenite (foyaite), pseudoleucite rocks, and porphyry, the last probably Eocene. The granite occurs as dikes in the pre-Cambrian schist. The porphyry, the main igneous rock of the uplift, forms an extensive laccolith with associated marginal intrusive sheets and minor laccoliths. The nepheline-syenite and pseudoleucite rocks are possibly somewhat older than the porphyry, but apparently together constitute an intrusive stock cutting the laccolith, and they are so shown in the section (figs. 1 and 2). In addition to these larger bodies of igneous rocks there are numerous dikes intruded in the porphyry, syenite, and pseudoleucite rocks and in the larger masses of pre-Cambrian schist. Those in the igneous rocks are confined chiefly to the Nigger Hill laccolith and its immediate vicinity. Two occurrences of igneous rocks, one a dike and the other a thin sheet, were noted in the Carboniferous strata also, near the southeast and southwest margins of the main uplift.

While the post-Cambrian igneous rocks of the Nigger Hill region may differ slightly in age, they probably all belong to the same geologic period and to the same general period of intrusion.

The porphyry which forms the Nigger Hill laccolith penetrated the Algonkian rocks and spread out along the basal contact of the Cambrian strata, elevating the overlying sedimentary rocks into an irregular dome. The Cambrian rocks thus constitute over the greater part of the area the basal portion of the original cover of the laccolith, remnants of which still remain. The floor of schist on which the porphyry rests is doubtless very irregular. In breaking through these rocks the porphyry tore away large masses and carried them to higher levels. These included masses still preserve in a general way their original dip and strike. The porphyry has also intruded the Cambrian rocks at a number of points. Following the bedding of these rocks, the porphyry has taken the form of sheets and minor laccoliths on the flanks of the main uplift. These intrusions in the Cambrian occur northwest and southeast of the main area.

While the porphyry has in general elevated the sedimentary rocks without fracturing them, it has at two points at least (at the northeast and southeast margins of the laccolith) broken across the Cambrian into the lower part of the Carboniferous. Thus the Needles, near the northeastern margin of the Nigger Hill laccolith, consist of a minor laccolithic intrusion of the porphyry connected with the main mass by a cross-cutting body of porphyry. Here the Cambrian rocks have been elevated on the south and west, while on the east the porphyry has broken across them, and locally, at least, across a part of the Pahasapa formation as well.

The porphyry occasionally exhibits a well-developed columnar structure, which was noted at the Needles, as well as at places along Beaver Creek and southeast of the settlement at Bear Gulch, where, as at the Needles, there is, in addition to the vertical jointing, a series of nearly horizontal joints, which occur at intervals several times as great as those between the vertical joints.

The western rim of the Needles consists of a massive outcrop of porphyry cut by vertical partings into great outstanding ribs which, toward the northern end of the group, form almost as pronounced a feature as the Needles themselves. The rim has a rather rude, horizontal, platy or columnar structure, far less pronounced than the vertical partings.

Bear Lodge Mountains.—The syenite-porphyry of this uplift was intruded at the base and between the beds of the Cambrian, and all the strata forming the cover of the laccolith have been eroded (see section A–A). The phonolites and related rocks are in most if not all cases the youngest igneous rocks of the uplift. They occur both as intrusive sheets and as minor laccoliths about the margin of the main uplift and also as dikes cutting the principal area of igneous rocks. Within this area the dikes are somewhat more numerous than has been indicated on the map, the omission being due largely to the difficulty of distinguishing these rocks from the trachytes when much weathered. The phonolitic rocks of the area mapped are for the most part fairly fresh. Excepting the phonolites and the granite, the igneous rocks of the uplift as a whole are greatly weathered, sometimes so much so that it is impossible to determine the original composition of even the freshest obtainable specimen from a given locality.

Black Buttes.—The Black Buttes laccolith differs from the laccoliths of Inyankara and Sundance mountains in that it has apparently been formed by several successive intrusions instead of a single one (see section D–D). It is not a simple but a compound laccolith, masses of igneous rock being irregularly intruded at various horizons among the sedimentary rocks. Owing to this irregularity in structure the main igneous mass forms a somewhat elongated angular area in which erosion has developed a group of peaks rather than a single dome.

There is little evidence as to the relative ages of the different rocks of Black Buttes, although it is probable that the intrusion of the southernmost and largest of the phonolitic masses was subsequent to that of the monzonite-porphyry and that it has formed an independent dome on the margin of the larger laccolith. The other phonolitic rocks appear to be of approximately the same age as the porphyry and to have been formed as differentiation products of the magma from which the porphyry was derived.

The southernmost area of the bostonite probably forms a minor laccolith, while the northern area occurs as a laccolithic sill.

Owing to differences in various factors, such as the mode of intrusion, the level at which it took place, the height to which the magmas were forced, the volume of the intrusion, and the resistance of the various rocks to weathering, each type presents characteristic erosion forms. The bostonite forms remarkably sharp peaks with steep slopes. The monzonite-porphyry occurs as a group of rugged hills, steep sided but less abrupt than those composed of bostonite and with moderately broad summits. The large southern area of phonolite, though forming the highest part of Black Buttes, has on the whole more moderate slopes and more broadly rounded summits. The smaller phonolitic areas as a rule occupy the valley bottoms. Where exposures are favorable the monzonite-porphyry usually shows well-defined jointing.

Inyankara Mountain.—The igneous rocks of Inyankara Mountain form its central mass and also its eastern and southern rim. The central part consists of two peaks separated by a shallow saddle. The igneous portion of the rim of the laccolith, which stands somewhat lower than the central peaks and is joined to the southern of these by a shallow saddle, has a gradual though marked descent toward the north. This ridge is characterized by a narrow top flanked on either side by steep slopes. As a rule the outer slope is the steeper, the angle for a considerable distance being about 30°.

The igneous rocks are everywhere jointed and break into thin plates, especially along the rim of the laccolith. In addition to the finer jointing the central area has two or more well-developed systems of coarser joints, the width of the divisions ranging from a few inches to several feet. To these joint systems the columnar structure of the central portion is due (see fig. 5 on illustration sheet). On the northern peak two systems were noted, the strike of one being N. 48° E., of the other N. 60° to 75° W. The strike of the two systems seen on the southern peak was N. 48° E. and N. 50° W. The dips of these joints, as shown in the resulting columnar structure and as seen from a distance, appear to be quaquaversal, radiating from some point above the summit of the north peak. The strike of the joints of the rim, as usually seen at any given point, is parallel to the direction of the rim at that point, though occasionally it is transverse. It is probable that there are two sets of joints, one parallel and the other transverse to the trend of the rim. These joints dip at a high angle, sometimes toward the center of the laccolith, and sometimes away from it.

STRUCTURE.

STRUCTURE OF THE BLACK HILLS UPLIFT.

The Black Hills uplift, if not eroded, would present an irregular dome rising on the northern end of an anticlinal axis extending northward from the Laramie or Front Range of the Rocky Mountains (see fig. 3). It is elongated to the south and northwest, has steep slopes on the sides, is nearly flat on top, and is subordinately fluted. The greatest vertical displacement of the strata, as indicated by the height at which the granite and schist floor is now found, amounts to about 9000 feet. The minor flutings of the dome are mainly along the eastern side of the uplift, the most notable ones being in the ridge of Minnekahta limestone just west of Hot Springs. Another fluting of considerable prominence occurs 3 miles east of Hot Springs and a smaller one rises a short distance east of Aladdin. These subordinate flexures are characterized by steeper dips on their west side and gentler dips to the east. They merge into the general dome to the north and run out with declining pitch to the south. In the northern Black Hills there are numerous local domes and flexures due mainly to laccolithic igneous intrusions, but no similar features are indicated by the structure of the southern portion.

Faults are rarely observed and not many have been found which amount to more than a few feet in vertical displacement, these being short breaks due to igneous intrusion.

STRUCTURE OF THE SUNDANCE QUADRANGLE.

Structure sections.—The principal structural features of this quadrangle are illustrated by the six structure sections on the structure-section sheet. Their position on the map is on the line of the upper edge of the blank space. The vertical and horizontal scales are the same, so that the actual form and slope of the land and the actual though generalized relations of the rocks are shown. The structure where buried is inferred from the position of the strata observed at the surface and from determinations of their thickness made where they are uplifted.

General structural features.—The Sundance quadrangle embraces a portion of the northwest slope of the Black Hills uplift, with rocks dipping to the west in the greater part of the quadrangle and to the north in the northeast corner of the quadrangle. There are several local irregularities in the monoclinal structure, which consists of some gentle undulations and of steep dome-shaped uplifts due to the intrusion of laccoliths or lens-shaped masses of igneous rocks.

In the southeast corner of the quadrangle the Pahasapa limestone lies nearly level, a structure which extends several miles eastward and southeastward in the high plateau on the central portion

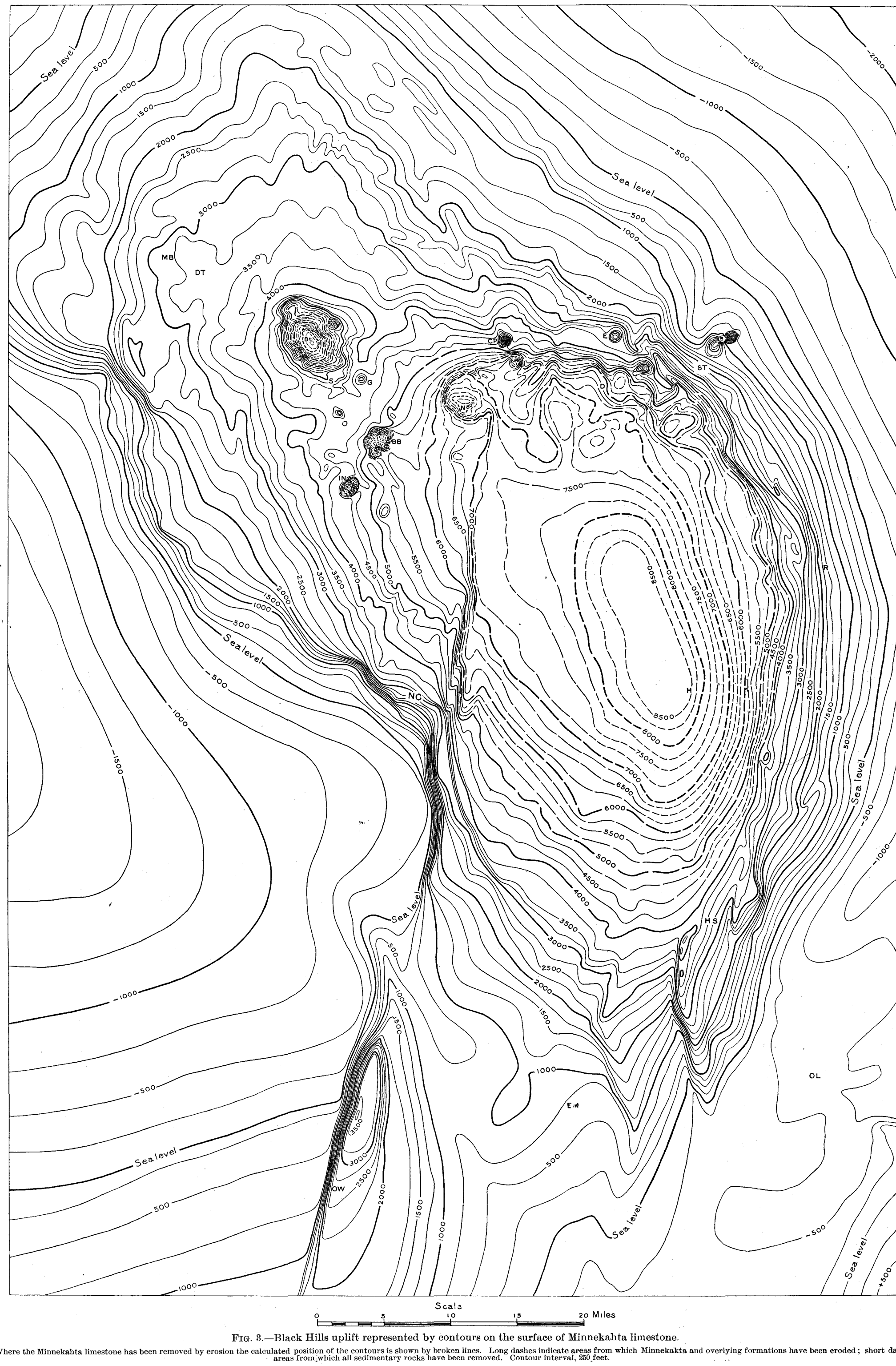


FIG. 3.—Black Hills uplift represented by contours on the surface of Minnekahta limestone.

Where the Minnekahta limestone has been removed by erosion the calculated position of the contours is shown by broken lines. Long dashes indicate areas from which Minnekakta and overlying formations have been eroded; short dashes, areas from which all sedimentary rocks have been removed. Contour interval, 250 feet.

B, Bear Butte; BB, Black Butte; BL, Bear Lodge Mountains; 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, Little Missouri Buttes; N, Nigger Hill; NC, Newcastle; OL, Oelrichs; OW, Old Woman Creek; R, Rapid; S, Sundance; ST, Sturgis.

of the uplifts. As they approach the State line, the beds pitch steeply downward to the west, but flatten again in the canyon of Stockade Beaver Creek. West of this canyon low westerly dips prevail, giving a wide expanse of Minnekahta limestone in the Canyon Springs Prairie district. In this area there are various undulations of the strata, the most notable of which are a low anticline which extends southward through Mount Pisgah and a strong general pitch of the beds to the south in the ridges east of T E ranch. A low local anticline extending east and west crosses Oil Creek Valley 1½ miles south of T E ranch. Gentle southwesterly dips prevail in the Black Canyon and Skull Creek and from Inyankara Creek to the southwest corner of the quadrangle. It is these low dips and the thinness of the formations that give such irregular boundary lines to the formations in the southern portion of the quadrangle. This is notably the case with the Minnekahta limestone in the vicinity of Soldier Creek Valley.

In the region east of Cold Springs Creek the Minnelusa formation presents a number of gentle undulations, composing a general flattened, broad anticline, sharply accented into a local dome at Bald Mountain, and rising steeply to the north over the great dome of the Nigger Hill uplift. West and north of these domes there is a general dip to the west and north, which is very gentle and regular far out into the Red Valley, except where it is interrupted by the local uplift of the Black Buttes.

North of Green Mountain there is a broad, shallow syncline occupied by Spearfish red beds, with a steep rise on the flanks of the Bear Lodge uplift to the west. The Green Mountain dome is a local feature, soon lost to the south, but repeated again on a smaller scale in Lime Buttes and Gypsum Buttes, east of which there is a broad, shallow syncline. In Black Flat the dips are very gentle to the west. South and west of Sundance the dips are low for some miles and there is a low anticline which passes near the west line of range 63, crosses Inyankara Creek 4 or 5 miles northwest of Inyankara Mountain, and merges into a general monocline of southwesterly dips in the vicinity of the Crook-Weston county line. West of this anticline there are gentle westerly dips that extend along the northwest side of the quadrangle, but steepen considerably along the west slope of the Bear Lodge uplift.

Laccolithic uplifts.—The most striking structural feature of the quadrangle is the presence of a number of laccolithic domes. These are nearly all of very local extent, and vary in size with the mass of igneous rock to which they are due. The Nigger Hill uplift is almost a perfect dome in shape, beginning with gentle dips in the Minnelusa formation. These become steeper on the flanks of the uplift and apparently materially diminish over its top, judging by the attitude of the Deadwood sandstone. Owing to the somewhat irregular intrusion of the igneous rock in the lower sedimentary formations of this uplift, there is great irregularity in the structure of the lower beds and fragments of them are completely inclosed in the igneous rock. In some cases portions of the formations have been carried above the present level and have been removed by erosion, a feature which is particularly marked at the eastern end of Cement Ridge, where for some miles the porphyry is in contact with the Minnelusa sandstone. Elsewhere there is a complete ring of the Pahasapa limestone around the uplift, with radial dips in all directions, steep on the flanks of the igneous rock but of less amount elsewhere. The dips on the north side of the laccolith are 10°, on its west side 40° in places, and on its southwest side from 14° to 25°. Their diminution to low angles farther away is shown by the long extension of the Pahasapa down Spottedtail and Sand creeks and Rattlesnake Canyon. The limestone is nearly flat north of the Needles, where the igneous rock cuts across it.

The regular but sharply uplifted dome of the Bald Mountain limestone area is apparently due to laccolithic intrusion, but none of the igneous rock is yet exposed. Strawberry Mountain is of similar character—a steep-sided dome affecting the Spearfish, Minnekahta, Opeche, and Minnelusa formations, but not exhibiting igneous rock. Green Mountain is a beautifully symmetrical dome with dips of 8° to 10° on its flanks. Its strata are eroded to the upper sandstone of the Minnelusa formation only (see fig. 4 on the illustration sheet). The two low domes of Lime and Gypsum buttes are also supposed to be laccolithic, but no igneous rock is exposed.

In the Black Buttes the structure is somewhat irregular, there being two domes considerably broken by cross intrusion. The Pahasapa limestone and a small area of the Deadwood formation are brought to the surface on the west and the east sides of the northern dome. The southern dome is almost completely inclosed by the Minnekahta limestone.

Inyankara Mountain is an irregular dome, with Pahasapa and Minnelusa formations dipping radially from the flanks of the igneous rock on the northern side. It is considerably broken and faulted on its southern side, where the igneous rock ascends to higher horizons, and, at one point in the western part of the ridge, has carried a mass of Pahasapa limestone to the level of the Cretaceous strata.

Sundance Mountain presents no evidence of disturbance of the surrounding strata, but probably it is a remnant of the lower part of a laccolith spread out horizontally in Sundance shales (see section B–B). The upturned overlying beds and the edges of the igneous lens have been removed by erosion. A similar remnant of laccolithic rock on a floor of Spearfish formation forms the sharp knob 2 miles southeast of Sheep Mountain.

The Bear Lodge intrusion is mainly a dome somewhat elongated from northwest to southeast, with the strata dipping away regularly on the sides, the dips being steepest on the west. Small masses of Deadwood sandstone have been included in the igneous mass and there has been minor intrusion at higher planes also. At its southern end, just north of the town of Sundance, is a small adjoining dome, mainly exhibited in the Minnekahta limestone, out of the sides of which igneous rock has broken along two lines of intrusion. A small branching dome of Minnekahta limestone rises locally east of the main Bear Lodge uplift at the forks of Rocky Ford Creek, R. 62 W. At Sheep Mountain the beds uplifted by the Bear Lodge intrusion are steeply upturned and profoundly faulted, evidently by the intrusion of igneous rock, which has lifted a small block of Deadwood formation nearly 1500 feet against Minnekahta and underlying formations. The fault passes along the western, southern, and eastern base of the mountain (see fig. 6, on the illustration sheet) and to the north gives place rapidly to a steep-sided flexure. The igneous mass, which probably underlies the uplifted block, does not appear, but there is a small sheet and dike in the Deadwood sandstone near the base of the mountain on its south side. Immediately west of the mountain and fault there is a shallow syncline containing a small mass of Minnekahta limestone.

GEOLOGIC HISTORY.

The general sedimentary record.—The rocks appearing at the surface within the limits of the Sundance quadrangle are mainly of sedimentary origin—that is, they were deposited by water. They consist of sandstone, shale, limestone, sand, loam, and gravels, all presenting more or less variety in composition and appearance. The principal materials of which they are composed were originally gravel, sand, or mud derived from the waste of older rocks, or chemical precipitates from salty waters. There are also igneous rocks which have been intruded in a molten condition, and two of the uplifts reveal small areas of the floor of schists and granites on which the sedimentary rocks lie.

These rocks afford a record of physical geography from middle Cambrian time to the present. The composition, appearance, and relations of strata indicate in some measure the conditions under which they were deposited. Sandstones ripple-marked by waters and cross-bedded by currents and shales cracked by drying on mud flats are deposited in shallow water; pure limestones generally indicate open seas and scarcity of land-derived sediment. The fossils that the strata contain may belong to species known to inhabit waters which are fresh, brackish, or salt, warm or cold, muddy or clear. The character of the adjacent land may be shown by the character of the sediments derived from its waste. The quartz sand and pebbles of coarse sandstones and conglomerates, such as are found in the Lakota formation, whatever their original source in crystalline rocks, have been repeatedly redistributed by streams and concentrated by wave action on beaches. Red shales and sandstones such as make up the "Red Beds" usually result directly from the revival of erosion on a land surface long exposed to rock decay and oxidation and hence covered by a deep residual soil. Limestones, on the other hand, if deposited near the shore, indicate that the land was low and that its streams were too sluggish to carry off coarse sediments, the sea receiving only fine sediment and substances in solution. The older formations exposed by the Black Hills uplift were laid down from seas which covered a large portion of the central-western United States, for many of the rocks are continuous over a vast area. The land surfaces were probably large islands of an archipelago, which was to some degree coextensive with the present Rocky Mountain province, but the peripheral shores are not even approximately determined for any one epoch, and the relations of land and sea varied greatly from time to time. Pursuing these general ideas in greater detail, one finds that the strata brought to view by the Black Hills uplift record many local variations in the ancient geography and topography of the continent.

Cambrian submergence.—One of the notable events of early North American geologic history was the wide expansion of an interior sea over the central-western region. The submergence reached the Rocky Mountain province during the early Cambrian and for a time the central portion of the Black Hills remained as one of the islands rising above the waters. From the ancient crystalline rocks streams and waves gathered and concentrated sands and pebbles, which were deposited as a widespread sheet of sandstone and conglomerate, partly on sea beaches, partly in shallow waters offshore, and partly in estuaries. Numerous exposures of these sediments, containing much local material, abut against the irregular surface of the crystalline rocks which formed the shore. Subsequently, the altitude being reduced by erosion and the area possibly being lessened by submergence, the islands yielded the finer-grained muds now represented by the shales which occur in the upper portion of the Cambrian in some areas. In many regions the land surface of crystalline rocks was buried beneath the sediments.

Ordovician-Devonian conditions.—From the close of Cambrian to the beginning of Carboniferous time the Black Hills area presents a scanty geologic record, the Ordovician, Silurian, and Devonian being absent to the south, and only a portion of the Ordovician (the Whitewood) being present in the north. This is probably due to the fact that during these periods there was in this whole region an extensive but very shallow sea, or land so low as to leave no noticeable evidence of erosion. Whether it remained land or sea, or alternated from one to the other condition, the region shows no evidence of having undergone any considerable uplift or depression until early in Carboniferous time, when there was a decided subsidence, which established relatively deep water and marine conditions, not only over the Black Hills area, but generally throughout the Rocky Mountain province.

Carboniferous sea.—Under the marine conditions that prevailed during early Carboniferous time there were laid down calcareous sediments, which are now represented by several hundred feet of nearly pure limestone, the greater part of which is known as the Pahasapa limestone. As no coarse deposits of this period are found, it is probable that no crystalline rocks were then exposed above water in this region, although elsewhere the limestone or some stratigraphic equivalent was deposited immediately upon them. In the latter part of the Carboniferous the conditions were so changed that fine sand was brought into the region in large amount and deposited in thick but regular beds, apparently with much calcareous precipitate and more or less ferruginous material, as is indicated by the color of many beds of the Minnelusa formation. Minnelusa deposition is believed to have been followed by an uplift which appears to have resulted in ponding saline water in lakes, in which accumulated the bright-red sands and sandy muds of the Opeche formation. The Minnekahta limestone, which is the next in sequence, was deposited from sea water, and from its fossils we know with a fair degree of certainty that it is a product of the latest Carboniferous or Permian time. It was laid down in thin layers, to a thickness now represented by only 40 feet of the limestone, yet the very great uniformity of this formation over the entire Black Hills area is an impressive feature, probably indicative of widespread submergence.

Red gypsiferous sediments.—At the close of the epoch represented by the Minnekahta limestone, there was a resumption of red-clay deposition and the great mass of red shales constituting the Spearfish was accumulated. These beds probably were laid down in vast salt lakes that resulted from extensive uplift and aridity. The mud accumulated in thin layers to a thickness of 600 feet or more, as now represented by the formation, which is so uniformly of a deep-red tint that this is undoubtedly its original color. This color is present not only throughout the extent of the formation, but also through its entire thickness, as is shown by deep borings, and therefore is not due to later or surface oxidation. Either the original material of the sediments was red, or it was colored during deposition by the precipitation of iron oxide. At various times, which were not synchronous throughout the region, accumulation of clay was interrupted by chemical precipitation of comparatively pure gypsum, free from mechanical sediment, in beds ranging in thickness from a few inches to 30 feet. It is believed that these beds are the products of evaporation during epochs of little or no rainfall and consequently of temporarily suspended erosion; otherwise it is difficult to understand their nearly general purity. The Spearfish red beds have been supposed to represent the Triassic, but there is no direct evidence of this, and in part at least they may be Permian. Their deposition appears to have been followed by extensive uplift without local structural deformation, but with general planation and occasional channeling, which represents a period of Triassic time of unknown duration, and was succeeded by the deposition of later Jurassic sediments.

Jurassic sea.—In the Black Hills region the Jurassic was a period of varying conditions, shallow and deep marine waters alternating. The materials are nearly all fine grained and indicate waters without strong currents. In the southeastern Black Hills region some of the earliest deposits are thin masses of coarse sandstone, indicating shore conditions, but generally the Spearfish red beds are overlain by shale which was deposited in moderately deep water. This shale is followed by the ripple-marked sandstone, evidently laid down in shallow water and probably the product of a time when sedimentation was in excess of submergence, if not during an arrest of submergence. The red color of the upper part of the medial sandy series in some portions of the Black Hills appears to show a transient return to arid conditions similar to those under which the Spearfish formation was laid down. An extensive marine fauna and limestone layers in the upper shales of the Sundance formation indicate that deeper water followed. After this stage marine conditions gave place to fresh-water bodies, probably through widespread uplift. The first product was the thick body of fine sand of the Unkpapa sandstone, now a prominent feature in the eastern portion of the Black Hills, but thinner or absent elsewhere.

Cretaceous seas.—During the Cretaceous period deposits of various kinds, but generally uniform over wide areas, gathered in a great series, beginning with such as are characteristic of shallow waters along a coastal plain, passing into sediments from deep marine waters, and changing toward the end to fresh-water sands and clays with marsh vegetation. The first deposits now constitute the Morrison formation, a widespread mantle of sandy shales, which is absent to the southeast, although probably originally deposited there to a greater or less thickness and then removed by erosion in consequence of slight but widespread uplift. The extent of this degradation is not known, but it caused a general erosional unconformity at the base of the Lakota sandstone, the next succeeding deposit, which is of coastal and possibly estuarian origin. This formation consists mainly of coarse sands spread by strong currents in beds 30 to 40 feet thick, but it includes several thin partings of clay and local accumulations of vegetal material. The next deposit was a thin calcareous series, represented by the Minnewaste limestone, which was apparently laid down only in a local basin in the southern portion of the Black Hills and is not present in the Sundance quadrangle. This was followed by a thin but widely extended sheet of clays of the Fuson formation. After the deposition of these clays there was a return to shallow waters and strong currents, as in Lakota times, and coarse sands of the Dakota formation were accumulated. At the beginning of the Benton there was everywhere in the region a rapid change of sediment from sand to clay.

During the great later Cretaceous submergence marine conditions prevailed throughout the Benton, Niobrara, and Pierre epochs, and several thousand feet of clay were deposited. In Benton time there were occasional deposits of sand, two of them in the latter part of the epoch that were general over the greater part of the Black Hills region, and one earlier that was local and produced the lenses of sandstone which are now found in the vicinity of Newcastle and elsewhere. Another marked episode was that which resulted in the general deposition of the thin Greenhorn limestone in the middle of the Benton sediments. The shale of the Benton was followed by several hundred feet of impure chalk, now constituting the Niobrara formation, and this in turn by over 1200 feet of Pierre shale, deposited under very uniform conditions; but these latter formations are not now present in the Sundance quadrangle. The retreat of the Cretaceous sea corresponds with the Fox Hills epoch, during which sands were spread in an extensive sheet over the clay beds, and resulted in the development of extensive bodies of brackish or fresh water, which received the sands, clays, and marsh deposits of the Laramie. Whether these two last-named groups of sediments were deposited over the area now occupied by the Black Hills is not definitely known, but it is possible that they were, as they are upturned around two sides of the uplift.

Early Tertiary mountain growth.—The Black Hills dome developed early in Tertiary time—or possibly in latest Cretaceous time—to a moderate height, and the larger topographic outlines of the region were established before the Oligocene epoch, the dome being truncated and its larger old valleys excavated in part to their present depths. This is indicated by the occurrence in them of White River (Oligocene) deposits, even in some of their deeper portions. Where the great mass of eroded material was carried is not known, for in the lower lands to the east and south there are no early Eocene deposits nearer than those on the Gulf coast and Mississippi embayment.

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

Oligocene fresh-water deposits.—Oligocene deposits were laid down by streams and in local lakes and finally covered the country to a level now far up the flanks of the Black Hills. Erosion has removed them from most of the higher regions where they formerly existed, especially along the western side of the hills, but in the vicinity of Lead small outliers remain at an altitude of over 5200 feet, and on the north end of the Bear Lodge Mountains they are seen 1000 feet higher. In many places on the slopes of the uplift there is clear evidence of superimposition of drainage due to a former capping of Oligocene formations.

Middle Tertiary mountain growth.—Just after the Oligocene epoch the dome was raised several hundred feet higher and was more extensively eroded. No representatives of the succeeding Loup Fork group—the Arikaree and Ogalalla formations—have been discovered in the immediate vicinity of the Black Hills, but they are extensively developed in Pine Ridge to the south and remain on some of the high buttes to the north. There was probably slow but continuous uplift during the Loup Fork epoch, and materials were contributed by the higher slopes of the Black Hills at that time, but whether the formations were ever deposited in the immediate vicinity is not ascertained.

Quaternary uplift and erosion.—During the early part of the Quaternary period there was widespread denudation of the preceding deposits, and many of the old valleys were revived, with much rearrangement of the drainage, which on the eastern side of the Black Hills was caused mainly by increased tilting to the northeast. This rearrangement has caused several streams, superimposed upon the Oligocene deposits, to cut across old divides, in some cases connecting a valley with its neighbor to the north. Such streams flow southeastward in pre-Oligocene valleys for some distance and then turn northward into canyons of post-Oligocene age, leaving numerous elevated saddles to mark the southeasterly course of the old valleys. Some of the offsetting in the present drainage has been largely increased by early Quaternary erosion and recent stream robbing.

There was apparently still further uplift in late Quaternary time, for the present valleys, below the level of the earlier Quaternary high-level deposits, seem to be cut more deeply than they would be in simply grading their profiles to the level of Missouri and Cheyenne rivers. Wide, shallow valleys have developed in the soft deposits, and canyons of moderate extent and depth in the harder rocks. Erosion has progressed without aggradation in the main, but in some cases, with the shifting of channels, there have been accumulations of local deposits on small terraces at various levels.

ECONOMIC GEOLOGY.

SOILS.

Derivation.—The soils in this region are closely related to the underlying rocks, from which they are residual products of decay and disintegration except when they are formed as alluvial deposits in the larger valleys. In the process of disintegration residual soil develops more or less rapidly on the several rocks of the region according to the character of the cement holding the particles together. Siliceous cement dissolves most slowly, and rocks in which it is present, such as quartzite and sandstones, are extremely durable and produce but a scanty soil. Calcareous cement, on the other hand, is more readily dissolved by water containing carbonic acid, and on its removal clay and sand remain, to form often a deep soil. If the calcareous cement is present in small proportion only, it is often leached out far below the surface, the rock retaining its form, but becoming soft and porous, as in the case of the Minnelusa sandstone. If, as on the limestone plateaus, the calcareous material forms a greater part of the rock, the insoluble portions collect on the surface as a mantle, varying in thickness with the character of the limestone, being thin where the latter is pure, but often very thick where the rock contains much insoluble matter. The amount of soil remaining on the rocks depends on erosion, for where there are slopes the erosion is often sufficient to remove the soil as rapidly as it forms, leaving bare rock surfaces. Crystalline schists and granitic rocks decompose mostly by hydration of a portion of the contained feldspar, and the result is usually a mixture of clay, quartz grains, mica, and other materials. Shales are disintegrated in consequence of changes of temperature, by frost, and by water, and thus by softening and washing give rise to soils. If they are sandy, sandy soils result, and if they are composed of relatively pure clay, a very clayey soil is the product. The character of the soils thus derived from the various geologic formations being known, their distribution may be approximately determined from the map showing the areal geology, which thus serves also as a soil map. It must be borne in mind that some of the geologic formations present alternations of beds of various materials, shales and sandstones, for instance, alternating with limestone. These give abrupt transitions in the character of their disintegration products, and soils which differ widely in composition and agricultural capabilities occur side by side. The only areas in which the boundaries between different varieties of soil do not coincide with the boundaries of the rock formations are in the river bottoms, in the sand dunes, in the areas of high-level gravels, in the smaller valleys, and on steep slopes where soils derived from rocks higher up the slope have washed down and mingled with or covered the soils derived from the rocks lying immediately beneath. Soils of this class are known as overplaced, and a special map of large scale would be required to show their distribution.

Distribution.—The arable lands of the Sundance quadrangle are irregularly distributed and occur on several formations. The most extensive farm areas are on the Canyon Springs Prairie and on alluvial deposits in the valleys of Sundance, Beaver, Inyankara, Mason, and Skull creeks. Many areas which have naturally fertile soils are not situated favorably for farming, especially those which are at such high altitudes that frosts are too prevalent. Scant rainfall is a great handicap in many parts of the area, especially in localities where there is not sufficient running water for irrigation.

The soils of the Pahasapa limestone are very fertile, especially on the gentler slopes and in the valleys, where there is admixture with more or less alluvial material, as in the valley of Cold Springs and Little Spearfish creeks, and these valleys are farmed to some extent. On account of the high altitude, however, only the more hardy products, such as oats, can be raised. The Minnelusa formation produces sandy soils which are relatively barren, but in the valleys of Soldier and Cold Springs creeks and in Red and Grand canyons, where there is also more or less alluvium, there are a number of small farms. The Minnekahta limestone yields a thin but fertile soil and presents broad areas of level lands, which at some localities are well suited for farming. Williams Divide and Canyon Springs Prairie are notable examples, especially the latter, which is now occupied by many farms that obtain good returns of the more hardy crops. These areas have less frost than the higher district farther east; they also appear to obtain much more frequent rainfall during the summer than the adjoining valleys on the west, and the soils are more retentive of moisture from both snows and rains. The increased rainfall is probably due to condensation from moisture-bearing breezes which meet the cooler air currents in ascending the slopes of the plateau. In the vicinity of Boyd part of Canyon Springs Prairie is occupied by a thin layer of Spearfish red beds thinly mantled by upland gravels and loams, and on such prairies are found the most favorable conditions for agriculture. The Red Valley has broad areas of barren Spearfish deposits, but on some of the broader flats there is more or less mingling of wash and alluvium, and good soils result. This is notably the case in Black Flat on which there are a number of good farms. The Sundance formation makes soils that are usually fertile, but it generally lies on dry slopes, where the rainfall in most seasons is not sufficient for raising crops. The Lakota and Dakota sandstones yield relatively barren soils and are usually so dry and so situated topographically that they are not favorable for farming. The soils of the Graneros shale are thin and poor, and they are not farmed at all in the Sundance quadrangle.

Along Sundance, Rocky Ford, Beaver, Inyankara, Mason, Skull, and Oil creeks there are alluvial deposits of considerable extent, often half a mile wide. There are several farms around Sundance and down the valley for the next 7 or 8 miles, and at intervals along Rocky Ford Creek and the other creeks above enumerated. The soils of these are usually moderately rich and often contain and retain moisture in considerable amount. These farms are within reach of irrigation, for they lie along creeks from which water has been taken at some points for use in this way, notably at the Holwell ranch. Water could be stored at many points in the Sundance region by building dams across the canyons, and supplies could be thus preserved for irrigation. The rainfall averages about 14 inches a year, and if this supply could be suitably preserved and used it would suffice for extensive irrigation. Large amounts of rock are available for the building of dams, especially along the slopes of the Minnekahta limestone and the flanks of the Bear Lodge Mountains. Sites for dams may be found on many canyons, which are wide enough and have sufficiently low declivity to hold moderate amounts of water.

MINERAL RESOURCES.

Gold.—Small amounts of gold have been obtained from igneous rocks or the adjoining strata in mines about Welcome and in some prospects in the Bear Lodge Mountains. In the Nigger Hill uplift gold occurs in the gravels of the larger streams; in the basal conglomerates of the Deadwood formation; in veins associated with dikes of igneous rock, especially about Mineral Hill; and in the pre-Cambrian schists and granite. Some prospecting has been done in the Carboniferous rocks bordering and outside of the Nigger Hill uplift, apparently with unsatisfactory results. In the igneous area near Welcome there has been extensive prospecting, especially in Mineral Hill and Nigger Hill. In the former there are several tunnels 200 feet or more in length, but their results were not encouraging. A stamp mill was erected at Welcome, for the purpose of crushing some supposed free-milling ores from the Inter-Ocean mine, situated on the west slope of Mineral Hill, but most of the ore found was not only of low grade, but proved to be refractory. In recent developments on the west side of Mineral Hill good assays have been obtained and it is claimed that ore bodies of considerable size are exposed, especially in one narrow vein which shows free gold in its walls. Some of the prospecting near Welcome has been done in the altered syenitic rock along Sand Creek, which is considerably broken and seamed and contains pyrite, both in seams and scattered through the rock. The pegmatite about Nigger Hill has been prospected for gold, though tin has been the principal mineral looked for here. The Deadwood sandstones are gold bearing in places in the northern Black Hills, especially in the conglomerate at their base known as "cement" by the miners. At many points in the Welcome uplift both the "cement" and the rocks above it have been prospected without finding valuable ores, so far as known.

The gravels of Sand, Bear, and Beaver creeks and their more important tributaries have been mined extensively for gold. The work has been done mainly within the limits of the porphyry area, but also, considerably outside of it, the gravels on Sand Creek having been mined for a distance of about 10 miles below Welcome.

At the present time mining on these streams is being carried on at a number of places in a desultory manner by a few miners, either singly or in groups of two or three. The methods used in washing the gravels are crude and hampered by the scarcity of water. This lack of sufficient water is the chief difficulty in handling the gravels and makes the work unprofitable except when it is done on a small scale. The gravels have been worked for many years (since 1875) and appear to be now largely exhausted, though they still yield small returns to the men engaged in working them. Coarse-gold nuggets have been occasionally found.

Probably all the rocks within the porphyry area, Cambrian, pre-Cambrian, and igneous, contribute some gold to these placers, though the chief supply very likely comes from the Algonkian schists. In working these gravels for gold a considerable quantity of the heavier and the less common minerals of the pegmatite and schists have been obtained, and among those which are listed are magnetite, hematite, cassiterite, columbite, tantalite, wolframite, garnet, zircon, and topaz.

In the Bear Lodge uplift there has been much prospecting, but no notable amount of gold has yet been produced. The igneous rock contains gold, but the amount is very small, even along the few faint zones of mineralization which have been discovered. In Ruby Canyon the lower sandstones and conglomerate of the Deadwood formation have been found to be sparingly gold bearing and a small mill was erected for testing them, but the results appear not to be very encouraging.

Tin.—As was noted above, cassiterite (stream tin) is one of the constituents of the placer gravels, particularly in Bear Gulch, where it occurs in considerable quantity. In the earlier days of mining in this region, before the nature and value of the mineral were known, it was thrown aside as worthless, or worse than worthless, for on account of its high gravity it interfered with the separation of the gold from the gravels. Now that it is known to contain tin, it is carefully saved and occasional small shipments of the ore are made to England. At the time the region was visited a little more than 2 tons had been sold at four cents a pound and shipped to England.

The stream tin occurs in small, angular grains, seldom reaching one-half inch in diameter. The grains, though generally of nearly pure cassiterite (oxide of tin), occasionally have small fragments of their parent rock adhering to them. The pegmatitic dikes of Nigger Hill and its vicinity are the sources of the stream tin, and it is the nearness to their source that accounts for the angular, unrolled character of these gravels, since in general they have not been transported far enough by the streams to be appreciably rounded.

So far as known only the pegmatite bodies on the ridge on which Nigger Hill is situated are tin bearing, those to the west of this ridge, including its westerly spurs, containing no cassiterite, or at least no appreciable quantity. The tin ore occurs in irregularly shaped grains of variable size and is very irregularly distributed through the rock. The pegmatites are somewhat auriferous and have been mined for both gold and tin. At the time this region was visited the shafts sunk in the granite were closed and the workings were inaccessible. The pegmatites of Nigger Hill are believed to be inclusions in the porphyry, and if this is true the depth to which they extend is limited. To judge from the amount of cassiterite in the rocks and from their probable limitation in depth (as inclusions in the porphyry), as well as from the practical results thus far obtained in attempting to work them for tin, it is probable that their yield will never be great. If they are made to pay at all, it will probably be only when worked with great economy and on a comparatively small scale.

Copper.—Thin veins and seams of copper occur at various places in the Bear Lodge trachyte, and at a locality 1 mile north of Warren Peaks these have been worked to some extent. Red oxide and malachite are the principal minerals, and a load of moderately good ore has been obtained by carefully sorting a large amount of excavated material. The ore is in joint planes and some decomposed portions of the rock, and though there is a considerable amount in sight, it is too widely scattered to promise profitable workings.

Silver-lead.—In the limestone in the central portion of the Black Buttes there are irregular deposits of silver-bearing lead ore which have been prospected to some extent. The principal opening is a tunnel on the north side of the road which crosses the buttes from east to west. A small amount of galena has been obtained, which is said to assay fairly high in silver. The ore occurs in limestone along the phonolite contact.

Coal.—In the basal part of the Lakota sandstone there are local deposits of coal, an extension northward of the Cambria coal field. The deposits are not continuous and thicken and thin irregularly. Owing to the talus of sandstone blocks which accumulates on the slopes along the Lakota-Morrison outcrop there is great difficulty in exploring the coal horizon. On the economic-geology map is shown the outcrop line of the horizon, but at only a very few points was it found bare of talus, and even at these localities the coal may have weathered or burned out and the sandstone roof closed down.

Coal has been mined to some extent for local use 2 miles southeast of Holwell ranch and at several localities west of Sundance. Recently some openings have been made 3 miles west of Inyankara Mountain, exposing a thick deposit. The main opening southeast of Holwell's is on the southeast quarter of sec. 31, T. 48, R. 62. An adit has been run about 115 feet, exposing a face of coal 8½ feet thick, comprising 5 feet of hard, pure coal, 1½ feet of bone merging into cannel coal, and, at the base, about 2 feet of very hard, pure coal, which is particularly valuable for blacksmith's use. The upper coal contains considerable sulphur, a mineral which is of infrequent occurrence in the lower bed. Over the coal are about 2 feet of sandy shales overlain by hard sandstone which makes an admirable roof. The floor is sandstone of the basal bed of the Lakota formation. The bone burns well, but leaves a large amount of white ash, and it slacks readily. The dip is very gentle to the southwest. About 60 feet above the main deposit is a smaller one, varying from 1½ feet to 3 feet in thickness, composed of a mixture of clay, sand, and coal, too impure for fuel. The following analyses of the coals of the main bed have been furnished through the kindness of Mr. Bidwell, of the Chicago and Northwestern Railway Company:

Analyses of coal from Holwell ranch, Wyoming.

	Sample No. 1, from large tunnel.	Sample No. 2, from small tunnel.	Sample No. 3, bituminous shale parting.
	Per cent.	*Per cent.*	*Per cent.*
Moisture	10.45	11.00	4.77
Volatile combustible matter	39.51	41.16	30.85
Fixed carbon	41.87	40.37	25.69
Ash	8.17	7.47	38.69
Total	100.00	100.00	100.00
Sulphur	3.63	4.03	2.40

In the same quarter section, about 500 feet west, is another adit, 100 feet long, on the main coal bed, which is here 6½ feet thick and does not contain the bony deposit near its bottom. The coal is very firm and of excellent quality. It is overlain by 3 feet of light-colored sandy clay capped by a thick mass of smooth, uniform sandstone, which forms a good roof. The floor is a very hard sandstone, as in the other adit. Two miles to the southwest, on sec. 12, T. 47, R. 63, near the north line of the northwest quarter, is another adit 100 feet long. The same bed as exposed here is about 5 feet 4 inches thick, and it is nearly all pure coal of more than usual hardness. The roof at this place is sandstone without the intervening shale. West of Holwell ranch, on the west side of Skull Creek, coal has been exposed at one or two points at the base of the sandstone cliffs, but its thickness and extent have not been ascertained, although apparently the deposit in this locality is of diminished thickness.

On the ridge west of Inyankara Mountain it is reported that the coal deposit near the base of the Lakota formation has a thickness of 9 feet including a number of layers of shale and bone. West of Sundance the principal coal opening exposes a bed somewhat over 4 feet in thickness and of excellent quality.

Gypsum.—The Spearfish red beds carry deposits of gypsum—a hydrous sulphate of lime—throughout their extent, and often the mineral occurs in thick beds. These are relatively pure, and if they were nearer to good markets, the deposits would be of value. The only commercial operations so far have been at Hot Springs and Sturgis, on the opposite side of the Black Hills, where the expense of taking the product to market has proved a serious hindrance. When the gypsum is calcined at a low red heat, to drive off the chemically combined water, and ground, the product is plaster of Paris. The area of the Spearfish formation is indicated on the economic geology map.

Bentonite.—This mineral is a hydrous silicate of alumina with some other components in small proportions, and is valuable on account of its high absorbent qualities, as it has the capacity of absorbing three times its weight of water. It occurs in considerable abundance in the Newcastle quadrangle and has been mined to some extent three-fourths of a mile east of Pedro switch, a mile west of that switch, and at a point 3½ miles northwest of Osage, on the east side of the railroad track. The material is a light-gray, fine-textured, soft, massive stone, but locally it occurs as a light powdered substance resembling white corn meal, in beds lying between thin layers of reddish-brown concretionary material. Near Pedro it is 12 feet thick and occurs in the steep-dipping transition beds at the top of the Niobrara formation. Near Osage the bed is about 4 feet thick and occurs in the Graneros shale, the dips of which are so low that the deposit is exposed over a considerable area. The mineral has been used with success in the manufacture of soap, but it has proved most valuable as a packing for a special kind of horseshoe, and as a diluent for certain powerful drugs sold in powdered form. An analysis made by the Wyoming State School of Mines is as follows:

Analysis of bentonite.

	Per cent.
Silica	63.25
Alumina	12.63
Magnesia	3.97
Lime	4.12
Potash	3.55
Iron oxide	3.70
Water	6.91
Sulphuric acid	1.58

Limestone.—The extensive exposures of Pahasapa and Minnekahta limestones afford an unlimited supply of rock for burning into lime or other purposes. The purity is sufficient for all ordinary uses, but aside from slight local needs for lime the formations are of little economic importance.

WATER SUPPLY.

SURFACE WATERS.

The amount of flowing water on the Sundance quadrangle is not great, and many of the draws, valleys, and canyons are dry except when there is rain or the snows are melting. None of the streams has a continuous flow from head to mouth, and many of them appear at intervals in springs or bottom seeps, which supply waters that flow for greater or less distances and then are either evaporated or pass underground. Often the water in a valley will consist of a series of pools. Probably the most vigorous streams are Stockade Beaver and Little Spearfish creeks, which are fed by numerous springs near their heads and receive other springs at intervals in their flow. They are both of about the same size, and in ordinary seasons carry about 10 second-feet of water. Sundance Creek has more or less flow from Sundance nearly to the north edge of the quadrangle, where the stream sinks. Sand Creek in its upper portion has a small flow, which has been extensively used for working the placer deposits, but sinks near its junction with Cold Springs Creek and emerges again in extensive springs at its junction with Red Canyon. The latter, above Sand Creek, contains little water and that mainly in local pools. Beaver Creek, in the Nigger Hill district, is a small flowing stream for part of its course, but seldom contains more than half a second-foot of water. Oil Creek and Skull Creek flow only in parts of their courses and in small volume. The largest amount of water in Skull Creek is found in the vicinity of Holwell ranch, where it flows nearly all the year about 2 second-feet. Soldier Creek has pools at intervals and is nearly always dry in its lower portion. Cold Springs Creek has extensive springs near the State line and water flows in it to the Crook-Weston county line and sometimes to below McCready's ranch, but for the remainder of its course it is dry or presents only occasional pools except in times of freshet. The various canyons east of Cold Springs Canyon ordinarily are dry, or only occasionally contain water pools. Inyankara Creek usually contains water below Inyankara, but the amount is very small and there are generally some points at which there is no flow. Beaver Creek, in the southwest corner of the quadrangle, does not flow but has a number of water holes which last far into the summer. Iron and Turner creeks contain a small amount of water in pools.

There are some notable springs in the Sundance quadrangle, the largest of which is on Sand Creek 2 miles below its junction within Red Canyon. From these there issues, within an area of a half acre, a large volume of water, estimated at about 12 second-feet, apparently derived from an underground flow rising through the Pahasapa limestone, which underlies a wide region farther south and into which the upper waters of Sand and other creeks undoubtedly pass underground. Two springs of considerable volume issue from the talus of the northwest corner of Sundance Mountain, which afford a supply for the town of Sundance. In the Nigger Hill uplift, in the Bear Lodge Mountains, and in Black Buttes there are numerous small springs. At Buckley's ranch an excellent spring issues from the Minnelusa sandstone. There are several small springs in the Pahasapa limestone in the southeastern part of the area, notably along Little Spearfish Creek and Stockade Beaver Creek. Small springs are found at intervals in the Minnekahta limestone and the Lakota sandstone. The Spearfish red beds seldom yield water, but at a point 2 miles southwest of Inyankara two springs of large volume issue from these beds and enter Inyankara Creek, sustaining in large part the flow of that stream.

UNDERGROUND WATERS.

Very little progress has been made in exploring for underground waters in the Sundance quadrangle, but doubtless some of the porous sandstones which underlie the greater part of the area at various horizons can be expected to yield water supplies to borings. The Dakota and Lakota sandstone beds which cross the southwest corner of the quadrangle yield a water supply to many wells in various portions of the plain immediately adjoining the Black Hills, and at Jerome, just beyond the margin of the quadrangle, there is an excellent flowing well which derives its water from this source at a depth of 520 feet. At Cambria, a few miles south of the quadrangle, a well has been sunk into the Pahasapa limestone and at a depth of 2115 feet obtains a large supply of water of excellent quality which is now used at Cambria and Newcastle. It is possible or even probable that this water horizon furnishes the large springs in Sand Creek below the mouth of Red Canyon and some of the excellent springs in the upper valleys of Cold Springs and Stockade Beaver creeks. In consideration of the probability that this is a continuous water horizon, its position is given on the artesian-water map in this folio. In the Deadwood sandstones which underlie the Pahasapa limestone there are prospects for water supplies also, but probably the horizons would lie too deep to be available. Their location is shown in the cross sections. The sandstones of the Minnelusa formation are porous at the surface and appear to have a constitution favorable for the flow of underground waters, but in the well at Cambria, where the entire thickness of the formation was penetrated, the sand grains of the rocks were so firmly cemented by carbonate of lime that the porosity is very slight. There is no evidence of water in the Minnekahta limestone, although in places it is cavernous and at some localities small springs emerge from it. The Spearfish red beds have not yielded water and their constitution is not favorable for its storage or flow. The vigorous springs which issue from the formation southeast of Inyankara probably come through crevices from the Minnelusa sandstone a few hundred feet below. The Sundance and Morrison formations consist in part of clay and fine-grained sediments which do not contain much water. The Dakota and Lakota sandstones probably contain considerable water and may be depended upon for an underground water supply in the southeast corner of the quadrangle, as is demonstrated by the well at Jerome, referred to above; and, as the sandstone ridge has considerable elevation, flowing wells may be expected.

The well at Jerome begins in Graneros shales and extends into Lakota sandstone. The Burlington and Missouri River Railroad Company has kindly furnished the following analysis of artesian water from this well:

Analysis of water from Jerome, S. Dak.

	Grains per gallon.
Sodium chloride	0.7
Sodium sulphate	20.8
Magnesia sulphate	7.0
Lime sulphate	2.3
Magnesia carbonate	.5

TIMBER.

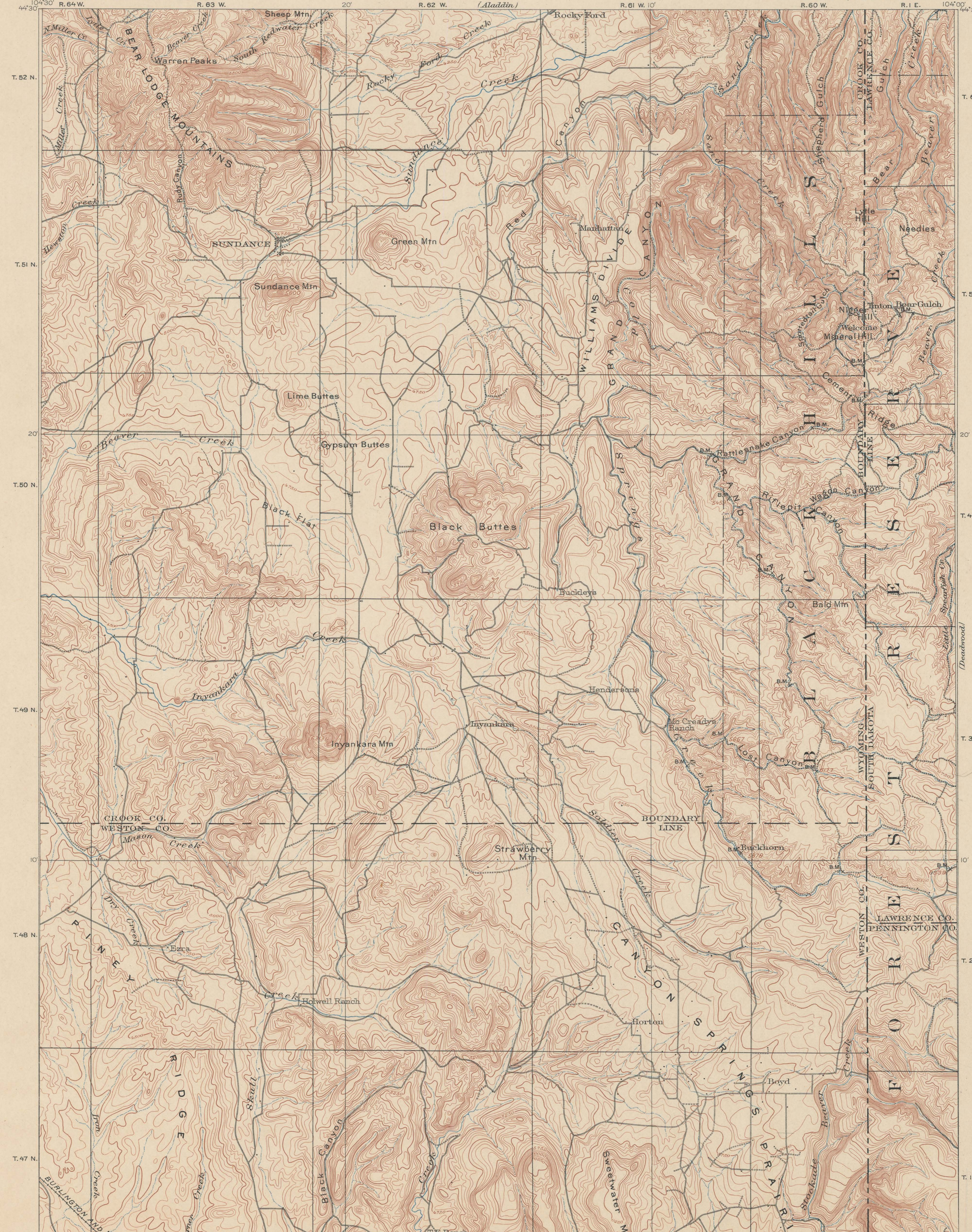
The Black Hills Forest Reserve extends into the Sundance quadrangle, including the greater part of the South Dakota area and parts of range 60 in townships 49 to 52 in Wyoming. In this district there are heavy bodies of pine timber, some of it of large size. Some pine is also found west to Cold Springs Creek Valley and to Black Buttes. Scattered bodies of pine and numerous individual trees grow on portions of the plateau and slopes of Minnekahta limestone and on Lakota sandstone and portions of the Graneros shale. Strawberry and Inyankara mountains bear a small amount of timber, mostly of small size, and on the slopes of the Bear Lodge Mountains there is an extensive pine growth. About Warren Peaks there is a central area which is treeless, owing, it is said, to heavy fires which once burned out the timber. The Red Valley is in greater part treeless, except for a few cottonwoods and an occasional pine or cedar on some of the steeper slopes.

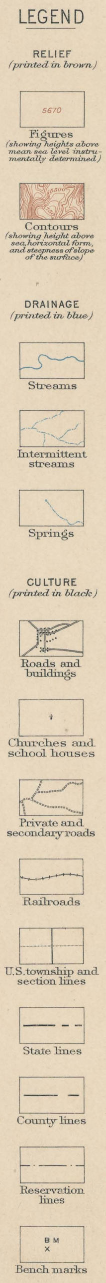
June, 1904.

U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

TOPOGRAPHY

WYOMING – SOUTH DAKOTA
SUNDANCE QUADRANGLE





Henry Gannett, Chief Topographer.
Jno. H. Renshawe, Topographer in charge.
Control by W. S. Post.
Topography by H. S. Wallace and W. H. Herron.
Surveyed in 1894 and 1899.

APPROXIMATE MEAN DECLINATION 1905.

Scale 1/125000

Contour interval 50 feet.
Datum is mean sea level.

DIAGRAM OF TOWNSHIP

Edition of May 1902, reprinted May 1905.

U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

AREAL GEOLOGY

WYOMING - SOUTH DAKOTA
SUNDANCE QUADRANGLE

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Wallace 1894 | Herron 1899

TRUE NORTH — MAGNETIC NORTH 14½°
APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

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Contour interval 50 feet.
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Edition of July 1905

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31	32	33	34	35	36

Geology by N. H. Darton,
assisted by W. S. Tangier Smith.
Surveyed in 1900-1903.

LEGEND

SEDIMENTARY ROCKS

(Areas of subaqueous deposits are shown by patterns of parallel lines, subaerial deposits by patterns of dots and circles)

QUATERNARY — *Pleistocene*
- Qt — Older terrace deposits *(gravel and loam)*

TERTIARY
- Tw — Sand, gravel, and conglomerate *(possibly of White River age)*

UNCONFORMITY

CRETACEOUS — *Upper Cretaceous* — *Benton group*
- Kcr — Carlile formation *(gray shale and thin sandstone)*
- Kg — Greenhorn limestone *(impure slabby limestone)*
- Kgs — Graneros shale *(dark fissile shale)*

CRETACEOUS — *Upper Cretaceous*
- Kd — Dakota sandstone *(brownish sandstone, mostly massive)*

CRETACEOUS — *Lower Cretaceous*
- Kf — Fuson formation *(shale and sandstone)*
- Klk — Lakota sandstone *(massive buff sandstone with coal bed locally near base)*
- Km — Morrison shale *(massive sandy shale, gray, greenish, and maroon)*

UNCONFORMITY?

JURASSIC
- Jsd — Sundance formation *(buff sandstone and red and greenish-gray shale)*

UNCONFORMITY

TRIASSIC ?
- Ꞧs — Spearfish formation *(red sandy shale with beds of gypsum; "red beds")*

CARBONIFEROUS — *Permian ?*
- Cmk — Minnekahta limestone *(very thin-bedded gray limestone)*
- Co — Opeche formation *(bright-red sandy shale)*

CARBONIFEROUS — *Pennsylvanian*
- Cml — Minnelusa sandstone *(gray, red, and buff limy sandstone with red shale at base)*

CARBONIFEROUS — *Mississippian*
- Cp — Pahasapa limestone *(massive gray limestone)*
- Ce — Englewood limestone *(pink limestone)*

UNCONFORMITY

ORDOVICIAN
- Ow — Whitewood limestone *(hard, massive, buff limestone)*

CAMBRIAN
- Єd — Deadwood formation *(brown sandstone and sandy shale)*

METAMORPHIC ROCKS OF UNKNOWN ORIGIN

(Areas of metamorphic rocks of unknown origin are shown by hachures)

ALGONKIAN
- As — Mica-schist

Legend is continued on the left margin.

LEGEND
(continued)

IGNEOUS ROCKS

(Areas of igneous rocks are shown by patterns of triangles and rhombs)

TERTIARY
- Tp — Phonolite
- Tb — Bostonite
- Tm — Monzonite and syenite-porphyries
- Dikes and sheets of various composition *(part of a large system of dikes, few of which are shown on map)*
- Tpl — Pseudo-leucite-porphyry *(much altered and cut by many dikes probably mainly feldspathic)*
- Tns — Nepheline-syenite *(cut by dikes of porphyry, marginal products pyroxenite, vogesite, and camptonite)*

ALGONKIAN ?
- Ag — Granite and pegmatite
- *Metamorphic* — Amphibolite-schist *(dikes in mica-schist)*

Faults

10° *Strike and dip of stratified rocks*

Sections

A–A, B–B, C–C, D–D, E–E, F–F

U.S. GEOLOGICAL SURVEY
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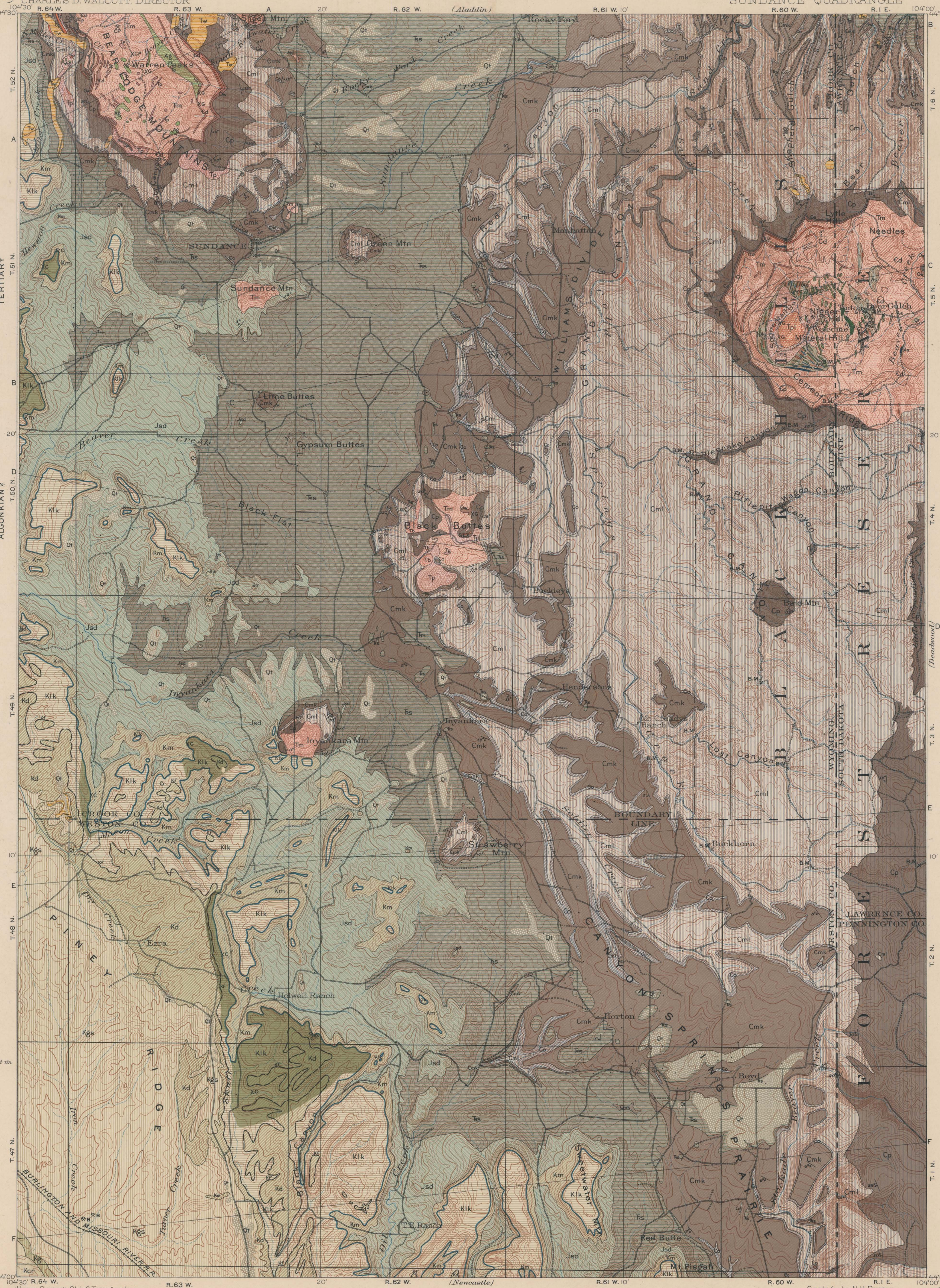
ECONOMIC GEOLOGY

WYOMING – SOUTH DAKOTA
SUNDANCE QUADRANGLE



LEGEND
(continued)

IGNEOUS ROCKS
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ALGONKIAN ?
- Ag — Granite and pegmatite
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Faults

10° Strike and dip of stratified rocks

Sections

Known productive areas
- Outcrop of coal horizon (coal occurs in local basins in lower portion of Lakota formation)
- Areas underlain by workable coal
- Gypsum (Spearfish formation contains several beds of gypsum)
- Limestone (Pahasapa, Minnekahta, Whitewood, and Englewood limestones)
- Tin-bearing pegmatite (in vicinity of Nigger Hill)

Mines
Placer mines
X Prospects
C, Coal — G, Gold
CP, Copper — T, Tin
SL, Silver-Lead — GT, Gold and tin
B, Bentonite

LEGEND

SEDIMENTARY ROCKS
(Areas of subaqueous deposits are shown by patterns of parallel lines; subaerial deposits by patterns of dots and circles)

QUATERNARY
- Pleistocene: Qt — Older terrace deposits (gravel and loam)

TERTIARY
- Tw — Sand, gravel, and conglomerate (possibly of White River age)

UNCONFORMITY

CRETACEOUS
- Upper Cretaceous, Benton group:
  - Kcr — Carlile formation (gray shale and thin sandstone)
  - Kg — Greenhorn limestone (impure slabby limestone)
  - Kgs — Graneros shale (dark fissile shale)
- Kd — Dakota sandstone (brownish sandstone, mostly massive)
- Lower Cretaceous:
  - Kf — Fuson formation (shale and sandstone)
  - Klk — Lakota sandstone (massive buff sandstone with coal bed locally near base)
  - Km — Morrison shale (massive sandy shale, gray, greenish, and maroon)

UNCONFORMITY?

JURASSIC
- Jsd — Sundance formation (buff sandstone and red and greenish-gray shale)

UNCONFORMITY

TRIASSIC ?
- Trs — Spearfish formation (red sandy shale with beds of gypsum; "Red beds")

CARBONIFEROUS
- Permian ?: Cmk — Minnekahta limestone (very thin-bedded gray limestone)
- Co — Opeche formation (bright-red sandy shale)
- Pennsylvanian: Cml — Minnelusa sandstone (gray, red, and buff limy sandstone with red shale at base)
- Mississippian:
  - Cp — Pahasapa limestone (massive gray limestone)
  - Ce — Englewood limestone (pink limestone)

UNCONFORMITY

ORDOVICIAN
- Ow — Whitewood limestone (hard, massive, buff limestone)

CAMBRIAN
- Єd — Deadwood formation (brown sandstone and sandy shale)

METAMORPHIC ROCKS OF UNKNOWN ORIGIN
(Areas of metamorphic rocks of unknown origin are shown by hachures)

ALGONKIAN
- As — Mica-schist

Legend is continued on the left margin.

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U. S. GEOLOGICAL SURVEY
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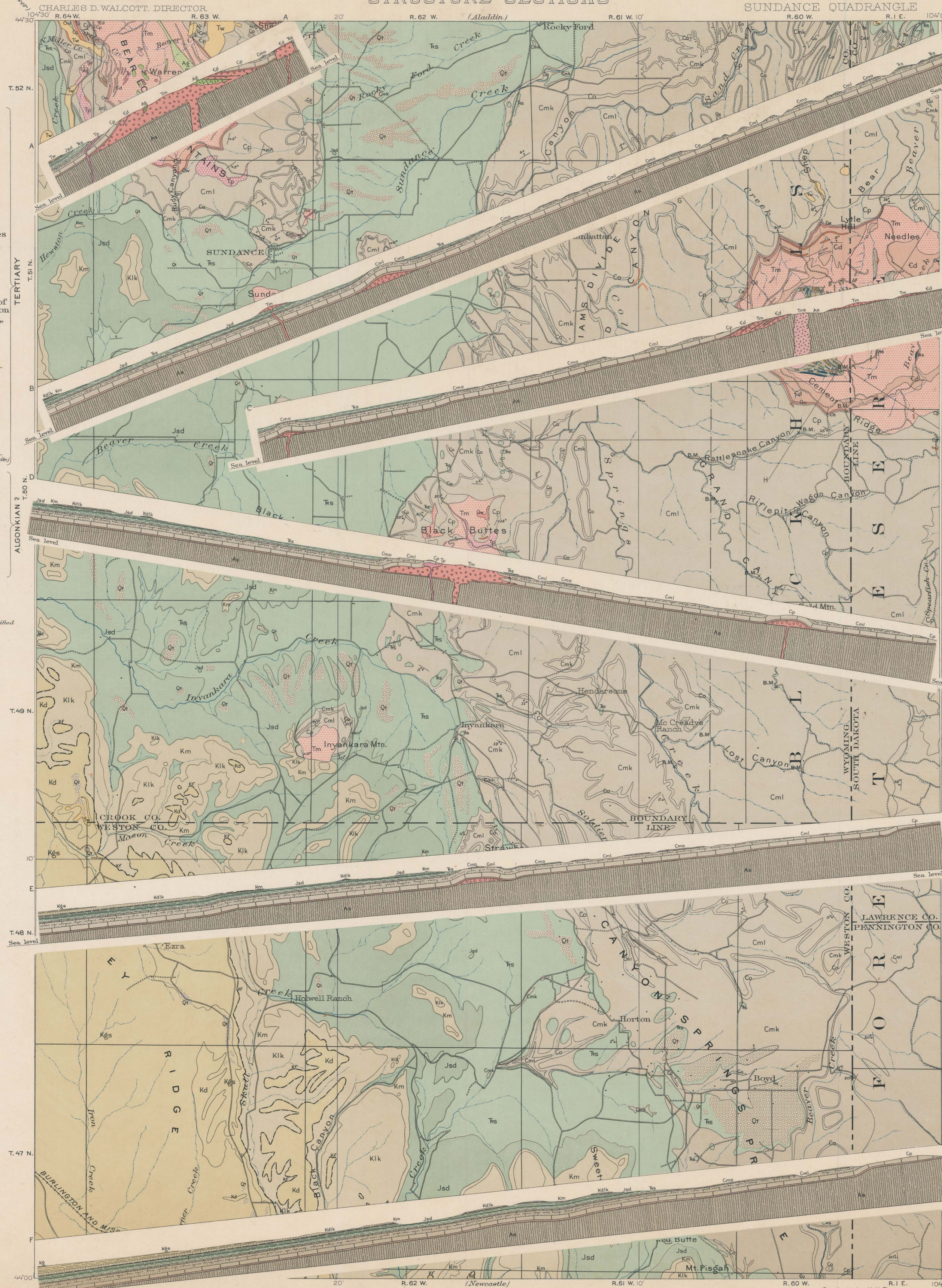
STRUCTURE SECTIONS

WYOMING – SOUTH DAKOTA
SUNDANCE QUADRANGLE



LEGEND
(continued)

IGNEOUS ROCKS

SHEET SYMBOL / SECTION SYMBOL

TERTIARY

- Tp — **Phonolite**
- Tb — **Bostonite**
- Tm — **Monzonite-and syenite-porphyries** (includes in sections laccoliths not exposed at the surface whose composition is not known)
- **Dikes and sheets of various composition** (part of a large system of dikes, few of which are shown on map)
- Tpl — **Pseudo-leucite-porphyry** (much altered and cut by many dikes probably mainly feldspathic)
- Tns — **Nepheline-syenite** (cut by dikes of porphyry, marginal products pyroxenite, vogesite, and camptonite)

ALGONKIAN ?

- Ag — **Granite and pegmatite**
- *Metamorphic* — **Amphibolite-schist** (dikes in mica-schist)

Faults

Strike and dip of stratified rocks

Sections G-G and H-H are shown in the text

LEGEND

SEDIMENTARY ROCKS

SHEET SYMBOL / SECTION SYMBOL

QUATERNARY — *Pleistocene*

- Qt — **Older terrace deposits** (gravel and loam)

TERTIARY

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CRETACEOUS — *Upper Cretaceous* (*Benton group*)

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- Kd — **Dakota sandstone** (brownish sandstone, mostly massive) — Combined with Lakota formation on sections

Lower Cretaceous

- Kf — **Fuson formation** (shale and sandstone) — Combined with Lakota formation on sections
- Klk / Kdlk — **Lakota sandstone** (massive buff sandstone with coal bed locally near base)
- Km — **Morrison shale** (massive sandy shale, gray, greenish, and maroon)

UNCONFORMITY?

JURASSIC

- Jsd — **Sundance formation** (buff sandstone and red and greenish-gray shale)

UNCONFORMITY

TRIASSIC ?

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- Cmk / Cmo — **Minnekahta limestone** (very thin-bedded gray limestone)
- Co — **Opeche formation** (bright-red sandy shale) — Combined with Minnekahta limestone on sections

Pennsylvanian

- Cml — **Minnelusa sandstone** (gray, red, and buff, limy sandstone with red shale at base)

Mississippian

- Cp — **Pahasapa limestone** (massive gray limestone)
- Ce — **Englewood limestone** (pink limestone) — Combined with Pahasapa limestone on sections

UNCONFORMITY

ORDOVICIAN

- Ow — **Whitewood limestone** (hard massive buff limestone) — Combined with Deadwood formation on sections

CAMBRIAN

- €d — **Deadwood formation** (brown sandstone and sandy shale)

METAMORPHIC ROCKS OF UNKNOWN ORIGIN

SHEET SYMBOL / SECTION SYMBOL

ALGONKIAN

- As — **Mica-schist**

Legend is continued on the left margin.

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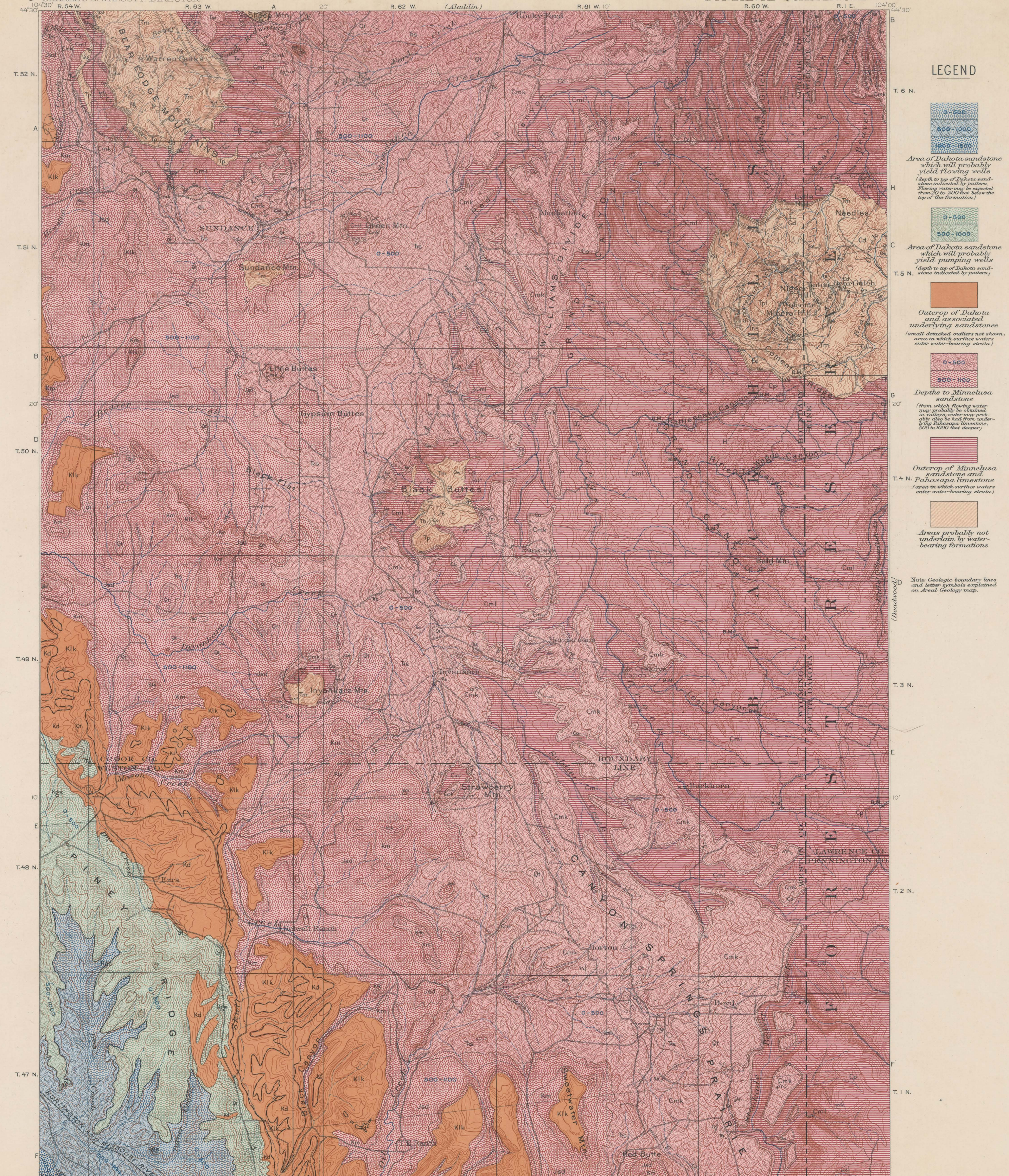
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

Geology by N. H. Darton, assisted by W. S. Tangier Smith.
Surveyed in 1900-1903.

U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

ARTESIAN WATER

WYOMING — SOUTH DAKOTA
SUNDANCE QUADRANGLE



Henry Gannett, Chief Topographer.
Jno. H. Renshawe, Topographer in charge.
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Topography by H. S. Wallace and W. H. Herron.
Surveyed in 1894 and 1899.

Wallace 1894 | Herron 1899

TRUE NORTH — MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{125000}$
1 ½ 0 1 2 3 4 5 Miles
1 ½ 0 1 2 3 4 5 Kilometers
Contour interval 50 feet.
Datum is mean sea level.
Edition of Nov. 1905

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

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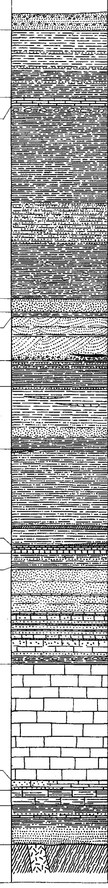
COLUMNAR SECTION

GENERALIZED SECTION FOR THE SUNDANCE QUADRANGLE.

SCALE: 1 INCH = 500 FEET.



System.	Series.	Formation Name.	Symbol.	Columnar Section.	Thickness in Feet.	Character of Rocks.	Character of Topography and Soils.
TERTIARY	OLIGOCENE?	Sand, gravel, and conglomerate.	Tw		25-150	Sand, gravel, and bowlders.	Plateaus with fertile soils, usually forested.
		UNCONFORMITY					
CRETACEOUS	UPPER CRETACEOUS	Carlile formation.	Kcr		350	Gray shale with thin beds of sandstone.	Bare shale slopes.
		Greenhorn limestone.	Kg		40	Thin-bedded, hard, gray, impure limestone with *Inoceramus labiatus.*	Bare, rocky ridge.
		Graneros shale.	Kgs		(500)	Dark-gray shale.	Shale slopes and valleys. Thin, sterile soil except where covered by alluvium.
					1000 (200)	Hard, sandy shale; weathers light gray.	Rocky ridge with pines.
					(300)	Dark shale with thin sandstone near top; contains hard, oval concretions.	Shale ridges and slopes. Thin, barren soil.
		Dakota sandstone.	Kd		40-100	Reddish-brown sandstone, mostly massive.	Rocky ridges and sloping plateaus with cliffs. Sandy soil.
	LOWER CRETACEOUS	Fuson formation.	Kf		10-40	Gray to red shale and sandstone.	Steep slopes below cliffs of Dakota sandstone.
		Lakota sandstone.	Klk		150-300	Massive, coarse, cross-bedded, gray to buff sandstone with local beds of coal and conglomerate near base.	High, flat-topped, steep-sided ridges, mostly forest covered. Thin, sandy soil.
		Morrison shale.	Km		125-150	Compact shale of gray, buff, pale-green, and maroon tints, with thin beds of gray sandstone.	Steep slopes below cliffs of Lakota sandstone.
		UNCONFORMITY?					
JURASSIC		Sundance formation.	Jsd		325	Thin layer of buff sandstone. Green shale with thin fossiliferous layers. Sandstone and sandy shale of dull-reddish color. Buff sandstone on dark shales.	Valleys and rolling slopes, generally with fertile soils.
		UNCONFORMITY					
TRIASSIC?		Spearfish formation.	Ꞧs		500+	Red, sandy shale with beds of gypsum.	Wide valleys. Sterile soils except where covered by alluvium.
CARBONIFEROUS	PERMIAN?	Minnekahta limestone.	Cmk		40	Thin-bedded, gray limestone.	Wide, sloping plateaus margined by cliffs and ridges. Fertile soil.
		Opeche formation.	Co		60-80	Red, sandy shale and red sandstone.	Steep slopes beneath cliffs of Minnekahta limestone.
	PENNSYLVANIAN?	Minnelusa sandstone.	Cml		500+	Massive, white, hard sandstone. Limy sandstone, buff, gray, yellow, brown, and red. Red shale with oval concretions of silica.	Rocky and sandy slopes and rolling mountain summits. Sandy soils, mostly covered by forest.
	MISSISSIPPIAN	Pahasapa limestone.	Cp		600	Massive, light-gray limestone.	Plateau, mountain slopes, and canyon walls. Soils rich and mostly forested.
		Englewood limestone.	Ce		50	Thin-bedded, pinkish limestone.	Slopes below Pahasapa cliffs.
		UNCONFORMITY					
ORD.		Whitewood limestone.	Ow		80	Massive, hard limestone, mottled pinkish.	Cliffs.
CAMBRIAN		Deadwood formation.	Ꞓd		100-300	Shales, limestone, and breccia. Sandstone and quartzite.	Rocky ridges and slopes.
ALGONKIAN?		Schist and granite.	As Ag			Schist, with granite, amphibolite, and other dikes.	Rocky slopes.

N. H. DARTON,
Geologist.

ILLUSTRATIONS

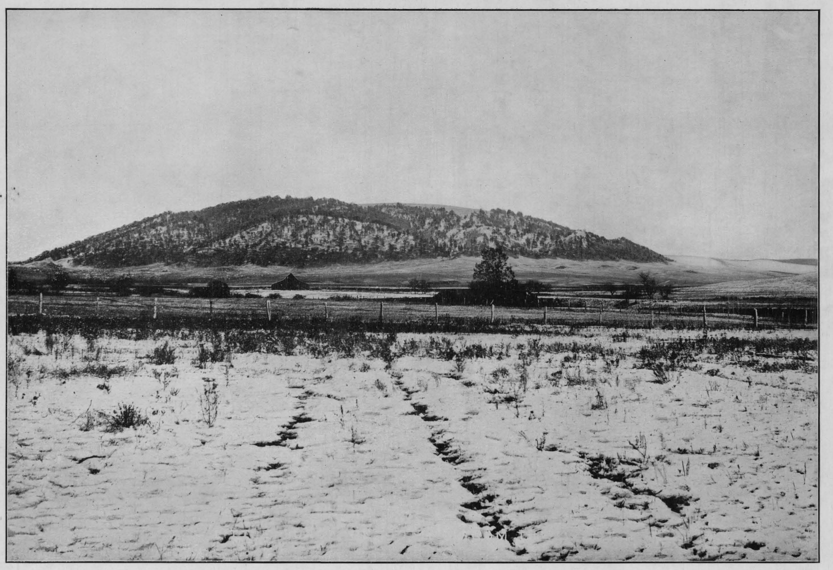


FIG. 4.—GREEN MOUNTAIN FROM THE NORTH.

A dome probably due to a laccolith. Slopes are of Minnekahta limestone; the center is of Minnelusa sandstone. To the right are ridges of gypsum.

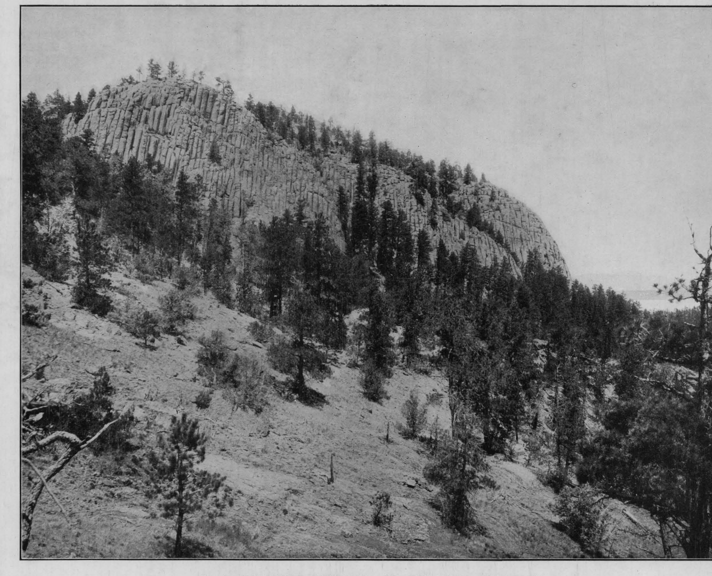


FIG. 5.—COLUMNAR PORPHYRY ON INYANKARA MOUNTAIN.

View of the central knob, looking northwest.

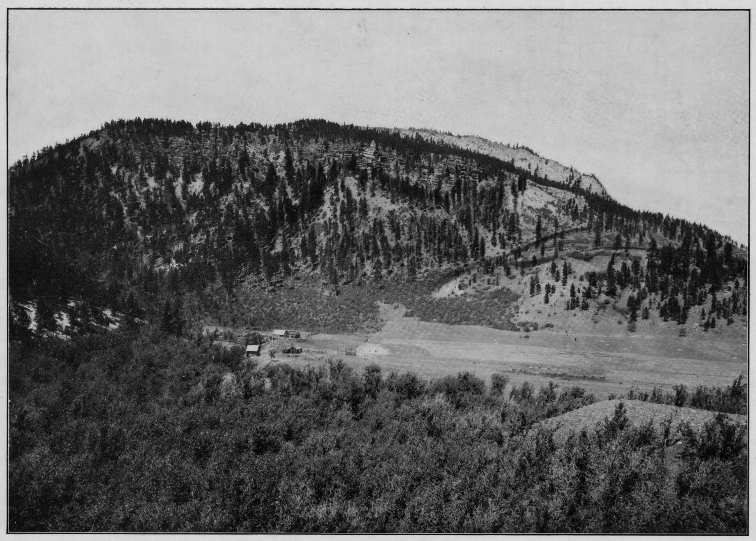


FIG. 6.—SHEEP MOUNTAIN FROM THE SOUTH.

An uplifted block of Deadwood formation overlain by Whitewood and Pahasapa limestones. Fault is at foot of cliff, beyond houses, and to the right curves around mountain. Spearfish red beds in foreground, Deadwood sandstone cliffs in middle-ground, and Pahasapa limestone to right in distance.

FIG. 7.—SUNDANCE MOUNTAIN.

The remnant of a laccolith lying on a platform of Sundance formation. Shows columnar to massive porphyry and characteristic talus. Spearfish red beds in foreground. Looking southwest from a point 1 mile east of Sundance.

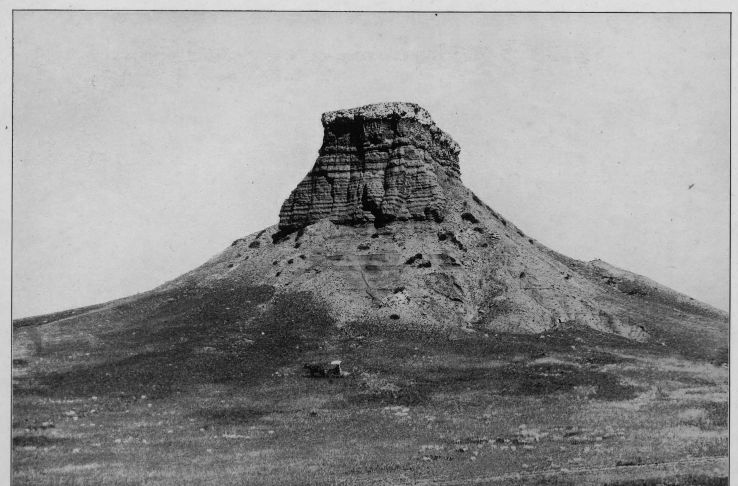


FIG. 8.—RED BUTTE, SOUTHEAST OF SWEETWATER MOUNTAIN.

Spearfish red beds capped by a 30-foot bed of gypsum.

FIG. 9.—CHARACTERISTIC FOSSILS (A) OF NIOBRARA FORMATION AND (B) OF GREENHORN LIMESTONE.

A, Ostrea congesta; *B*, Inoceramus labiatus.

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