DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

GEOLOGIC ATLAS

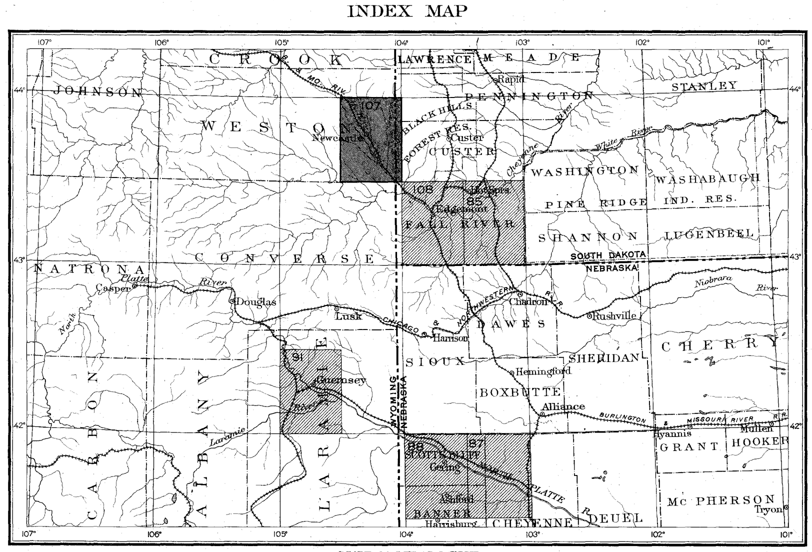
OF THE

UNITED STATES

NEWCASTLE FOLIO

WYOMING-SOUTH DAKOTA

INDEX MAP



SCALE: 40 MILES-1 INCH

AREA OF THE NEWCASTLE FOLIO

AREA OF OTHER PUBLISHED FOLIOS

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LIBRARY EDITION

NEWCASTLE FOLIO
NO. 107

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

1904

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).

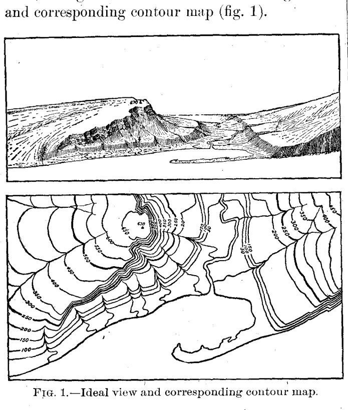


FIG. 1.—Ideal view and corresponding contour map.

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		℞	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	€	Brick-red.
	Algonkian		A	Brownish-red.
	Archean		Æ	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:

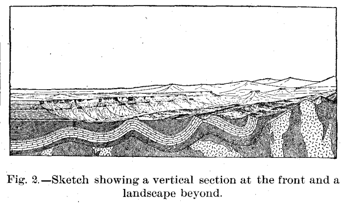


Fig. 2.—Sketch showing a vertical section at the front and a landscape beyond.

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:

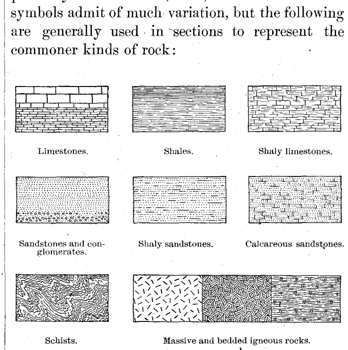


Fig. 3.—Symbols used in sections to represent different kinds of rocks.

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

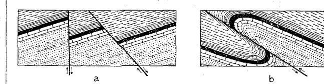


Fig. 4.—Ideal sections of strata, showing (a) *normal* faults and (b) a *thrust* fault.

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 NEWCASTLE QUADRANGLE.

By N. H. Darton.

GEOGRAPHY.

Position and extent.—The Newcastle quadrangle embraces the quarter of a square degree which lies between parallels 43° 30′ and 44° north latitude and meridians 104° and 104° 30′ west longitude. It measures approximately 34½ miles from north to south and 25⅛ miles from east to west, and its area is 863¾ square miles. It lies mainly in the eastern portion of Weston County, Wyo., but includes also a narrow area of western Custer and Pennington counties, S. Dak. The northeastern portion of the quadrangle lies on the slopes of the Black Hills, but the larger part of it belongs to the Great Plains, although these plains are lower here than in the greater part of adjoining portions of Nebraska and Wyoming. The district is drained by branches of the South Branch of Cheyenne River.

Being part of the Black Hills and the Great Plains, this quadrangle exhibits many features of both, but as its area is small, a general account of these provinces will be given before the detailed description of the quadrangle is presented.

THE GREAT PLAINS PROVINCE.

General features.—The Great Plains province is that part of the continental slope which extends from the foot of the Rocky Mountains eastward to the valley of the Mississippi, where it merges into the prairies on the north and the low plains adjoining the Gulf coast and the Mississippi embayment on the south. The plains present wide areas of tabular surfaces traversed by broad, shallow valleys of large rivers that rise mainly in the Rocky Mountains, and more or less deeply cut by narrower valleys of the lateral drainage. Smooth surfaces and eastward-sloping plains are the characteristic features, but in portions of the province there are buttes, extended escarpments, and local areas of bad lands. Wide districts of sand hills surmount the plains in some localities, notably in northwestern Nebraska, where sand dunes occupy an area of several thousand square miles. The province is developed on a great thickness of soft rocks, sands, clays, and loams, in general spread in thin but extensive beds sloping gently eastward with the slope of the plains. These deposits lie on relatively smooth surfaces of the older rocks. The materials of the formations were derived mainly from the west and were deposited, layer by layer, either by streams on their flood plains or in lakes and, during earlier times, in the sea. Aside from a few very local flexures, the region has not been subjected to folding, but has been broadly uplifted and depressed successively. The general smoothness of the region to-day was surpassed by the almost complete planation of the surface during earlier epochs. Owing to the great breadth of the plains and their relatively gentle declivity, general erosion has progressed slowly notwithstanding the softness of the formations; and as at times of freshet many of the rivers bring out of the mountains a larger load of sediment than they carry to the Mississippi, they are now building up their valleys rather than deepening them.

Altitudes and slopes.—The Great Plains province as a whole descends to the east about 10 feet in each mile from altitudes approaching 6000 feet at the foot of the Rocky Mountains to about 1000 feet above sea near Mississippi River. The altitudes and rates of slope vary considerably in different districts, particularly to the north, along the middle course of Missouri River, where the general level has been greatly reduced. West of Denver the plains rise to an altitude of 6200 feet at the foot of the Rocky Mountains, and maintain this elevation far to the north, along the foot of the Laramie Mountains. High altitudes are also attained in Pine Ridge, a great escarpment which extends from near the north end of the Laramie Mountains eastward through Wyoming, across the northwest corner of Nebraska, and for many miles into southern South Dakota. Pine Ridge marks the northern margin of the higher levels of the Great Plains, and presents cliffs and steep slopes descending a thousand feet into the drainage basin of Cheyenne River, one of the most important branches of the Missouri. From this basin northward there is a succession of other basins with relatively low intervening divides, which do not attain the high level of the Great Plains to the south. It is in this lower portion of the plains that the Newcastle quadrangle is situated.

Drainage.—The northern portion of the Great Plains above described is drained by the middle branches of Missouri River, of which the larger members are Yellowstone, Powder, Little Missouri, Grand, Cannonball, Moreau, Cheyenne, Bad, and White rivers. On the summit of Pine Ridge not far south of the escarpment is Niobrara River, which rises in the midst of the plains some distance east of the northern end of the Laramie Mountains. To the south are Platte River with two large branches heading far back in the Rocky Mountains, the Rio Grande, and Arkansas River, which crosses the plains to the southeast and affords an outlet for the drainage from a large watershed of mountain and plains. Between the Rio Grande and the Arkansas are Cimarron River and numerous smaller streams heading in the western portion of the plains. Between Arkansas and Platte rivers is Republican River, rising near the one hundred and fifth meridian, and an extended system of local drainage in eastern Kansas and Nebraska.

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. Having abundant rainfall, it constitutes, through its vegetation and streams, 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 separated by 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 rising 800 feet above the central valleys. It attains altitudes of 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. Rising in shallow, park-like valleys on the plateau, they sink into deep canyons with precipitous walls of limestone often many hundred feet high. The limestone plateau extending south swings around to the eastern side of the hills, where, owing to the steeper dip of the strata, it narrows to a ridge having a steep western face. This ridge is interrupted by the water gaps of all the larger streams in the southeastern and eastern portion of the hills, which rise in the high limestone plateau, cross the region of crystalline rocks, and flow through canyons in the flanking rocks 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. The minor escarpment and slope is at intervals sharply notched 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 side. It is often 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 are separated by divides which are usually so low as to give the Red Valley the appearance of being continuous. In its middle eastern section, however, 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 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 the 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 toward the northern end of the uplift.

TOPOGRAPHIC FEATURES OF THE QUADRANGLE.

The Newcastle quadrangle presents a considerable variety of topographic forms, comprising the western margin of a portion of the limestone plateau of the Black Hills, a zone of the Red Valley 20 miles long, and an extensive development of the hogback rim of the hills, which, north of Newcastle, spreads out into a plateau of considerable area. More than two-thirds of the quadrangle lies in the plains, a region of low ridges and wide valleys, here traversed by a low but distinct sandstone escarpment west of Beaver Creek, beyond which the plains extend for many miles at a gradually increasing height.

Drainage.—The drainage is to the south and southeast into Beaver Creek, which empties into Cheyenne River a short distance beyond the southeast corner of the quadrangle. The principal tributaries of Beaver Creek that come out of the Black Hills uplift do not flow down the direction of greatest slope, which is to the west; their valleys trend almost due south. Stockade Beaver Creek, the largest of these streams, rises in the plateau area of the Black Hills, flows out into the Red Valley, which it traverses for several miles, and then passes out through a gate in the hogback range and continues its southward course to Beaver Creek along the base of the foothills. Its two principal branches are Whoopup Creek, heading in canyons in the limestone plateau, and Salt Creek, flowing through a deep canyon in the plateau to which the hogback range gives place north of Newcastle. Oil Creek and Little Oil Creek rise on the plateau north and northwest of Newcastle, and flow through canyons of considerable depth, out of which they pass westward into the plains, to join the main Beaver Creek near the center of the quadrangle. Main Beaver Creek flows across the quadrangle from northwest to southeast in a wide, shallow valley of low declivity cut in the shales of the plains. From the west it receives numerous small branches that rise on the higher levels of the plains. It is the outlet of a drainage basin comprising over a thousand square miles, but except in times of freshet it is a very insignificant watercourse.

Relief.—The surface features of this quadrangle are very closely related to rock texture, the thicker masses of hard rocks giving rise to ridges, the softer beds being excavated into valleys. Valleys cut in large areas of soft rock are wide; those which have been excavated through hard rock are narrow. The limestone plateau of the higher portion of the Black Hills extends a short distance into the northwest corner of the Newcastle quadrangle, presenting a tabular surface with altitudes ranging from 6000 to 6750 feet, deeply trenched by canyons having walls 500 to 600 feet high, and containing branches of Stockade Beaver and Whoopup drainage. These canyons open to the west and south and deepen rapidly from their heads. Northwest of the LAK ranch the limestone plateau terminates in a steep slope that is due to the steep westward dip of the rocks—a slope that presents high, rugged cliffs, some of which, in their brilliant coloring, are highly picturesque. A view of this portion of the range is shown in fig. 8 on the illustration sheet. The Red Valley crosses the northeast corner of the quadrangle, with a width varying from 3 miles in the portion east of Cambria to a quarter of a mile north of the LAK ranch, its narrowness here being due to the increased dip of the rocks. Southeast of the LAK ranch it averages less than a mile in width, but south of Elk Mountain it widens rapidly. It is occupied by Stockade Beaver Creek to the north, and extends through a low divide just east of the LAK ranch and thence southward along the eastern side of the Elk Mountain range. South of Newcastle the hogback range presents its typical features—a steep east-facing escarpment and gentler western slope—and varies in width from 1 mile to 3 miles. It attains its greatest prominence at Elk Mountain, which is somewhat over 5700 feet high. In its broader portion south of Elk Mountain its western slope is deeply trenched by numerous canyons. North of Newcastle the hogback range is spread out into a wide plateau sloping to the southwest. This plateau is deeply trenched by canyons of the branches of Oil Creek, and to the east, in its higher portions, considerable areas of it have been cut away by Salt Creek and its branches, leaving outlying portions of the plateau on the summits of an irregular series of ridges. Mount Pisgah is the most prominent of these, attaining an altitude of over 6350 feet. The canyons north of Newcastle average about 400 feet deep. The plateau is cut into long, irregular ridges by these canyons, the broadest area being in the vicinity of the Mount Zion ranch, southwest of Cambria. The altitudes here are from 4900 to 5200 feet. Along Oil Creek and two of the branches of Plum Creek the plateau remnants are the detached summits of several narrow ridges. On the west side of Oil Creek there is a continuous crest line of plateau, which slopes westward and ends in the valley of Skull

Creek. In the vicinity of Newcastle and for some distance east and west there is a subordinate hogback ridge separated from the main range by a narrow valley and a series of low divides. From the foot of these ranges a great region of rolling plains stretches far to the west, with altitudes ranging from 3750 to 4200 feet in greater part. It presents some low but sharply marked ridges, due to harder beds of rock lying near the base of the shale series. One of the most conspicuous of these ridges has a low escarpment extending from the northwest corner of the quadrangle to the LAK ranch. It is separated from the main hogback range by a valley which is 5 miles wide near Osage. East of Pedro, where the continuity of the ridge is somewhat broken, this valley narrows greatly, but it widens again to from 1 to 3 miles near Newcastle. The escarpment presents to the northeast a face from 10 to 50 feet high surmounting long, gentle slopes. To the southwest it merges into a zone of low, rocky ridges which finally slope into the plains south. West of the main Beaver Valley the plains are traversed from the northwest to the southeast by a low but distinct escarpment, from 50 to 150 feet high, which is surmounted by a region of rolling plains with many low cliffs and numerous detached buttes. Alkali Butte is one of the most prominent features of this region, attaining an altitude of 4500 feet; and although this is only about 200 feet above the adjoining rolling plains, the butte is so situated that it is a conspicuous landmark from the east.

GEOLOGY.

GEOLOGIC HISTORY.

The general sedimentary record.—The rocks appearing at the surface within the limits of the Newcastle quadrangle are 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.

These rocks afford a record of physical geography from early Carboniferous time to the present, and other sediments which underlie them extend the record back to the middle Cambrian. The composition, appearance, and relations of strata show 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 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, had their original source in the crystalline rocks, but 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 sediments 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 great events of early North American geologic history was the wide expansion of an interior sea over the western central 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 on sea beaches, partly in shallow waters off shore, and partly in estuaries. Abutting against the irregular surface of the crystalline rocks which formed the shore are numerous exposures of these sediments containing much local material. 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 Silurian and Devonian being absent and only a portion of the Ordovician being present at the north. This is probably because there was 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 occur, it is probable that no crystalline rocks were then exposed above water in this region, although elsewhere the limestone, or its 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 with 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 of Permian, time. It was laid down in thin layers and to a thickness now represented by only 40 feet of 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-bed deposition and the great mass of red shales constituting the Spearfish formation 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 500 feet or more, as now represented by the formation, and it is so uniformly of a deep-red tint that this is undoubtedly the original color. The 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 the same for all parts of the region, accumulation of clay was interrupted by chemical precipitation of comparatively pure gypsum in beds ranging in thickness from a few inches to 30 feet, and free from mechanical sediment. 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 portion 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 there is shale lying directly on the Spearfish red shales, which was deposited in moderately deep water. Upon this shale is 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 the deeper water that 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 peculiar to 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 gave rise to a general erosional unconformity at the base of the Lakota sandstone, the next succeeding deposit, which is of coastal and possibly estuarine origin. This formation consists mainly of coarse sands spread by strong currents in beds 30 to 40 feet thick, but includes several thin partings of clay and local accumulations of vegetable material. Next there was deposited a thin calcareous series, represented by the Minnewaste limestone, but apparently it was laid down only in a local basin in the southern portion of the Black Hills. Over this was spread 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 later 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 uniform conditions. 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 to a moderate height early in Tertiary time—or possibly in latest Cretaceous time—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 southeast there are no early Eocene deposits nearer than those of the Gulf coast and along the Mississippi embayment.

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 Bearlodge Mountains they are seen a thousand 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.

Later Tertiary mountain growth.—Following the Oligocene epoch the dome was raised several hundred feet higher and 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, in the northwest corner of South Dakota. 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 ever were deposited in the immediate vicinity of the hills is not ascertained.

Quaternary uplift and erosion.—During the early portion 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 next neighbor to the north. Such streams flow southeastward for some distance in pre-Oligocene valleys and then turn abruptly northward into canyons of post-Oligocene age, leaving 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 deeper than they would be in simply grading their profiles to the level of the 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 in the main without aggradation, but in some cases, with the shifting of channels, there have been accumulations of local deposits on small terraces at various levels.

DESCRIPTION OF THE ROCKS.

The stratified rocks in the Newcastle quadrangle have a thickness of about 6350 feet. The order of succession of the limestones, sandstones, and shales, and their general character, are given in the columnar section sheet.

CARBONIFEROUS SYSTEM.

Pahasapa limestone.—This formation is a limestone of light-gray color, weathering to a somewhat bluish or dove tint. The rock is massively bedded and presents steep walls in the sides of the canyons and slopes of the hills. The greatest thickness exhibited is in the steep monocline east of Stockade Beaver Creek in the southwest corner of Range 1, Township 1, in South Dakota, where about 500 feet are exposed, apparently representing about two-thirds of the formation. These are the lowest rocks exposed in the Newcastle quadrangle, their exposure being due to the removal of the Minnelusa formation in some of the canyons and along the steep western face of the ridge. The area of outcrop is small, being less than 5 square miles in all. The limestone underlies all of the adjoining region for many miles, but under the plains east of Newcastle it lies at a depth of 5000 feet or more. It was reached by the deep well at Cambria at a depth of 1947 feet and was penetrated to 2345 feet. The borings exhibited nearly pure limestone of light color, mostly white or light gray, but including some beds of pale pinkish and buff tints. At the top of the formation are a few feet of red sandy shale containing hard, lens-shaped siliceous concretions, mostly from 8 inches to 2 feet in diameter.

The Pahasapa limestone contains fossils of Mississippian age and is of approximately the same age as the Madison limestone of the Northwest. The principal species are *Spirifer rockymontana* and *Seminula dawsoni.*

Minnelusa sandstone.—This formation consists mainly of sandstones in which much of the cement is calcareous. The upper members comprise a hard white sandstone at the top, averaging about 70 feet in thickness, a red brecciated sandstone in the middle, from 100 to 140 feet thick, and a white sandstone below, which varies in thickness from 35 to 50 feet. The lower members consist of a succession of gray and buff slabby sandstones. These beds are best exposed in the steep-sided uplift east of the upper portion of the Stockade Beaver Valley, where there is an area of about 30 square miles of the Minnelusa formation. The beds rise rapidly from beneath the surface a short distance west of the State line, and then to the east lie nearly level, giving rise to an elevated plateau. The formation is extensively exposed in the canyons that are deeply incised in this uplift, the upper white sandstone being a conspicuous feature in the upper portions of their walls and forming gateways at their mouths. The brecciated sandstone is of a brownish red color and its brilliant-hued cliffs are picturesque features in many of the canyons. The thickness of Minnelusa beds exposed east of Stockade Beaver Creek is about 600 feet. In its outcrops the sandstones of the formation appear to be porous, but in the deep boring at Cambria, which penetrated the formation from 1096 feet to about 1947 feet, much of the material was found to be thoroughly cemented by carbonate of lime. Nearly all of the rocks in the boring were very compact and fine grained. It is apparent, therefore, that the predominance of sand in the surface outcrops is due to the leaching away of a portion of the calcareous cement, for it is not likely that the original character of the beds was greatly different in areas so closely adjacent. The increase of thickness to 850 feet in the area to the west, as shown by the well record, is an interesting and unexpected feature.

Section of Minnelusa sandstone in boring at Cambria, Wyo.

	Thickness in feet.	Depth of base in feet.
Hard, pinkish calcareous sandstone	4	1100
Light-buff sandstone, very little lime	17	1117
Chocolate sandstone, somewhat calcareous	8	1125
Buff calcareous sandstone	10	1135
Dark-brown calcareous sandstone	5	1140
Buff calcareous sandstone	45	1185
Buff limestone, sandy	6	1191
Light-brown limestone, sandy	4	1195
Light-buff limestone, some sandy	12	1207
Light-buff sandstone, very little lime	15	1222
Hard, brownish-red sandstone, some lime	3	1225
Light tan-colored calcareous sandstone	15	1240
Light-pinkish buff calcareous sandstone	60	1300
Pink sandstone, very little lime	90±	1390
Pink calcareous sandstone	40±	1430
Pale-pink sandstone, little lime	40±	1470
Chocolate sandstone, little lime	2	1472
Dark-gray sandstone	2	1474
Light-gray shale, no lime	4	1478
Black shale, 20 per cent carbon	3	1481
Light-buff calcareous sandstone	9	1490
Brownish-buff sandstone and shale	6	1496
Alternations of light-gray and buff sandstone, but little lime	95	1591
Black calcareous shale	4	1595
Dark-gray sandstone and shale	2	1597
Light-gray and buff calcareous sandstone	43	1640
Dark shale	2	1642
Gray and pale buff calcareous sandstones	67	1709
Dark-gray calcareous sandstone	4	1713
Nearly white sandstone	9	1722
Light-brown sandstone	3	1725
Nearly white sandstone, some lime	13	1738
Gray sandstone, upper part calcareous	62	1800
Greenish-gray shale, some lime	8	1808
Gray sandstone, but little lime	2	1810
Chocolate-brown sandstone, very little lime	83	1893
Brown sandstone, with gray limestone layers	54	1947

The only fossils observed in the Minnelusa formation were some remains of brachiopods found in the upper member near Hot Springs. These appear to be of Pennsylvanian age, but are not sufficiently distinctive to furnish conclusive evidence in this regard.

Opeche formation.—This thin series of red beds lying next above the Minnelusa sandstone averages 75 feet in thickness and consists of moderately soft, brownish red sandstones, usually in beds varying in thickness from 1 to 4 inches, and red sandy shales. It is observed mainly in slopes beneath the escarpment of overlying Minnekahta limestone. In Gillette Canyon a thin local bed of gypsum is included. 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 formation may be seen in the walls of many small canyons which cut through the Minnekahta limestone in the slopes along the east side of the valley of Stockade Beaver Creek and the Red Valley southeast of the LAK ranch, and also in Redbird and Gillette canyons. The age of this formation has not yet been definitely determined, for so far it has yielded no fossils. From the fact that the overlying Minnekahta limestone is of probably Permian age and that there are red deposits in the upper part of the Permian of Kansas and eastern Nebraska, it is supposed that its age is Permian.

Minnekahta limestone.—This formation, formerly known as the "Purple limestone," is prominent in the Black Hills region, but occupies only a limited area in the northeast corner of this quadrangle. It is thin, averaging slightly less than 40 feet in thickness, but owing to its hardness and flexibility it gives rise to prominent topographic features. Its outcrop is marked by a series of rocky ridges rising with steep slopes out of the Red Valley and extending some distance up the long declivities of the Minnelusa formation. Its surface is usually bare or covered with scattered bushes and its edge is always marked by escarpments that present 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 color as a whole is a light gray, but there is always a slight pinkish or purplish tinge, from which the term "Purple limestone" originated. Its composition varies somewhat, mainly in the proportion of carbonate of magnesia, usually present in considerable amount, and of clay, which is a small but 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. The dip of the formation is mainly to the west along the east side of Stockade Beaver Valley, being steep at first and diminishing in amount as the formation extends eastward over the rounded slope of the monocline. In Redbird and Gillette canyons it passes over an undulating anticline that pitches south-southwest. There are frequent local variations in the amount and direction of the dip, as the limestone is a thin, relatively hard bed of homogeneous rock lying between masses of softer beds, and consequently was much affected by local conditions of pressure. The thin layers of the limestone are often minutely crumpled and faulted, but, considering the large amount of deformation to which the formation has been subjected, the flexures are but little broken. In its contacts with adjoining formations the Minnekahta limestone presents an abrupt change in material but no evidence of unconformity. The formation is classed as Permian because of fossils which it has yielded in the region west of Hot Springs.

TRIASSIC (?) SYSTEM.

Spearfish formation.—The outcrop of this series of gypsiferous red beds extends along the eastern side of the Newcastle quadrangle, giving rise to a valley of varying width, occupied for several miles by Stockade Beaver Creek and thence continuing southward along the eastern side of Elk Mountain. Two small areas of the formation are revealed by erosion in the valley of Salt Creek and one of its branches northeast and east of Cambria. The thickness of the formation averages 500 feet, as nearly as could be determined, and 496 feet of it were found in the deep well at Cambria. Its materials are red sandy shale with intercalated beds of gypsum which sometimes are 30 feet thick, and it outcrops extensively in wide, bare slopes and high buttes of bright-red color, with outcrops of snow-white gypsum in striking contrast. The bedding is generally thin and moderately distinct. Red clay, fine sand, and occasional flakes of mica are the principal constituents. The gypsum occurs in the formation at various horizons, but is most prominent at the top and near the bottom. Some of the larger gypsum beds extend continuously over wide areas. There are also throughout the formation small veins of gypsum due to secondary deposition. In the lower portion of the valley of Stockade Beaver Creek the formation is hidden to some extent under alluvial deposits. In the range of hills culminating in Mount Pisgah the formation extends high up the slopes, outcropping in great cliffs of brilliant hue, which to the north have a height of nearly 200 feet in some places. At the top of the formation in this vicinity there is a continuous bed of gypsum from 10 to 15 feet thick, and in the valley 2 miles southeast of Mount Pisgah there is a series of thick beds of gypsum near the base of the formation. On the eastern slopes of Elk Mountain and southward along the west side of the Red Valley the Spearfish beds rise high in the slopes and their brilliant red color makes them conspicuous features in the landscape. A 3-foot bed of gypsum occurs at the top. In the region of steep dips in the Stockade Beaver Valley, for some distance above the LAK ranch, the outcrop of the Spearfish formation is narrow and is mostly covered by alluvial deposits. A measurement was made a mile and a half north of the LAK ranch, in which there were found 450 feet, or possibly more, of the formation, including two thick beds of gypsum. In this section there is a lower bed of gypsum about 150 feet above the Minnekahta limestone, then about 40 feet of red clays, a 2-foot bed of gypsum, 15 feet of red clays with two thin gypsum beds near the top, a bed of gypsum which locally attains a thickness of 30 feet, and, at the top, about 200 feet of red shale and red sandy shale, which extend to the base of the Sundance formation. The principal bed of gypsum, in the center of the formation, extends northward for several miles. Another gypsum bed appears at the top of the formation and soon attains a thickness of from 10 to 12 feet, the amount gradually increasing northward. This upper bed is overlain by dark shales, here constituting the base of the Sundance formation. Northeast of Cambria there are 25 feet of gypsum at the top of the formation, several thick beds in its center, and a local thin bed of gypsum at its base, lying directly on the Minnekahta limestone. In the boring at Cambria the members of the Spearfish formation were reported as follows:

Section of Spearfish formation at Cambria, Wyo.

	Feet.
Gypsum	8
Red clay	28
Red and dark clay	28
Red clay	181
Gypsum	7
Red clay	58
Gypsum	4
Red clay and gypsum	78
Gypsum	12
Red clay lying on Minnekahta limestone	88

No fossils have been discovered in the Spearfish formation, and its precise age is not known. From the fact that it lies between the Permian limestone 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 Jurassic by an unconformity which may possibly represent all of Triassic time.

JURASSIC SYSTEM.

Sundance formation.—The rocks of the Sundance formation comprise a series of shales and sandstones which vary but little from place to place in order and character. At the top are 150 feet or more of dark greenish-gray shales, usually including thin layers of limestone which are highly fossiliferous. Next below are sandy shales of reddish color, underlain by buff sandstone, including a prominent layer about 25 feet thick. At the base are dark shales, averaging about 60 feet thick. The total thickness averages 350 feet throughout.

The formation lies unconformably on the Spearfish formation and its outcrop occupies a portion of the slope which rises from the Red Valley to the crest of the hogback range. In the vicinity of the LAK ranch and farther south, near and beyond Elk Mountain, the outcrop zone is narrow and the rocks are often partly covered by talus. To the north, where the dips are low, Salt Creek has cut away the overlying Lakota and Morrison formations for some distance, giving rise to a wide outcrop area of Sundance formation, which extends through passes in the divides and connects with the areas lying along the slopes next west of the valley of Stockade Beaver Creek. A small area is also exposed in the deep canyons of Oil and West Plum creeks near the northern margin of the quadrangle.

A typical section of the Sundance formation is as follows:

Section of Sundance formation on west side of valley of Stockade Beaver Creek, Wyo.

	Feet.
Morrison shales at top.	
Greenish shales with fossiliferous limestone layers	150
Red sandy shales	60
Thin sandstones and shales	25
Light-buff, massive sandstones, some beds ripple marked	30
Greenish-gray shales lying on gypsum at top of Spearfish red shales	70

In the eastern front of Elk Mountain similar features are presented, but the thickness of the lower members is less. The following section is representative of this region:

Section of Sundance formation near Elk Mountain, Wyo.

	Feet.
Morrison shales at top.	
Greenish shales with fossiliferous limestone layers	150
Light-colored, thin-bedded sandstones and shales	25
Pale-red sandy shales	35
Gray sandy shales and thin sandstones	35
Massive cream-colored sandstone	15
Thin sandstones and soft sandy shales	10
White sandstones	3
Dark-green shale lying on a 3-foot gypsum bed at the top of the Spearfish red shales	55

The sandstone in the lower part of the Sundance formation is the most prominent feature in the outcrops, being marked by a distinct bench and precipitous ledge in the general shaly slope (see fig. 9). In the valley of Salt Creek this sandstone gives rise to numerous benches, terraces, and low buttes. In the canyons northwest of Cambria the Sundance formation is not far below the surface, and on Oil and West Plum creeks, which cut somewhat deeper than the other streams in that region, its upper beds are revealed for a few miles, rising from below the Morrison shales on the gentle dip to the southward. Fossils are very abundant both in the thin limestone layers or concretions in the upper green shales and in the buff sandstones in the lower part of the formation. They occur also in the other beds, but in much less number. The most characteristic species is *Belemnites densus*, represented by cigar-shaped bodies varying in size from an inch or less to 4 inches in length, of dark color, and radiated structure when seen in transverse section. This fossil occurs mainly in the upper green shales.

In the boring at Cambria the Sundance formation was entered at a depth of about 150 feet, but the well record was not sufficiently explicit to note the slight change in the character of the shales in passing out of the Morrison formation. The beds named in the next table were reported from 150 feet to 496 feet, where gypsum at the top of the Spearfish formation was found.

The total thickness of these beds is 346 feet. The red series in the middle of the formation is finer grained than in the surface outcrops, but the other features are about the same, including the basal dark shale and its overlying soft buff sandstone and the thick mass of gray shales at the top of the formation.

Section of boring at Cambria, Wyo.

	Thickness in feet.	Depth of base in feet.
Shales, light gray	150	300
Shales, sandy, pinkish	10	310
Shales, red	39	349
Shale, sandy, light gray	30	379
Sandstone and sandy clay, light greenish gray	22	401
Shale, sandy, very pale greenish gray	9	410
Sandstone, soft, buff	25	435
Shale, dark greenish gray, lying on 8 feet of gypsum	61	496

CRETACEOUS SYSTEM.

Morrison shale.—The Sundance shales are overlain by a series of massive shales with layers of fine-grained sandstones which have been called the Beulah shales or clays, but have been ascertained to be equivalent to the Morrison formation. This formation extends along the eastern front of the Rocky Mountains and to the "Como stage" of central Wyoming. The deposits are mostly of light-gray color, but portions are buff, pale green, and maroon. Their thickness averages a little more than 150 feet, being greatest to the north, and they outcrop mainly along the inner side of the hogback range below the cliffs of Lakota sandstone or conglomerate. In the region east of Salt Creek they occur in extensive outliers overlain by protecting caps of Lakota sandstone, and in the sloping plateau north of Newcastle they are revealed in the deep canyons. Outcrops of the formation are often obscured by talus derived from the sandstone cliffs above and by soil and wash that accumulate on the slopes. The contact with the Sundance formation shows an abrupt change in the character of the material. From its relations and fauna in other regions it is believed that the Morrison shale is of fresh-water origin.

At Cambria a drill hole in the floor of the coal mine penetrated 12 feet of sandstone with coaly layers at the base of the Lakota formation and passed through the following beds, probably all belonging to the Morrison formation:

Section of drill hole in floor of coal mine at Cambria, Wyo.

	Feet.
Fire clay, gray	3
Sandstone, light gray, moderately hard	1½
Fire clay	7½
Sandstone, gray, upper half very hard	4
Shales, lead colored, soft at base	11
Shale and fine sand	3
Shale, bluish gray	18
Sandstone, moderately hard	1
Clay, bluish and purplish, hard below	20

The deep drill hole near by began on a level with the base of the 7½ feet of fire clay and passed through about 150 feet of the formation, as nearly as could be ascertained from the well records. The Morrison shale contains bones of saurians, and, in the northern portion of the Black Hills, a few fresh-water shells. By some paleontologists the saurians of this formation are thought to be of later Jurassic age, but others class them as early Cretaceous. From the stratigraphic relations of the Morrison beds in northern Oklahoma and southeastern Colorado they are believed to be of early Cretaceous age.

Lakota formation.—The Lakota formation is one of the most prominent members brought to the surface by the Black Hills uplift. It is mainly a massive sandstone of considerable hardness which, together with the overlying Dakota sandstone, gives rise to the prominent hogback rim of the hills. Its prominence is enhanced by the softness of the underlying shales, above which it rises in high cliffs. Its thickness usually varies from 150 to 200 feet, but locally the amount may be somewhat greater. The sandstones are coarse grained, cross bedded, and massive, with partings of shale or thin-bedded sandstone of no great thickness. The color varies from light gray or even white to buff, the last named being most frequent. At or near the base there is a coal horizon, in which coal of excellent quality attains a thickness of from 5 to 7 feet in an area of moderate extent about Cambria. This coal appears not to occur east and south of the gap in which the range is crossed by Stockade Beaver Creek. In the Elk Mountain region and farther south the formation lies in a gently westward-dipping monocline that gives rise to a long, deeply canyoned mountain slope terminating in a line of high cliffs fronting east. The rocks comprise a thick bed of moderately coarse, brown conglomerate at the base of the formation, overlain by a pinkish quartzite sandstone, which is a prominent feature on Elk Mountain and some of the high summits to the south. The upper beds are gray to buff sandstones, moderately hard, massive and cross bedded, with occasional intercalations of thinner bedded sandstones. The thickness here averages 200 feet.

East and northeast of the LAK ranch, where the beds are all tilted at a high angle, the Lakota formation occupies a zone 200 feet wide marked by a high ridge cut into knobs by the cross valleys. Northwest of the ranch, where the dips diminish, the outcrop widens into a high, tabular ridge, sloping to the south. To the north and west, where the dips are low, the outcrop of the formation spreads widely, forming the extensive plateau about Cambria. To the east of this region Salt Creek and its branches have cut away much of a former plateau, and detached areas of Lakota sandstone remain, capping a series of high ridges lying between the valleys of Stockade Beaver and Salt creeks. West of Salt Creek the plateau presents a long line of cliffs of Lakota sandstone, rising gradually to the north on the gentle dip. The plateau is deeply trenched by canyons of Little Oil, East Plum, West Plum, and Oil creeks and their branches. In their deeper portions these cut through to the Morrison shales and expose the entire thickness of the Lakota formation in their precipitous walls. The presence of a valuable coal bed and numerous variations in stratigraphy give the formation special interest. In the plateaus north of Newcastle the upper member of the Lakota formation is a massive sandstone of gray color, usually about 90 feet thick, often with conglomeratic streaks. At the base of this member there is considerable evidence of local unconformity, and often a thin series of coaly shale. Next below is a massive, finer grained, even-textured sandstone, usually light-ash-gray near the top, but often darker below, and locally rusty or tan colored throughout. It averages about 50 feet thick. Under it is found the main coal series, which, with the thinner bedded sandstones and shales underlying the coal in some places, attains a thickness of 25 feet. Often where the coal is thin or absent its horizon is either immediately above the Morrison shale or an intervening thin layer of sandstone. The area in which the coal is 5 feet or more in thickness and the outcrop of the coal horizon are indicated on the economic geology map. Outside of the Cambria basin the coal thins rapidly and merges into a shale that contains thin beds of coal or carbonaceous shale. Along the west side of East Plum Creek the main coal horizon is represented by 12 to 14 feet of coaly shale containing scarcely any usable coal. In the upper sandstone of the Lakota in the region west of Newcastle there are two horizons containing more or less gravel, which are seen in most of the exposures. The upper of these horizons contains small, gray gravel, constituting conglomerate layers in a massive, tan-colored sandstone. The lower horizon contains coarse, rust-red gravels scattered more or less thickly through a bed 10 to 12 feet thick, which lies about 30 feet above the coal horizon. The two horizons are separated by a light-tan-colored, massive sandstone varying in thickness but averaging about 20 feet. The horizon of carbonaceous shale, usually occurring in the middle of the Lakota formation, is well developed on Oil Creek and its branches, but it is of variable thickness and composition. It contains some thin coaly layers and has been prospected in places with the hope that it would be found to contain an upper coal horizon. Some typical sections of the Lakota and immediately associated formations are here given, the first being at Cambria in the bore hole of the Antelope mine.

Section of Lakota and associated formations at Cambria, Wyo.

		Feet.
Dakota	Sandstone, thin bedded, at top of table	20
	Sandstone, hard, massive, buff colored	40
Fuson	Shale and talus	20
Lakota	Sandstone, light colored, conglomeratic in part	60
	Talus and sandstone ledges	70
	Sandstone, light gray, soft, fine grained	50
	Coal	7
	Sandstone, hard, light brown	5
	Sandstone, soft dark brown	2
	Sandstone, light gray, moderately hard	1½
	Coal with sandstone, shale, and pebbly layers	½
	Sandstone, dark gray, soft	1
	Coal, shales, and sandstone	2
Morrison	Fire clay, gray	3
	Sandstone, light gray, moderately hard	1½
	Fire clay	7½
	Sandstones, gray, upper half very hard	4
	Shales with some thin sandstones	54+

In the canyon of Little Oil Creek below Cambria there are high walls of Lakota sandstone surmounting a slope of Morrison shale from 40 to 90 feet high, and a capping of Dakota sandstone with its underlying mass of Fuson formation. A section 2 miles above Newcastle is as follows:

Section of canyon of Little Oil Creek below Cambria, Wyo.

		Feet.
Dakota	Sandstone, thin bedded	20
	Sandstone, massive, reddish	30
Fuson	Shales and thin sandstones	15±
Lakota	Sandstones, buff, partly concealed	40±
	Sandstone, massive, nearly white	45
	Shale with coaly layers	6
	Sandstone, gray to brown	20±
Morrison	Shale to bottom	90

The formation passes beneath the surface a short distance north of Newcastle, where the dip rapidly changes from 3° to 22°.

On the east side of the ridge 2 miles south of Cambria the bluff exposes the following section of the Lakota and associated formations:

Section on east side of ridge 2 miles south of Cambria, Wyo.

		Feet.
Dakota	Sandstone, rust colored, thin bedded at top and bottom	33
Fuson	Clay, massive, purple to maroon	17
Lakota	Sandstone, massive, dull gray above, yellowish tan color below	40
	Shale, purplish, partly covered by talus	12
	Sandstone, massive, salmon to brick red	60
	Sandstone, massive, white	8
	Bottom concealed by talus.	

On the west side of the ridge, opposite, there are many scattered outcrops in which the sandstones show considerable local variations in color. At one point a 5-foot coal bed is exposed. The following section sets forth the principal features:

Section on west side of ridge 2 miles south of Cambria, Wyo.

		Feet.
Dakota	Sandstone, light brown, mostly thin bedded	30
Fuson+	Talus	35
Lakota	Sandstone, massive, salmon colored, conglomeratic at base	60
	Talus, on sandstone in part	35
	Sandstone, light gray to buff	35
	Shale, gray	4
	Sandstone, massive, brown	12
	Coal and bone	1½
	Sandstone, massive, brown	2
	Coal, underlain by some sandstone	5
Morrison	Shales.	

On the west side of East Plum Creek, near the northern margin of the quadrangle, is presented a thickness of about 160 feet of massive, light-colored sandstones with local conglomeratic streaks and some intercalations of thinner bedded members about 70 feet above the base. The details of a partly well-exposed section on the west side of East Plum Creek just north of Deford's ranch, 2 miles northwest of Cambria, are as follows:

Section on west side of East Plum Creek 2 miles northwest of Cambria, Wyo.

		Feet.
Dakota	Sandstone, massive, tan colored	20
Dakota ? and Fuson	Sandstones, thin bedded, and shales of various colors	53
Lakota	Concealed	40
	Sandstone, massive, pale pink to buff, conglomeratic at base	15
	Sandstone, light buff, cross bedded, conglomeratic at base.	22
	Unconformity?	
	Sandstones, compact, pale pink to light gray	12
	Sandstone, coarse, conglomeratic, brown	18
	Sandstone, dark buff	24
	Impure coal and coaly shale	6
	Sandstone and shale	3
	Coaly shale and thin coal beds	7
	Sandstone, massive, tan colored	6
	Shale, sandy, light gray	2
	Sandstone, massive, buff	30
	Concealed	15
Morrison	Shale	90+

In the canyon just southwest of Mount Zion ranch the Lakota and associated formations are as shown in the next table.

In Oil Creek and Blacktail canyons the Lakota varies in thickness from 125 to 160 feet. A typical section on the west side of Oil Creek Canyon 1½ miles below the mouth of Plum Creek has the following components, including also the Fuson and Dakota formations:

Section in canyon southwest of Mount Zion ranch, Wyo.

		Feet.
Dakota	Sandstone, massive, light colored	30
Fuson	Sandstone and dark shales	20-30
Lakota	Sandstone, buff and tan colored, conglomeratic streaks	115
	Coal, bony	½
	Sandstone, hard	3
	Coal	4
	Sandstone with carbonaceous streaks	1
	Coal	2
	Sandstone, massive, partly cross bedded, nearly white	40
Morrison	Shales, greenish.	

Section on west side of Oil Creek Canyon 1½ miles below mouth of Plum Creek, Wyo.

		Feet.
Dakota	Sandstone, massive, rust colored.	40
Dakota?	Sandy shale, gray	9
	Sandstone, reddish	2
Fuson (in greater part)	Sandstone, thin bedded, gray	1
	Sandstone, dark pinkish	5
	Sandstone, thin bedded, rust colored, with dark shale layers.	25
	Shale, gray	10
	Sandstone, reddish	2
	Shale, carbonaceous	1
	Concealed	3
	Sandstone, cross bedded, gray	12
	Concealed	15
Lakota	Sandstone, cross bedded, massive, light colored	30
	Sandstone, conglomeratic, light gray	25
	Sandstone and coaly shale	2
	Unconformity?	
	Sandstone, massive, rust colored above, lighter below	19
	Shale and sandstone, gray	20
	Sandstone, massive, reddish tan to salmon colored	30
Morrison	Talus and shales	80

Two miles farther north, above the mouth of Plum Creek, the cliffs on the west side of Oil Creek Canyon exhibit the following section:

Section on west side of Oil Creek Canyon 2 miles above mouth of Plum Creek, Wyo.

		Feet.
Dakota	Sandstone, massive, tan colored.	55
	Sandy shale, gray	3
	Sandstone, thin bedded, rust colored	24
Fuson and Lakota	Concealed	50
Lakota	Sandstone, massive, cross bedded, gray	15
	Sandstone, massive, cross bedded, conglomeratic, tan to salmon colored	36
	Sandstone, thin bedded, rust colored, with some shale	8
	Shale, gray	1
	Sandstone, massive, cross bedded, tan colored	25
	Shale, carbonaceous	½
	Unconformity.	
	Sandstone, thin bedded, gray	6
	Shale, purple	1½
	Sandstone, mas-ive, cross bedded, light gray	24
	Sandstone, massive, cross bedded, rust-red colored	30
Morrison	Shales to Oil Creek	6

Owing to a local flattening of dip a short distance north, the lower sandstone descends to the water level and crosses the valley, but it soon rises again, and near the northern margin of the quadrangle it is over 150 feet above the creek; there, however, its thickness is greatly diminished.

Fuson formation.—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 often red or maroon in color, but are mostly gray and buff. They merge into sandstones that are thin bedded and contain shaly partings in most cases. Possibly in some localities the formation is absent, but in nearly all clear exposures it appears to be separable from the adjoining beds. For much of its course it is hidden by talus derived from the sandstones above. Its thickness varies from 10 or 15 feet to as much as 40 feet in exceptional cases. East of Clifton it often consists of alternations of pink clay and thin-bedded sandstone 30 feet thick. The clearest exposures are in the canyons of Oil, Plum, and Little Oil creeks and along the western slope of the ridge south of Elk Mountain. No fossils were found in the formation in this area, but in the Hay Creek region numerous plant remains of lower Cretaceous age were obtained by W. P. Jenney from his "Division No. 2" of the "Dakota group," which includes the Fuson.

Dakota sandstone.—This formation lies along the lower western slopes of the hogback range, but north of Newcastle it appears to extend far to the north, capping the long sloping plateaus. Its thickness varies from 50 to 100 feet. The most characteristic feature of the formation is a lower member of hard sandstone with massive structure and reddish brown color. The upper member is a series of thinner bedded sandstones. The formation gives rise to tabular surfaces, ending in precipitous cliffs from which the rock of the lower member generally breaks off in great vertical slabs or irregular columns. A very characteristic aspect is shown in fig. 13 of the illustration sheet. In some localities this massive character is lacking, especially in portions of the region north of Newcastle, where the formation is softer or thinner bedded. A most exceptional phase of the formation is exposed in the canyon of Little Oil Creek just above Newcastle, where it is represented by a series of alternating sandstones, mostly thin bedded, and shales of dark color. As the Fuson formation is less distinctive here than usual it is difficult to recognize the precise dividing line between the two formations. In the valleys of the branches of Plum Creek the formation has been extensively eroded, but small outliers remain on the summits of some of the adjoining ridges. Its identity here is in some cases doubtful. In the region north of Newcastle there is a general thinning of the formation to the north and northeast. On the high tables about Cambria the thickness varies from 40 to 60 feet, the massive lower bed appearing in the thicker portions.

Graneros formation.—The lowlands lying next west of the slope of the hogback range are underlain by a thick mass of soft, fine-grained deposits, of the Graneros formation, varying in thickness from 950 to 1100 feet, the greater thickness being in the vicinity of Newcastle and a short distance north. The formation consists mainly of shales of dark gray to black color. It includes, about 175 to 275 feet above the base of the formation, an elongated lens of sandstone, which attains a thickness of 30 to 40 feet in the vicinity of Newcastle. West of Oil Creek this sandstone thins rapidly, and in the vicinity of Osage it finally is lost or becomes inconspicuous among other thin sandstone layers in the formation. In the Whoopup Creek region it has a thickness of 15 to 20 feet and the rocks are spread out by some low flexures in which the Graneros sandstone caps several prominent ridges. To the south, near Clifton, it passes beneath alluvial deposits and does not appear again. The rock is hard and always gives rise to a ridge of greater or less height, which from the LAK ranch to Oil Creek rises in prominent hogbacks just south of the main range of Dakota sandstone, from which it is separated by a line of narrow valleys underlain by the basal black shales. Immediately west of Newcastle this ridge attains a height of 500 feet. In this vicinity the rock contains petroleum, which at several points flows out in natural springs of small volume (for location see economic geology map). A section of the lower members of the Graneros formation at an oil spring 4 miles west of Newcastle is as follows:

Section of lower members of Graneros formation 4 miles west of Newcastle, Wyo.

	Feet.
Sandstone, hard, slabby, shale partings, oil spring	8
Sandy clay, light colored	1½
Shale, very dark	3
Sandstone	1½
Shale, dark	6
Sandstone, slabby, ripple marked, buff	2
Shale, dark, few thin sandstone layers	20
Sandstone, massive, light buff; contains oil	15½
Sandstone	1
Shales, dark, to top of Dakota sandstone	250

Several hundred feet of the lower portion of the Graneros formation were penetrated in two deep borings for oil a short distance south of Newcastle. The following beds were reported in one of these:

Partial section of Graneros formation in Shreve oil well, Newcastle, Wyo.

	Thickness in feet.	Depth of base in feet.
Gravel, sand, and clay	50	50
Shale	150	200
Sand, some oil (?)	15	215
Shale	188	403
Shale, much gas	8	411
Sand with gas	15	426
Shale	204	630
Sand with oil and water, main "oil sand"	10	640
Shale with few layers of sandstone	160	800
Sandstone, much water	20	820
No record	492	1312

This boring is about a half mile southwest of the railroad station and was made several years ago. The main "oil sand" appears to be 630 feet below the surface in this boring, and if so the Dakota sandstone probably was reached at a depth of about 820 feet and furnished the principal flow of water.

In a boring made in 1902 about a quarter of a mile due south of the above the following beds were reported:

Partial section of Graneros formation in Well No. 1, Northern Pacific Oil Company, Newcastle, Wyo.

	Thickness in feet.	Depth of base in feet.
Shale	150	150
Hard sandstone	14	164
Dark shale	239	403
Hard sandstone (concretion)	2	405
Light-colored shale	7	412
Dark shale	52	464
Very hard sandstone (concretion)	2	466
Gray shale	8	474
Very hard, coarse sandstone	14	488
Very hard, fine-grained rock	4	492
Shale	7	499
Sandstone, water and oil, main "oil sand"	32	531
Dark shale	30	561
Sandstone	7	568
Shale and sandstone	5	573
Shale	200+	
Sandstone (Dakota) to bottom		900

The beds in this well are nearly the same as in the first, for the strata rise but slightly to the north. The main "oil sand" at 630 feet in the first well is probably the same as the one at 499 feet in the second well. The precise thickness of the underlying shale below 531 feet was not reported, but it is said that the Dakota sandstone was entered at about 800 feet, which indicates a thickness of about 270 feet.

Near the LAK ranch the sandstone in the Graneros formation is underlain by only 175 feet of shales, but the amount increases somewhat to the south. In the gorge above Newcastle the thickness is 205 feet, not including some doubtful beds of passage into Dakota sandstone.

West of Newcastle the stratigraphy of the sandstone series in the lower part of the Graneros formation is variable, there being frequent changes in the thickness of the sandstone beds and the succession of intercalated shales. A section at the mouth of Oil Creek Canyon shows the following beds:

Section of Graneros formation at mouth of Oil Creek Canyon.

	Feet.
Shale, black	50+
Shales, dark, with thin sandstone layers	67
Sandstone, brick red to maroon	7
Shale, black	8
Sandstones, thin bedded, rust colored	5
Shale, light gray to buff	5
Sandstone, massive, light buff	15

The lower or principal sandstone bed thins gradually from this point northward. In the vicinity of Osage it varies in thickness from a few inches to 6 feet and a still lower sandstone series comes in. In one locality, a mile east of Osage, there are two 10-foot layers of hard, massive sandstone separated by 4 feet of dark sandy shales and overlain by a succession of thin sandstones and sandy shales 17 feet thick capped by the sandstone bed, here 6 feet thick, which extends far southward.

Overlying the sandstone of the lower portion of the Graneros formation are 800 feet of shales, which are mostly black and fissile below and dark gray above. A few feet above the sandstone there is a conspicuous series of hard, light-bluish-gray sandy shales, containing a large number of fish scales. These shales weather nearly white and form a characteristic horizon. Their best exposures are in the railroad cuts 1 to 2 miles west of Newcastle. In the shales lying next above are some thin beds of sandstone and numerous lens-shaped concretions of hard material. At the top of the formation, especially in outcrops northwest of Pedro, there are many large concretions in gray shale lying below the Greenhorn limestone. In the region near Newcastle the upper members include some limy beds constituting beds of passage to the Greenhorn limestone. Owing to many variations in structure along the margin of the Black Hills uplift, the Graneros formation presents considerable diversity in its surface distribution. From the S & G ranch to Clifton it is spread out widely by very low dips and gentle undulations, and this is also the case north of Clifton, where the lower beds have a wide outcrop area, but there the beds above the sandstone dip steeply and occupy a narrow belt extending to the LAK ranch. South of Newcastle there are low dips in the upper beds and they occupy a wide area for a few miles. The outcrop zone narrows rapidly west of Little Oil Creek and for some distance is only a quarter of a mile across. From Pedro to Osage low dips are again found and the outcrop widens correspondingly. The sandstone here caps the low ridge northeast of the railroad. The Graneros shales contain very few fossils except the fish scales above referred to. Some molluscan remains observed in this region and elsewhere are of lower Benton species.

Greenhorn limestone.—Near the center of the Benton group there is a thin but very distinctive series of beds of hard, impure limestone, known as the Greenhorn limestone, which, owing to its hardness, usually gives rise to a prominent ridge or east-facing escarpment lying a few miles west of the hogback range. This feature is most conspicuous north of Pedro, south of Newcastle, and west of the S & G ranch. Between Oil Creek and Little Oil Creek and from the LAK ranch southward to beyond Clifton Siding, where the formation has a steep dip, its presence is marked by a small but prominent ridge, often with a companion ridge just west, due to a bed of hard sandstone in the Carlile formation (see fig. 11 on illustration sheet). The thickness of the Greenhorn limestone averages 50 feet or less, the limits being somewhat indefinite. Beds of passage into the adjoining formations are calcareous shales, but in the center of the Greenhorn limestone there are found 20 to 30 feet of hard, thin-bedded, impure limestone with some shale intercalations. The rock is characterized by vast numbers of impressions of *Inoceramus labiatus*, a fossil which is of infrequent occurrence in other formations of the Benton group (see fig. 12 on illustration sheet). The limestone appears to gain hardness on weathering, for on the hill slopes it breaks up into hard, pale-buff slabs covered with impressions of the distinctive fossil. In other regions the limestone usually is distinctly separated from the black shales of the Graneros formation, but in the Newcastle region there are beds of passage.

Carlile formation.—This formation consists mainly of shales with occasional thin beds of sandstone. Its thickness averages about 700 feet. The outcrop area extends diagonally across the Newcastle quadrangle from northwest to southeast, the beds dipping to the southwest in the northern portion of the quadrangle and almost due west in a narrow zone of outcrops extending south from LAK ranch. In this zone the dips are steep, as they are also between Little Oil Creek and Oil Creek. South of Newcastle the formation is spread out in an area of considerable extent, and northwest of Pedro, where the dips are very low, its outcrop has an average width of 3 miles. The usual order of beds in the Carlile formation is a basal series of dark shales and alternations of gray shales with thin-bedded sandstones, then an extensive series of drab shales, and at the top gray shales containing numerous large concretions. Two typical sections are as follows:

Section of Carlile formation 3 miles west of Newcastle, Wyo.

	Feet.
Niobrara chalk at top.	
Dark shales, with light-colored concretions near top	130
Dark shales	200
Calcareous concretions	3
Sandy shales, with thin sandstones	170
Brown sandstone	4
Dark shales	200
Greenhorn limestone.	

Section of Carlile formation north of Pedro, Wyo.

	Feet.
Niobrara chalk at top.	
Drab shales, with numerous concretions near top	550
Thin-bedded sandstone	5
Shale	30
Sandstone, drab below, reddish above	30
Dark shale	50
Thin-bedded, light-brown sandstone	35
Gray shales	90
Greenhorn limestone.	

The sandstones in the Carlile formation give rise to sharp ridges, and where the beds have steep dips these present a very ragged crest line. This is notably the case for some miles west of Little Oil Creek and in the ridge west of Clifton Siding. At some points west of Newcastle one of the lower sandstones, of light-brown color, has a concretionary structure, which is shown by the development of disks from 2 to 3 feet in diameter, locally termed "cart wheels." The Carlile formation contains fossils, mainly mollusks and fish remains of upper Benton age.

Niobrara formation.—This is the least conspicuous formation in the Newcastle quadrangle, and owing to the softness of the materials the beds are rarely well exposed. In most places it underlies a shallow valley lying at the foot of the slopes of the harder rocks of the Carlile formation. The material is soft, shaly limestone or impure chalk, containing a greater or less admixture of fine sand and clay. Its weathered outcrops have a bright-yellow color which is characteristic, but in unweathered exposures the material is usually light gray in color. The thickness of the formation, including some obscure beds of passage into the adjoining formations, averages about 200 feet, as nearly as could be ascertained. In the Niobrara formation are often found thin beds of hard limestone consisting of an aggregation of shells of *Ostrea congesta*, a fossil very distinctive of the formation when it occurs in this manner (see fig. 12 on illustration sheet).

In the beds of passage at the top of this formation in the vicinity of Pedro are some thin lenticular masses of a peculiar white clay known as bentonite, which has the capacity of absorbing several times its bulk of water and is of considerable commercial value. Its principal exposures are in a very small ridge a half-mile east of Pedro Siding and on the hill slope a mile west of that siding, where it has been excavated for shipment. When dry the clay is massive and moderately hard, breaking with conchoidal fracture, but when moist it is like soft soap in consistency and gives rise to miry "soap holes." Three miles northwest of Osage a similar deposit occurs in the Graneros shale.

Pierre shale.—The wide region of low plains and valleys occupying the central portion of the Newcastle quadrangle is underlain by Pierre shale, a thick mass of dark-colored clay or shale, weathering light brown and relatively uniform in composition throughout. Its outcrop area is a region of low, rounded hills sparsely covered with grass and not very useful for agriculture. The formation is about 1250 feet thick, but it is only rarely that its thickness can be ascertained, and where the dip is gentle it is almost impossible to measure it. At a horizon about 1000 feet above its base it includes scattered lenses of limestone, usually containing numerous shells of *Lucina occidentalis*. Although these lenses also occur sparingly at lower horizons, they are most characteristic of the horizon mentioned, and as they occur at intervals nearly all over the area they throw much light on the structure of the formation. It is from this evidence that the cross sections and the determination of depth to Dakota sandstone have been made in the Pierre shale area. The limestone lenses with *Lucina* vary in size from 2 to 3 cubic feet to masses 20 feet in diameter and 6 or 8 feet thick and usually of irregular lens shape. When these lenses are uncovered by erosion they give rise to low, conical buttes resembling in form a very squat tepee, and they have therefore been designated "tepee" buttes. Their height varies from 20 to 50 feet in most cases. The Pierre beds are usually somewhat steeply tilted along their eastern margin from Pedro to the southern boundary of the quadrangle, but to the west the dips diminish and there are wide areas in which the beds lie nearly level or are traversed by gentle undulations. Numerous concretions appear in the Pierre shales at various horizons and usually contain large numbers of very distinctive fossils, especially in the upper beds. The more abundant are of the following species: *Baculites compressus, Inoceramus sagensis, Nautilus dekayi, Placenticeras placenta, Heteroceras nebrascense*, and an occasional *Lucina occidentalis*. The concretions are generally of small size, of a siliceous nature, and break into small pyramidal fragments which are scattered more or less abundantly all over the shale surfaces.

Fox Hills formation.—West of the wide valley region in which the Pierre formation occurs there rises a low escarpment due to a series of thin beds of hard sandstone which belongs to the Fox Hills formation. There are two or three thin layers of this sandstone, with shaly beds intercalated, and an underlying series of soft, clayey sandstones having a thickness of only 50 feet. The basal members contain abundant distinctive fossils, including at some places large numbers of *Veniella*. There is a conformable transition to Pierre shale through 20 or 30 feet of sandy shales lying near the base of the slope. Farther south, lower sandy beds of the formation often contain large, fairly well-defined concretions due mainly to local increase of lithification. The two following sections (figs. 1 and 2) show some of the distinctive features and the topographic relations.

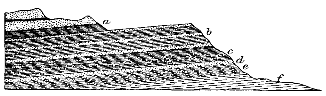


FIG. 1.—Section of escarpment in Fox Hills formation in Weston County southeast of Newcastle, Wyo.

Laramie formation: *a*, sandstones and clays. Fox Hills formation: *b*, sandy shale with thin, hard sandstone beds; *c*, 30 feet of sandy gray shale with soft fossiliferous concretions; *d*, thin layer of ferruginous sand; *e*, lead-colored sandy clay. Pierre shale: *f*, gray fossiliferous shale.

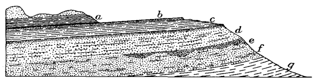


FIG. 2.—Section of escarpment in Fox Hills formation in Weston County west of Clifton Siding, Wyo.

Laramie formation: *a*, shales. Fox Hills formation: *b*, brownish-gray sandstone; *c*, sandy shale; *d*, 35 feet of greenish to gray, soft, thin-bedded sandstone; *e*, very fossiliferous lenses of harder gray sandstone; *f*, 50 feet of massive, soft, pale-greenish-buff sandstone and sandy shale. Pierre shale: *g*, gray clay.

The breadth of the outcrop of the Fox Hills formation is not over a mile in most places and is often considerably less. South of Robbers Roost Creek it widens to 5 miles. The thickness of the formation is from 150 to perhaps 200 feet, increasing southward, but gradually diminishing to the north to 75 feet, the decrease being largely in the lower beds. There is some doubt as to the upper limit of the formation, and there are indications that the line of lithologic change is not a constant horizon throughout; thus it may be that some of the lower members represented as Laramie formation in this region belong to the Fox Hills in other districts.

Laramie formation.—The extreme western and southwestern portions of the Newcastle quadrangle are occupied by the Laramie formation. This consists of soft, massive sandstones intercalated with carbonaceous sandy clays. The thickness is 700 to 800 feet, as nearly as can be ascertained. The beds dip very gently to the west. The region is one of irregular slopes, steep where there are sandstones, gentler where there are shales, and with many detached buttes and hills. The highest of these, known as Alkali Butte, is a prominent landmark from the east, although it rises only about 200 feet above the adjoining rolling hills. The section it exposes is as follows:

Section exposed in Alkali Butte, Weston County, Wyo.

	Feet.
Light-brown sandstone, hard	20
Light-buff, massive sandstone, coarse but soft	50±
Brownish buff, massive sandstone, with a few large, irregular concretions	20
Dark, sandy, and lignitic clays, with thin sandstone partings	60±
Hard, brown sandstone	3
Soft, massive stone	25±
Hard, brown sandstone	2
Light-gray sandstone, with dark-gray, hard sandstone layers and concretions	40±

Below the beds exposed in this butte there is an alternation of several hundred feet of sandstone and carbonaceous shales in beds from 30 to 40 feet thick in greater part. Next above the Fox Hills beds are 80 feet of gray clays overlain by sandstones. The sandstones of the Laramie formation consist mainly of fine-grained, loosely cemented sand of light-buff color, often having a thickness of 40 feet. They contain very characteristic concretions of gray color and great variety of shape. This material is simply the sand locally lithified to increased hardness and slightly darkened. The size of the concretions varies from a few inches to many feet. They are usually elongated, with rounded outlines, but spherical and lens-shaped concretions abound. Some representative forms are shown in fig. 10 of the illustration sheet. The beds of shale which occur interbedded among the sandstones of the Laramie formation are usually of dark-gray color and in places lignitic, but no coal deposits have been found in them in this region.

QUATERNARY SYSTEM.

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

Alluvium.—The principal alluvial deposits are in the wide valleys excavated in the Pierre and Graneros shales, but narrow areas of recent alluvium extend up all the valleys and merge into the general talus and wash on the hill slopes. Only the larger alluvial areas are represented on the map. The most extensive of these are in the valleys of Beaver Creek, Oil Creek and its branches, South Beaver Creek, the lower portion of Blacktail Creek, Stockade Beaver Creek, and the valley extending along the foot of the hogback range from Whoopup Creek to the S & G ranch. Alluvial flats of considerable size also extend up portions of Redbird and Gillette canyons and along Stockade Beaver Creek in the Red Valley. The materials of these deposits are mainly loams and sands, with some admixture of coarser material. Along Oil

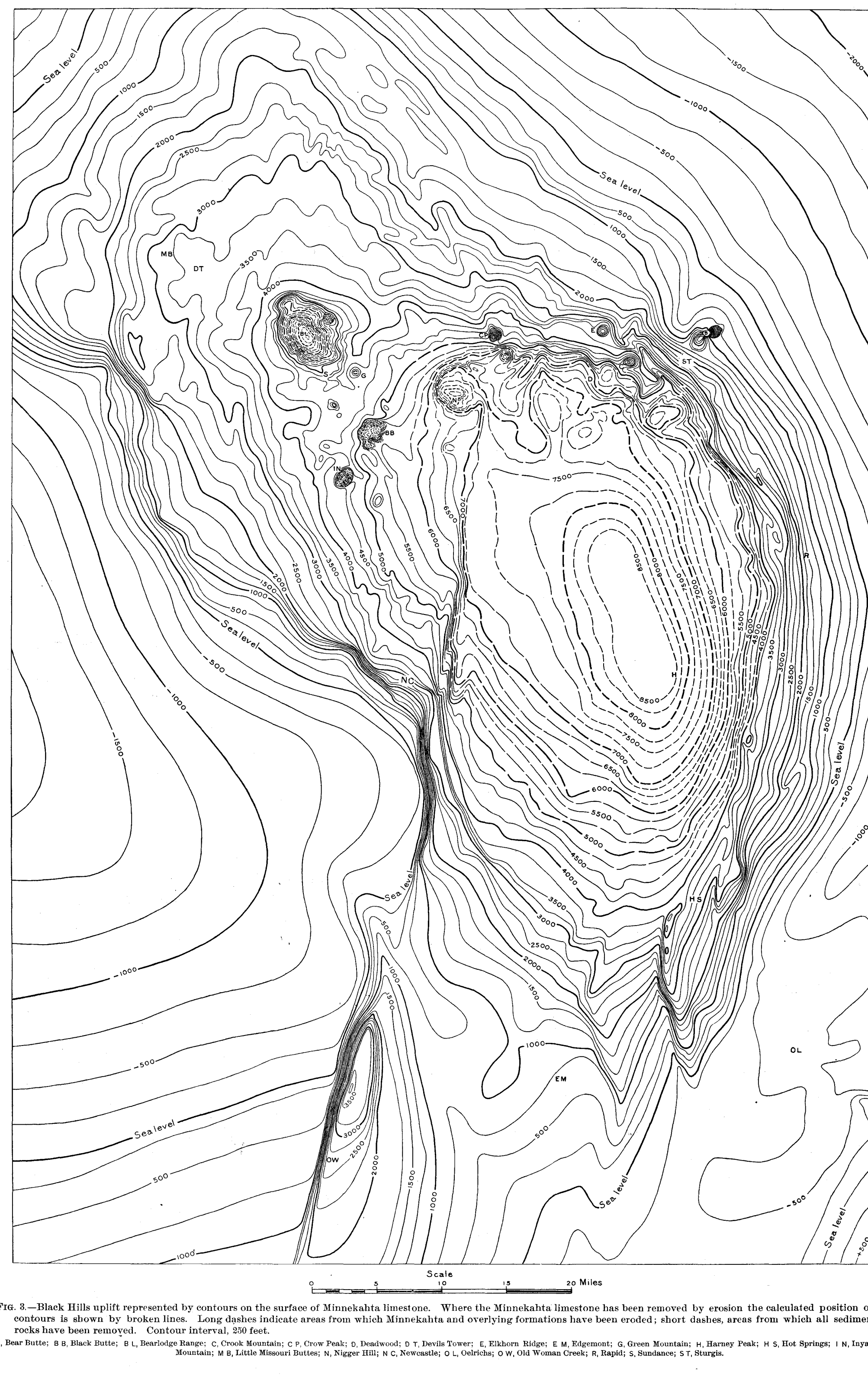


FIG. 3.—Black Hills uplift represented by contours on the surface of Minnekahta limestone. Where the Minnekahta limestone has been removed by erosion the calculated position of the contours is shown by broken lines. Long dashes indicate areas from which Minnekahta and overlying formations have been eroded; short dashes, areas from which all sedimentary rocks have been removed. Contour interval, 250 feet.

B, Bear Butte; BB, Black Butte; BL, Bearlodge Range; C, Crook Mountain; CP, Crow Peak; D, Deadwood; DT, Devils Tower; E, Elkhorn Ridge; EM, Edgemont; G, Green Mountain; H, Harney Peak; HS, Hot Springs; IN, Inyankara Mountain; MB, Little Missouri Buttes; N, Nigger Hill; NC, Newcastle; OL, Oelrichs; OW, Old Woman Creek; R, Rapid; S, Sundance; ST, Sturgis.

Creek there is considerable reddish material of a predominantly sandy character. This owes its reddish color to sediments brought down from the Red Valley, which is drained by Oil Creek north of the northern margin of the Newcastle quadrangle. The deposits along Beaver Creek are mostly the dark clays from the Pierre shale, which it traverses. Their thickness varies from 15 to 20 feet. In many places the creek cuts through the deposit and exposes the underlying Pierre shale, but, owing to the numerous caved banks, it has not been possible to map this feature in detail. Several low knolls of shale rise through alluvium in the valley.

Terrace deposits.—The earlier terrace deposits cap some of the low ridges, mostly in the Pierre and Graneros shale region, and extend on shelves up some of the valleys of the higher lands. They mark the courses of old streams which have since cut to lower levels, and undoubtedly they were much more extensive originally, but with the degradation of the country a large amount of the material has been removed or widely scattered, especially in areas where it was thin. One of the most conspicuous deposits remains in detached outliers capping the deeply dissected ridge which lies between Stockade Beaver and Blacktail creeks. A continuation of probably the same deposit is found on the ridges southeast, south, and west of the S & G ranch, on benches along the foot of the hogback of Dakota sandstone to and beyond Clifton Siding, and at intervals on the ridges south of the LAK ranch. It lies from 150 to 200 feet above the surrounding valleys in greater part, and there are higher portions on the summit of the hogback range west of Whoopup Creek. Other deposits are found on terraces on the sides of the valley of Stockade Beaver Creek north of the LAK ranch. These deposits undoubtedly owe their origin to a predecessor of Stockade Beaver Creek which had a course approximately the same as the present valley. Small gravel deposits are found on the ridges adjoining Skull Creek from southwest of Newcastle north to the northern margin of the quadrangle. They lie from 125 to 150 feet above the creek and evidently represent an earlier period of deposition from the same drainage basin that is now occupied by Skull Creek. Many small outliers of gravel lie on the ridge between Oil Creek and Blacktail Creek, representing a terrace which has been very nearly all removed by erosion.

STRUCTURAL GEOLOGY.

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.

In the northern 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 hills.

Faults are rarely observed; of those seen, not many amount to more than a few feet in vertical displacement, and these are short breaks due to igneous intrusion.

Structure sections.—The sections on the structure-section sheet represent the strata as they would appear in the sides of deep trenches cut across the country. Their position with reference to the map is on the line at 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 but 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 where they are uplifted.

Structure of the Newcastle area.—The Newcastle quadrangle embraces a portion of the southwestern slope of the Black Hills uplift, with rocks dipping more or less steeply to the southwest, and a portion of the Great Plains, in which the beds lie nearly level. There are local irregularities in the monoclinal structures, consisting mainly of variations of strike and pitch and the presence of several low diagonal undulations of the strata. In the northeast corner of the quadrangle there is a portion of the crest of the dome of the general uplift of the Black Hills in which the rocks lie nearly level. Near the State line the dip rapidly steepens and in some localities there are nearly vertical dips. This is notably the case in the steep westward-dipping monocline shown in the exposures of the Minnelusa and Minnekahta formations in the steep slopes northeast of the LAK ranch (see fig. 8 of illustration sheet.) At several points in this portion of the monocline the beds are nearly vertical and the harder sandstone and limestone ledges give rise to a succession of saw-toothed ridges of brilliantly colored beds. This steep-dipping corrugation of the monocline trends south by west and passes into higher and higher beds in succession, being continued nearly to the southern margin of the quadrangle, where it affects the upper members of the Benton group. In the zone of low dips next east there is a downward pitch to the south, which spreads the outcrop area of Minnekahta limestone about Redbird and Gillette canyons, and widens the hogback range at Elk Mountain and for some distance southward. It finally passes out into the Graneros shales, which, near Clifton Siding, are spread out widely under its influence. West of the steep-dipping portion of the monocline above described there is a rapid diminution of inclination of the beds. At the north there is a wide valley of Spearfish formation and a broad zone of Sundance formation with outlying ridges capped by Lakota sandstone. The dips are mainly to the west at low angles and there are several very low corrugations and a general pitch to the south. In the Cambria region the monocline dips very gently southwestward and the hard sandstones of the Lakota and Dakota formations are spread out into a wide, sloping plateau deeply dissected by canyons. The change of dip from west to southwest takes place gradually in the latitude of Cambria, but farther south, in the vicinity of the LAK ranch, there is a very sudden change in direction, marked by an almost right-angle bend in the strike about the LAK ranch. South of Newcastle there is a broad area of relatively low dips, west of which for some distance the Graneros to lower Pierre beds dip at a steep angle. The dips are to the southwest and are steepest between Oil Creek and Little Oil Creek. They diminish in steepness toward Pedro and to the northwest they are low. In the center of the quadrangle, in the Pierre shale region, the steep inclinations west of Newcastle and south of the LAK ranch rapidly diminish and there is a broad area of almost horizontal leds traversed by a few very low undulations. West of Beaver Creek there is a general low dip to the west-southwest which continues to the margin of the quadrangle. The maximum dips observed in this region are less than 3 degrees.

No faults of any appreciable amount are found in the area of the Newcastle quadrangle. Occasional small slips are exposed, but no notable dislocations. There have been many landslides along cliffs of the Lakota sandstone where the soft underlying shale is inadequate to sustain the heavy masses of overlying rock. Joint planes extensively developed in the Dakota sandstone trend nearly due northeast in most cases observed.

MINERAL RESOURCES.

SOILS.

Derivation.—The soils in this region are closely related to the underlying rocks, of which they are residual products due to 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; if they are composed of relatively pure clay, a very clayey soil is the product. The character of the soil 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, such, for instance, as shales and sandstones alternating with limestone. These give abrupt transitions in the character of their disintegration products, soils which differ widely in composition and agricultural capabilities occurring side by side. The only areas in which the boundaries between different varieties of soil do not coincide with the boundaries of the rock formation are in the river bottoms, in the sand dunes, in the areas of high-level gravels, in the smaller valleys, and upon 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 Newcastle quadrangle are underlain mainly by shale and alluvium. The Pierre shale covers the most extensive area, and as it consists mostly of clay its disintegration gives rise to a stiff gumbo, which is not only very barren in itself but is acidic from decomposing pyrites and too sticky for agricultural use. It is covered with grass, which originally afforded excellent pasturage, but in some areas it has been grazed down by excessive herding. As the soil is not rich and the climate is semiarid, the grass grows slowly, and after close grazing requires some time to regain its former growth.

In almost all the wide valleys in the Pierre shale region there are alluvial deposits, which are usually fertile. Along main Beaver, Stockade Beaver, South Beaver, Skull, and Oil creeks these deposits are wide and would be well suited for agriculture if they could be irrigated. Along the main Beaver Valley above the mouth of Oil Creek the deposits contain so much clay that their soil is in places a gumbo. In the valley of Oil Creek there is a reddish, sandy loam of moderate fertility. The soils of the formations of the Benton group are mostly thin and poor. The Niobrara formation from Pedro west and north underlies a narrow valley the soils of which are somewhat more fertile than those of the surrounding areas owing to the calcareous nature of the formation, but in the Beaver Valley the formation is mostly covered by alluvium. The hogback range of Lakota and Dakota sandstones has a thin, sandy soil which supports more or less forest growth. It has been tilled in the vicinity of Mount Zion ranch, where there are several large fields under cultivation. The Sundance formation outcrops in a wide area along Salt Creek Valley, and the soil would be mostly fertile if the climatic conditions were not so arid. The red, sandy clays of the Spearfish formation produce a relatively barren soil, but along Stockade Beaver Creek in the Red Valley there is a series of alluvial flats which have been irrigated and produce excellent crops. In fact it is in this valley, from the LAK ranch northward for 8 or 9 miles, that the principal farms of the quadrangle lie. The soils are rich and there is a good supply of creek water for irrigation. The Minnekahta limestone presents rocky slopes with thin soils, supporting a growth of bushes and cedars. The Minnelusa sandstone, which occupies the northeast corner of the quadrangle, has considerable soil on the gentler slopes and the higher plateau surfaces, which sustains an extensive forest of pines and other trees, with grass in the more open spaces.

The region occupied by the Fox Hills and Laramie formations is in greater part sandy, barren, and dry. There are some narrow strips of loamy soils derived from the sandy shales in the Laramie formation, but they are mainly on the higher land and entirely too dry for agriculture. Along the larger valleys in this region there are occasional flats of considerable width which yield an excellent growth of hay and which, by irrigation, could in some cases be made to produce other crops. The Laramie formation usually supports an excellent growth of grass, and in some districts there are wide areas of good grazing grounds.

WATER SUPPLY.

SURFACE WATERS.

The average annual rainfall of the region about Newcastle, as nearly as can be ascertained, is about 15 inches, the amount being considerably greater in the high lands east of Stockade Beaver Creek. A portion of the precipitation is in the form of snow, and the remainder falls mostly in heavy showers of short duration during the spring and early summer months. As most of the surface of the country has a very thin soil and only limited areas present porous rocks, the water of rains and melting snow runs off rapidly, usually in freshets that follow storms or the melting of snow, the latter often melting very rapidly during the sudden warm spells in spring. In consequence of these conditions there is but little running water in the region during the greater part of the year. Springs are rare and of small volume in the lower lands. A large amount of the run-off in this region could be saved by dams and made available for irrigation. There are suitable dam sites at many localities, especially along the slopes of the Black Hills. One dam southwest of Clifton Siding holds a large volume of water, as shown in fig. 11 of the illustration sheet. It was built in a small valley, across a narrow gap due to vertical beds of hard Greenhorn limestone and Carlile sandstone.

Stockade Beaver Creek.—This fine stream rises in ravines heading in the Minnelusa sandstone and Pahasapa limestone in the northeast corner of Weston County, Wyo., and carries a large volume of water to the main Beaver Creek, into which it empties in the southeast corner of the county. It receives water from a number of springs in the Minnekahta limestone east of Newcastle, one of the most prominent of which lies a short distance west of the foot of Fannie Peak. Another source of water is Salt Creek, which brings a small volume of saline water from the springs northeast of Cambria. Portions of the valley contain flats suitable for moderately extensive agriculture by irrigation, and several small ditches are now in operation east of Newcastle, notably one for irrigating the extensive alfalfa fields of the LAK ranch. Stockade Beaver Creek receives the drainage of the western slope of Elk Mountain and of a wide area of the western portion of the limestone plateau and slopes in the northwest corner of Custer County and the southwest corner of Pennington County. Two of the most extensive drainage basins empty through Redbird and Gillette canyons, but the waters of these rarely reach the main creek. Redbird Canyon has at its head two branches—Antelope Spring and Preacher Spring—which yield small flows of water that sink in a short distance. This also is the case with Buck Spring and some minor seeps of the adjoining limestone area. Nearly all the springs of this series and others at the head of Stockade Beaver Creek are near the contact of the Minnelusa sandstone and Pahasapa limestone, where there are porous, water-bearing beds.

Beaver Creek.—This stream occupies the valley lying between the western slope of the Black Hills and the escarpment of Fox Hills sandstone in the southeastern portion of Weston County, Wyo. The origin of its water is difficult to determine, but west of Newcastle it has considerable volume, which flows more or less continuously to its junction with Stockade Beaver Creek. The combined waters of the two streams flow into Cheyenne River in the northwest corner of Fall River County, constituting the principal volume of water to Edgemont. The main Beaver Creek receives several branches that probably carry more or less water as underflow. Those heading in the Fox Hills and Laramie regions to the west are dry at the surface. Oil Creek and its two branches, Skull Creek and Little Oil Creek, contain running water in the canyons north and northeast of Newcastle, but in dry weather their waters do not flow to the main Beaver Creek. The waters of Oil Creek are used for irrigation west of Newcastle, just north of the railroad. The valley of Beaver Creek is wide and contains some land that could be irrigated, but no attempts have yet been made to utilize it.

UNDERGROUND WATERS.

Throughout this quadrangle there are prospects of water supplies from wells of greater or less depth. The succession of formations, as is shown in the columnar section, includes several beds of water-bearing sandstone, which receive water supplies at the surface in the higher ridges and slopes of the Black Hills. These sandstones are carried underground in the general outward dip on the flanks of the hills, and, owing to the relative steepness of this dip, soon attain considerable depth. In most parts of the quadrangle the inclination of the strata diminishes away from the Black Hills, and there is a wide area of the surrounding country under which the water-bearing beds lie at a depth that is within reach of the well borer. As the region is semiarid, with surface waters often containing much "alkali," at most places there is great need of underground water. The principal water-bearing horizons all rise above the surface on the slopes of the Black Hills in regular succession, as described on a previous page. They outcrop in wide zones encircling the hills, and receive a large amount of water, not only from the rainfall on their surface, but from the streams which at many points sink into them in whole or in part in crossing their outcrops. The sinking of streams in this manner is to be observed in almost every valley leading out of the central rock area. Few of the streams carry more than a small portion of the total original run-off of their watersheds into Cheyenne River, as much of it sinks underground in crossing the sandstones, particularly those of the Minnelusa, Lakota, and Dakota formations. The waters thus trapped by the sandstone pass far beneath the surface, as the water-bearing beds descend on the slopes of the Black Hills uplift.

Dakota-Lakota sandstones.—The Dakota and Lakota sandstones are the principal formations in which water supplies are to be expected in the plains portion of the Newcastle quadrangle. They pass beneath the overlying shales with dips varying considerably in amount (see cross-section sheet), but which finally carry them far below the surface. In a zone of greater or less width adjoining the hills their depth is less than 1000 feet, and they afford an important source of water supply. They have been tested by a number of wells and found to contain water which rises to the surface and overflows in moderate volume. These wells are at Argentine, the next railroad siding south of the S & G ranch; at Clifton; north of Clifton; at Newcastle; and at Jerome, a siding 7 miles north of Osage. The horizon is the same as that which yields a vast volume of water to the numerous wells in eastern South Dakota and in Nebraska. In the Newcastle quadrangle and vicinity the water varies greatly in quality, in some localities being too highly mineralized for use. At Clifton water of good quality is obtained from a well 300 feet deep sunk into the Lakota sandstone a few rods west of the Dakota sandstone ledges. The Argentine well is 550 feet deep and has a moderately large flow of water containing 56 grains of mineral matter per gallon, mostly sulphate of soda. A flowing well 4 miles north of Clifton Siding, at the side of the railroad, just south of Whoopup Creek, yields water too highly mineralized to be of any use. Its depth is 1002 feet, and there are flows at 72, 210, 490, and 925 feet. Its present flow is less than a half gallon a minute and the pressure is very low. Its log as reported by the well drillers is given in fig. 4.

The upper 20-foot sandstone, which contains water, appears to be in the lower part of the Graneros shales, which outcrop in the small ridge east of the well. The Dakota sandstone extends from 200 to 255 feet and yielded the flow at 210 feet. The Fuson formation appears to extend from 255 to 270 feet, or possibly lower, and then there are several hundred feet of Lakota sandstone, with some shale in its upper portion, extending to a depth of 537 feet or possibly lower. It yielded the flow at 490 feet. The limits of the Morrison and Sundance beds are not clearly indicated by the report of the borings, the sand rocks reported at 582 and 652 feet probably being sandy portions of the Morrison formation. The 120 feet of so-called red

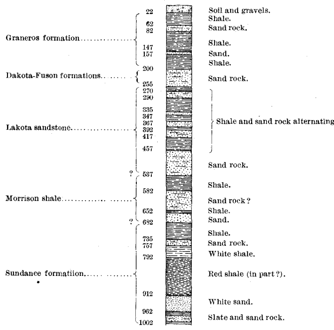


FIG. 4.—Log of artesian well at Whoopup, 4 miles north of Clifton Siding, Wyo.

beds reported to extend from 792 to 912 feet probably are in part the usual red member of the upper part of the Sundance formation, but also include some of the adjoining shales which are not red. The white sand and sand rock from 912 feet down, which yields a flow at 925 feet, is probably the sandstone near the bottom of the Sundance formation. There is another flowing well a mile and a half farther north, which yields a supply of very saline ferruginous water. Its depth could not be ascertained.

In the various borings which have been made for oil about Newcastle more or less water has been found in the Dakota-Lakota sandstone. Two miles west of the town there is a boring said to be 1950 feet deep, sunk for oil. Unfortunately a complete record could not be obtained. The oil sand, 40 feet thick, was found at a depth of 95 feet, under shales. At 600 feet a flow of water was found, apparently in the lower part of the Lakota sandstone, which is still running in good volume, but the water is too highly mineralized to be of use.

A boring a half mile southwest of Newcastle, also sunk for oil, has a depth of 1340 feet, or 1312 feet according to another account; its record is given on page 5. A small flow of water which was found at a depth of 820 feet is probably from the top of the Dakota sandstone; it is mixed with oil from the oil sand at 630 feet. In another well, sunk in 1902, a mile and a half southwest of the town, a large supply of water was found at 650 feet.

There is a flowing well at Jerome Siding, on the Burlington and Missouri River Railroad, 7 miles north of Osage Siding, just outside of the Newcastle quadrangle. It indicates a continuation of the artesian conditions northward from Newcastle in the lowlands bordering the western slopes of the Black Hills. The depth of the Jerome well is 520 feet. It begins in Graneros shales and extends into Lakota sandstone. The railroad company has kindly furnished the following analysis:

Analysis of artesian water from Jerome, Wyo.

	Grains per gallon.
Sodium chloride	0.7
Sodium sulphate	29.8
Magnesium sulphate	7.0
Lime sulphate	2.3
Magnesium carbonate	.5

Morrison, Sundance, and Spearfish formations.—The great succession of shales lying below the Lakota sandstone appears to contain no water supplies either at the surface or for deep wells. They have been tested by a number of borings for oil and yielded no water. Their aggregate thickness is 1000 feet.

Minnekahta and Opeche formations.—The Minnekahta limestone is too dense to carry water, and although in some places it is cavernous, it appears not to be a water-bearing formation. The underlying Opeche red sandstones are also barren of water.

Minnelusa formation.—In its outcrops the Minnelusa formation appears to consist of very porous sandstone, likely to imbibe much surface water and to constitute a water-bearing horizon available in deep wells, and a number of small springs emerge from the top beds of the formation at several localities, notably at a point 4 miles north of the LAK ranch, but when the formation was penetrated by the deep boring at Cambria it was found to consist of very fine-textured rock, the sand grains being so closely cemented by lime that the interstices are filled up. Accordingly it is probable that this formation will yield no water supply to deep boring anywhere in the Newcastle quadrangle, for there is no likelihood that its character changes materially in other portions of the region.

Pahasapa limestone.—The deep boring at Cambria was begun just below the base of the Lakota sandstone and continued to a depth of 2345 feet for the purpose of testing all the formations down to the granite, which, it was expected, would be found not far below 2500 feet. When the boring was at 2345 feet the owners concluded to test a water supply found at about 2115 feet, before going farther. The water at that depth was found to yield 200 gallons a minute and its quality was entirely satisfactory, so that it has been adequate for the needs of the town. The log of the boring is given in the following figure:

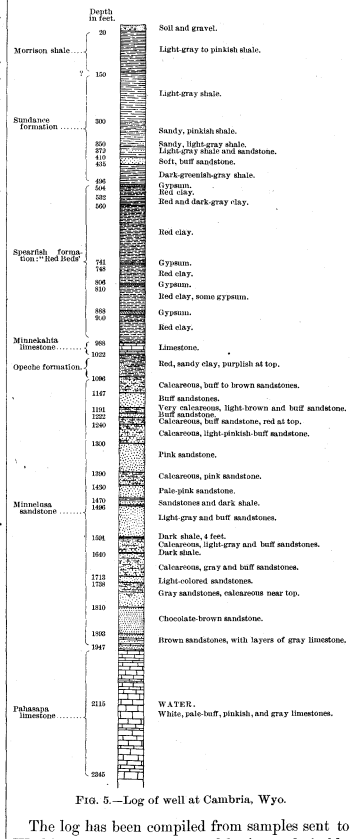


FIG. 5.—Log of well at Cambria, Wyo.

The log has been compiled from samples sent to Washington and from a set of borings admirably preserved in glass tubes by Mr. Mouck, the superintendent of the Cambria mines. It throws very important light on the underground geology of this portion of the Black Hills region. It reached the base of the Sundance formation at 496 feet, passed through the distinctive gypsiferous red deposits of the Spearfish formation from 496 to 988 feet and then through the 40 feet of Minnekahta limestone below. Next came 74 feet of Opeche formation, extending to 1096 feet, as nearly as could be ascertained, and then a great thickness of Minnelusa sandstone, mainly calcareous, extending to 1947 feet. The lowest beds are light-colored, nearly pure limestones of the Pahasapa formation. The water-bearing horizon may be the same as the one which yields numerous springs, often of large volume, at the contact of the Pahasapa limestone and the Minnelusa formation in the outcrop region east, apparently rising through fissures and caverns in the limestone. If so, the Cambria well indicates an extention of a water-bearing horizon far underground and its availability under a large area of the country on the slope of the Black Hills. On the artesian water sheet of this folio there is represented the depth to this horizon in the region lying east of the hogback range of Lakota sandstone. Farther west it lies too deep to be available for ordinary wells. In the town of Newcastle, for instance, it should be expected at a depth of about 2740 feet.

Deadwood sandstone.—Below the Pahasapa limestone lies a series of shales and sandstones which probably contain a water supply. It lies below about 600 feet of Pahasapa limestone, has a thickness of probably 200 feet, and is underlain by schists and granite. The Deadwood formation is too far beneath the surface in this quadrangle to be reached by ordinary boring operations.

COAL.

In the vicinity of Cambria, north of Newcastle, there is a coal basin of considerable extent, the principal coal bed in which is 7 feet or more in thickness and of excellent quality. Coal has been mined at Cambria for the last decade, and during this time nearly 4,000,000 tons have been produced, having an average shipping value of about $1.50 per ton. The product for 1889 was over a half million tons, valued at over $800,000. A portion of the product is converted into coke, which is shipped to smelting works in the northern Black Hills.

The mines are at Cambria, 6½ miles north of Newcastle, where a settlement of about 500 inhabitants owes its existence and sustenance to the mining and coking operations (see fig. 7 of illustration sheet). It is connected with Newcastle by a branch line from the Burlington and Missouri River Railroad. The distribution of coal and the structural relations of this region are shown by the economic geology map of this folio. It will be seen that the coal underlies all of the plateau on the west side of Salt Creek, but the coal measures have been cut through by Little Oil Creek, Oil Creek, Plum Creek, and their branches. To the south and west they dip below the surface, and pass beneath a thick mass of overlying sandstone and shale. The structure is shown in the cross sections. The coal in this area varies greatly in thickness and purity, but, as shown on the map, there is a large area in which it is 5 feet thick or more, and in places it reaches a thickness of over 7 feet. In adjoining areas its thickness rapidly diminishes and the coal becomes extremely impure, in greater part giving place to dark carbonaceous shales. The principal basin of purer, thicker coal trends northeast and southwest, its center passing through Cambria. To the northeast it has been entirely eroded away by Salt Creek, and, although some Lakota sandstone remains on the high ridges east of the valley of that stream, it appears not to be underlain by coal. To the southwest the coal dips gently downward, lying from 250 to 325 feet below the surface of the table, to the Mount Zion ranch, beyond which an abrupt increase in dip carries it rapidly below the surface. In the canyon a few rods southwest of Mount Zion ranch, the following section was measured:

Section near Mount Zion ranch, Wyo.

	Feet.
Bony coal	½
Hard sandstone	3
Good coal	4
Sandstone with coaly streaks	½ to 1½
Coal	2

This section is 150 feet below the top of the plateau. The overlying formations are sandstone and conglomerate. Underneath there are 40 feet of very light-colored, massive sandstones, in part cross bedded, lying on the Morrison shale. A mile northeast of this locality two shafts were sunk in

Section in Camp Canyon, Wyo.

	Feet.
Coal	2½ to 3
Shale and bone	1½
Coal	6

which the coal was found at depths of 312 and 324 feet, exhibiting a thickness of from 5½ to 6½ feet. A mile farther northeast are the mines of which the workings to the year 1902 occupy the area indicated on the economic geology map. In the mines the thickness of the coal averages from 6 to 7 feet over a wide area. In Camp Canyon, northwest of Cambria, a trial pit exhibited the section last given.

There are three mines—the Jumbo, lying east of Cambria; Antelope No. 1, between Cambria and Camp Canyon; and Antelope No. 2, between Camp Canyon and Grant Canyon. The two Antelope mines are connected by a continuous main gallery leading out to a breaker on the west side of the valley at Cambria, while the Jumbo mine is worked from the main drift opening on the east side of that valley. The dip is gentle to the southwest, so that the drainage of the mines is easily effected, the workings being 50 to 60 feet above the valleys which were cut across the coal horizon.

A coal bed averaging 6 feet in thickness contains about 3,000,000 tons of coal per mile, but there is considerable loss in working. There are now in the Cambria coal field about 10 square miles underlain by coal that would average 5 feet or more in thickness, so situated that it is available for working, which on this estimate would yield a total tonnage of 30,000,000 tons.

PETROLEUM.

In the vicinity of the town of Newcastle explorations to develop an oil field have been in progress for several years. Small supplies of excellent petroleum have been obtained from borings and from two oil springs. The oil is very heavy and even in its crude state is a high-grade lubricant. It occurs in a sandstone in the lower portion of the Graneros formation, which is extensively developed in the vicinity of Newcastle. This sandstone lies 250 to 275 feet above the Dakota sandstone, from which it is separated by the basal black shales of the formation. The Graneros sandstone here varies in thickness from 10 to 30 feet in greater part, and its surface outcrops give rise to ridges of considerable height. The first line of ridges lying west-northwest of Newcastle owes its prominence to the locally increased thickness and hardness of this sandstone. Where the rock has been exposed to the weather it is hard, moderately fine-grained, light-gray sandstone in massive beds. As it passes below the surface it is softer in texture, buff or brown in color, and usually strongly charged with petroleum. At two localities the oil oozes out of the sandstone and collects in springs, which for many years have yielded a small supply of oil for local use. One of these springs is $2\frac{1}{4}$ miles due west of Newcastle, just north of the railroad, and the other is 2 miles farther northwest and slightly farther north of the railroad. At these points the oil-bearing sandstone passes beneath the surface in small valleys, and the escaping oil accumulates in the loose materials adjacent. Cisterns have been constructed in such manner as to catch the oil—a few gallons a week—which finds ready sale as a lubricant. Several attempts have been made to develop the oil sand in its extension underground by means of wells in the region west and southwest of Newcastle, but so far these operations have not yielded a large supply of oil. In most cases the oil horizon has been passed through and the boring uselessly extended far into the underlying shales and sandstones. As the sandstone appears to contain considerable oil in the vicinity of the oil springs, and as it underlies a wide area about Newcastle, it is difficult to understand why the wells have not obtained more encouraging results. From the statements made by the promoters of the enterprise, it seems probable that the oil sand was not always recognized in the boring operations, and, at any rate in most cases, was not adequately tested. The oil is very viscid and should hardly be expected to flow from wells at any point in the area, but possibly by dynamiting and pumping a supply can be obtained.

The sections in fig. 6 show the conditions under which the oil sand passes underground, the thickness and nature of the overlying materials, and the location of some of the wells which have been bored. These formations are relatively uniform in thickness and invariably lie in regular sequence. In surface exposures they are all distinctive in appearance, particularly the bed of Greenhorn limestone which lies 800 feet above the oil sand, the thin sandstone layers 300 feet higher, and the Niobrara chalk which begins about 1500 feet above. The distinctive fossils of the Greenhorn limestone and the Niobrara chalk are shown in fig. 12 of the illustration sheet. In sections 1 and 2 of fig. 6 may be seen the manner in which the formations dip steeply beneath the surface in the vicinity of the railroad, so that to the southeast the oil sand lies under 2500 feet or more of shales. On approaching Newcastle, as shown in sections 3 and 4, the dips diminish rapidly and there is a basin of considerable size in which the formations are spread out widely. The deepest boring in the region, the one shown in section 3, has a depth of 1950 feet. It passed through the oil sand at a depth of about 100 feet and then penetrated the basal Graneros shales, the Dakota and Lakota sandstones, and the underlying Morrison, Sundance, and upper Spearfish beds. From the Lakota sandstone it obtained a flow of water which is still running out of the well. Only a small amount of oil was reported. The well half a mile southwest of Newcastle, 1340 feet deep, penetrated the oil sand at a depth of 630 feet, and a small amount of oil brought up by the water from the underlying sandstones is still flowing out of the casing. The 420-foot well, a short distance northwest of the 1340-foot well, is said to have just reached the top of the oil sand, where a promising showing of oil was observed. The 720-foot well, $3\frac{1}{2}$ miles southwest of Newcastle, as shown by section 2, was entirely in shale and failed to reach the oil-bearing sandstone by about 2000 feet. It is greatly to be regretted that this boring was not continued sufficiently deep to test the contents of the oil sand, where it lies deeply buried and so far from surface outcrop as to permit the accumulation of considerable head if there is any oil present. In the vicinity of section 1, three deep borings have been made in the steep-dipping beds near the outcrop of the sandstone, but the results so far have not been successful, although the borings are midway between the two oil springs described on a preceding page. A well nearly a mile south of Newcastle was completed in 1902, but found only a very small supply of oil in the oil sand at a depth of 499 to 531 feet. It was drilled to 900 feet, passing into the Dakota sandstone and, as was to be expected, obtained no oil from that formation. Another well, a mile west of the last, was sunk to a depth of 879 feet but although it obtained a large flow of water, it disclosed no indications of an oil supply. The prospects of the Newcastle oil field as an oil producer appear not to be good, but it is believed that the capabilities of the oil-bearing sand have not been adequately tested and further exploration may be warranted. The oil-sand horizon extends southward nearly to Clifton and is over 30 feet thick near the LAK ranch. To the north it thins out near Skull Creek. Whether it contains oil away from the immediate vicinity of Newcastle remains to be ascertained by borings.

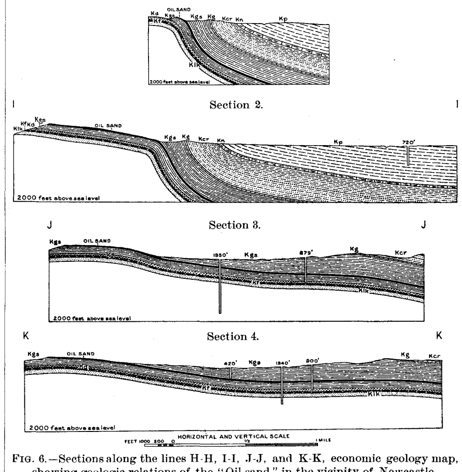


FIG. 6.—Sections along the lines H-H, I-I, J-J, and K-K, economic geology map, showing geologic relations of the "Oil sand" in the vicinity of Newcastle.

Kp, Pierre shale; Kn, Niobrara formation; Kcr, Carlile formation; Kg, Greenhorn limestone; Kgs, Graneros formation containing the "Oil sand;" Kd, Dakota sandstone, Kf, Fuson formation; Klk, Lakota sandstone. The numbers show depths of wells.

GYPSUM.

The Spearfish red shales carry deposits of gypsum—a hydrous sulphate of lime—throughout their extent, and often the mineral occurs in very thick beds. These are relatively pure, and if nearer to good markets the deposits would be valuable. The only commercial operations so far have been at Hot Springs and Sturgis, on the opposite side of the Black Hills, where progress has been greatly handicapped by the expense of taking the product to market. When gypsum is calcined at a moderate heat to drive off the greater portion of the chemically combined water, and then ground, the product is plaster of Paris. The preceeding analysis indicates the character of a typical gypsum from the Black Hills. It was made by Mr. Steiger in the laboratory of the United States Geological Survey.

Analysis of gypsum from near Hot Springs, S. Dak.

	Per cent.
Lime (CaO)	32.44
Magnesia (MgO)	.33
Alumina (Al_2O_3)	.12
Silica (SiO_2)	.10
Sulphuric acid (SO_3)	45.45
Carbonic acid (CO_2)	.85
Water (H_2O)	20.80
Total	100.09

The most extensive exposures of gypsum are a short distance northeast of the LAK ranch, in the middle of the formation, and in the valley 2 miles southeast of Mount Pisgah, not far above the basal beds. East of Newcastle a bed, beginning at the top of the formation, gradually thickens to the north and attains a thickness of 25 feet northeast of Cambria. Gypsum beds underlie part of the alluvium in the valley of Stockade Beaver Creek for several miles north of the LAK ranch.

SALT.

At the head of Salt Creek salt water issues in large volume from the red shales of the Spearfish formation, giving rise to a creek that flows for many miles and finally empties into Stockade Beaver Creek. For a number of years the water has been evaporated for the purpose of obtaining salt for local use. It is probable that the output could be increased and a moderate amount of salt of good quality obtained for shipment. An analysis of the brine, made in the laboratory of the United States Geological Survey by Mr. Steiger, gave the following results:

Analysis of brine from salt springs on Salt Creek, Wyo.

	Per cent.
Lime	0.20
Magnesia	.04
Soda	2.73
SO_3	.36
Chlorine	3.15
Bromine	None
Iodine	None
	6.48
Less O—Cl	0.71
	5.77

This is equal to a little more than 5 per cent of sodium chloride or common salt. The flow from the spring is about a gallon per second, which is equivalent to a production of about 35,000 pounds of salt every twenty-four hours.

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, having 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-quarters of a mile east of Pedro switch, a mile west of that place, and at a point $3\frac{1}{2}$ miles northwest of Osage on the east side of the railroad track. The material is a light-gray, fine-textured, soft, massive clay, but locally it outcrops as a light, powdered substance resembling white corn meal, in beds lying between thin layers of reddish brown concretionary material. Near Pedro a deposit 12 feet thick is found in the steep-dipping transition beds at the top of the Niobrara formation. Near Osage there is a bed about 4 feet thick occurring 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 as a soap filler and also in the manufacture of soap, but it has proved most valuable as a packing for a special kind of horse shoe, 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

BUILDING STONE.

In the Black Hills there are abundant materials for building, but hard rocks are scarce in the adjoining plains. In the Newcastle quadrangle there is a considerable variety of rocks suitable for building, but most of them are not sufficiently attractive for shipment to market. The Pahasapa limestone is in part a light-colored, tough rock, easily dressed and of pleasing appearance. It is durable and does not stain on weathering, although in time it assumes a bluish tint. Sandstones in the Minnelusa formation are of various colors—buff, nearly pure white, pink, brown, and gray—and material of this sort is available in many places in the northeastern portion of the area. Some of the pink and gray sandstones are sufficiently compact to be satisfactory in point of durability, and their appearance is good. The Spearfish formation has a beautiful red color, but the rocks are all too soft for use as building stone. The buff sandstone in the Sundance formation is sometimes moderately compact and easy to dress. It has been used to some extent locally for building in the Salt Creek Valley. The Lakota and Dakota sandstones are mostly of a dirty color on the surface, but some of the unweathered materials are hard, white, gray, or buff sandstones which are durable, easily worked and very satisfactory for local use. In the Plains west of the Black Hills the principal rocks are the limestone in the tepee buttes, some of the sandstones in the Fox Hills formation, and the concretions in the Laramie sandstones. These are suited only for local use.

LIMESTONE.

Limestone for lime or other purposes may be obtained in abundance from the Pahasapa and Minnekahta formations. The Greenhorn limestone and the rock of the tepee buttes can also be used for burning into lime, although the product is an inferior one.

February, 1903.

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

TOPOGRAPHY

WYOMING–SOUTH DAKOTA
NEWCASTLE QUADRANGLE

E.M. Douglas, Geographer in charge.
Triangulation by Frank Tweedy and R.H. Chapman.
Topography by W.H. Herron.
Surveyed in 1899.

APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{125000}$

Contour interval 50 feet.
Datum is mean sea level.

DIAGRAM OF TOWNSHIP

Edition of June 1903.

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

AREAL GEOLOGY

WYOMING–SOUTH DAKOTA
NEWCASTLE QUADRANGLE

E.M. Douglas, Geographer in charge.
Triangulation by Frank Tweedy and R.H. Chapman.
Topography by W.H. Herron.
Surveyed in 1899.

APPROXIMATE MEAN DECLINATION 1902. (TRUE NORTH, MAGNETIC NORTH, 15°)

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 Sept. 1903.

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

Geology by N.H. Darton.
Assisted by C.A. Fisher.
Surveyed 1899-1901.

LEGEND

SEDIMENTARY ROCKS

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

QUATERNARY

Recent

- Qal — Alluvium *(only the larger deposits represented)*
- Qt — Older terrace deposits *(gravel and loam)*

CRETACEOUS

Upper Cretaceous series

- Kl — Laramie formation *(sandstone and carbonaceous shale)*
- Kfh — Fox Hills formation *(sandstone and sandy shale)*
- Kp — Pierre shale *(dark-gray shale or clay with concretions)*
- Limestone lentils in Pierre shale *(form "Tepee buttes")*
- Kn — Niobrara formation *(limy shale and impure chalk)*

Benton group

- Kcr — Carlile formation *(gray shale and thin sandstone)*
- Kg — Greenhorn limestone *(impure slabby limestone)*
- Kgs — Graneros formation exclusive of sandstone lentil *(dark fissile shale containing an extensive sandstone lentil)*
- Ks — Sandstone lentil in Graneros formation

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

Lower Cretaceous series

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

JURASSIC

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

TRIASSIC ?

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

CARBONIFEROUS

Permian series ?

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

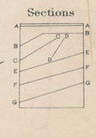
Pennsylvanian ?

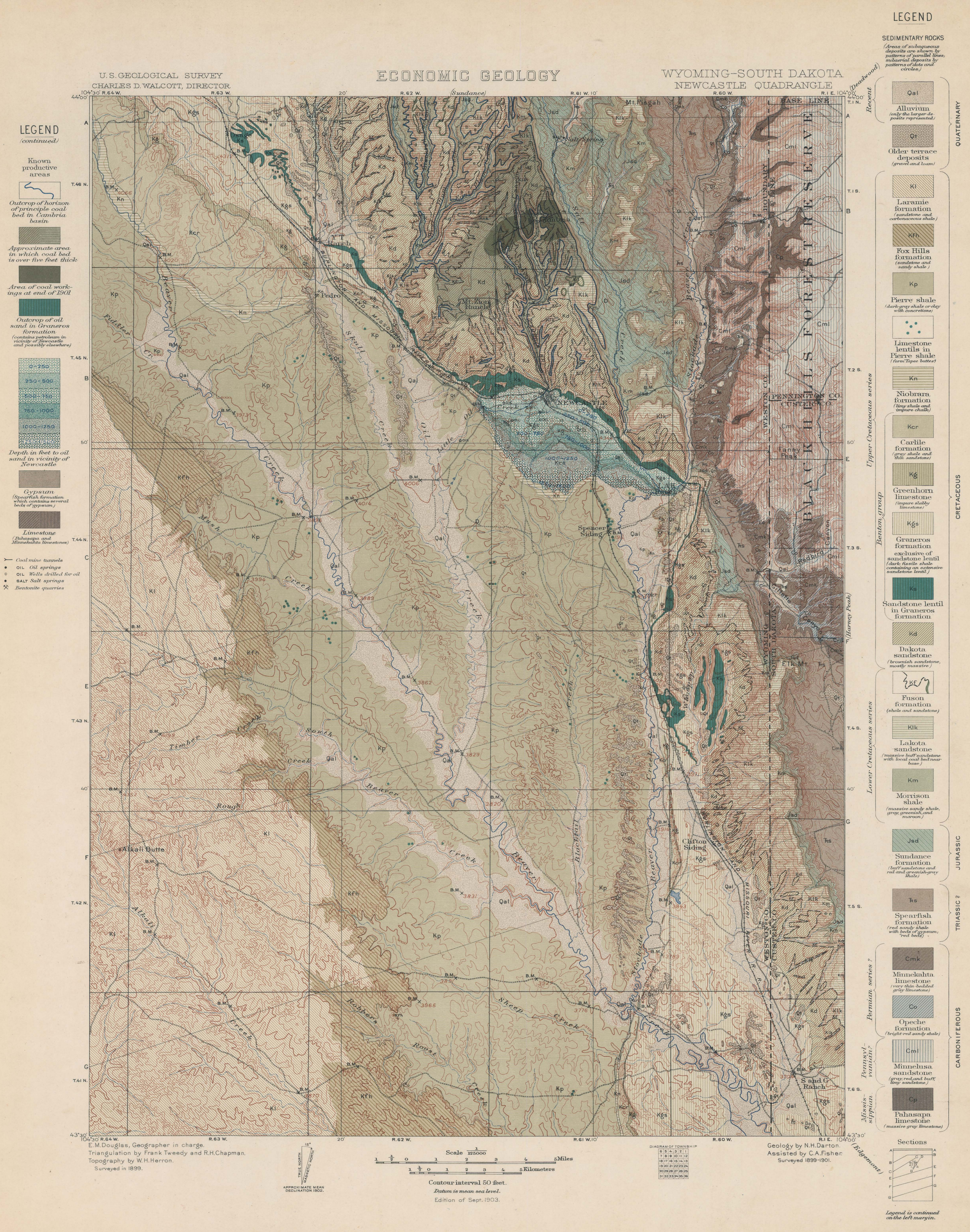
- Cml — Minnelusa sandstone *(gray, red, and buff, limy sandstone)*

Mississippian.

- Cp — Pahasapa limestone *(massive gray limestone)*

Sections

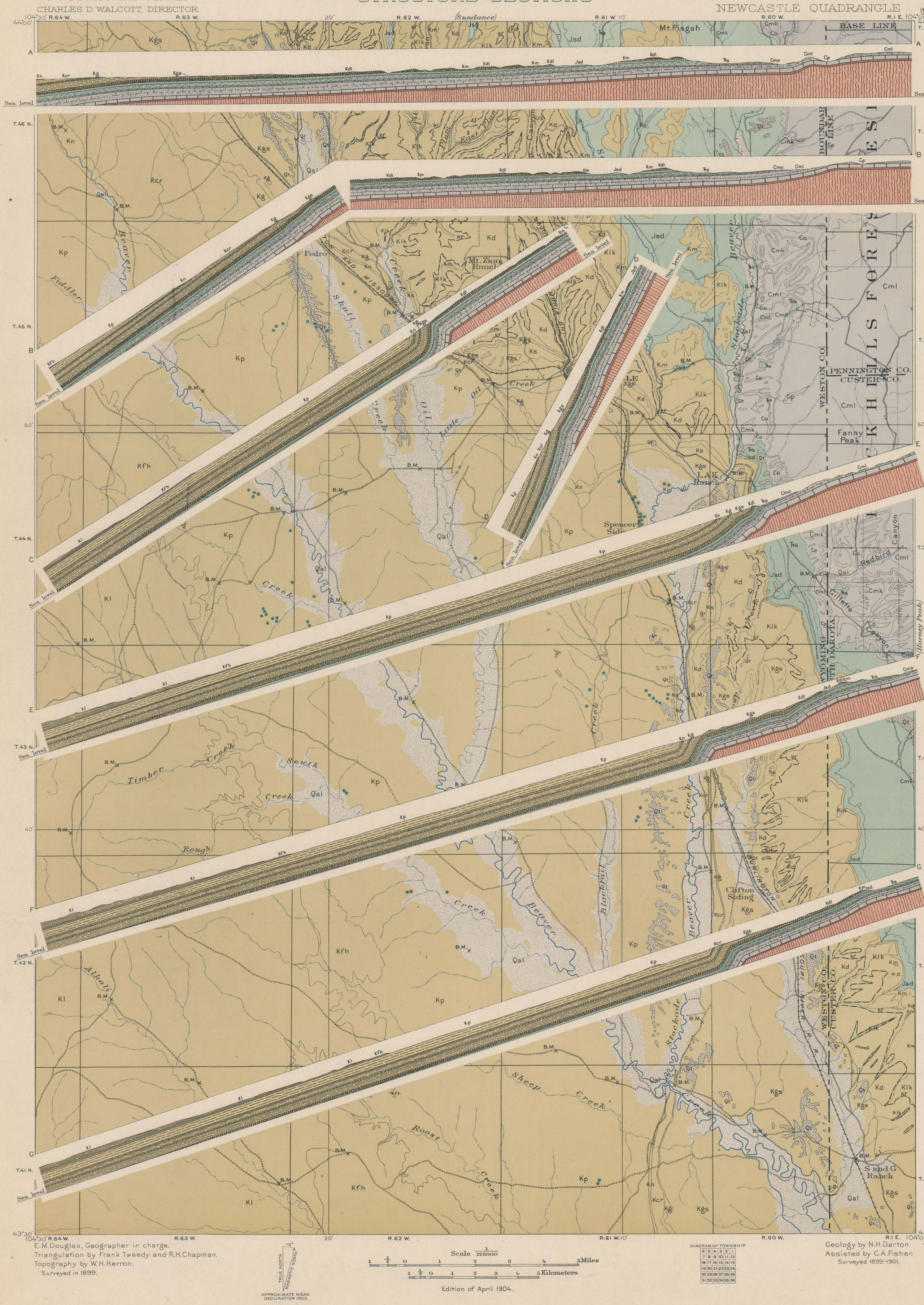


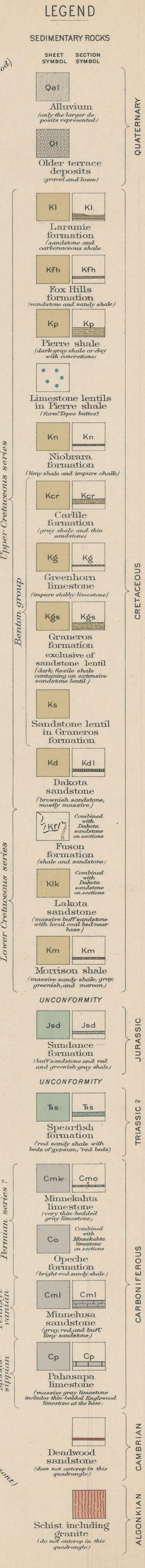

U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR.
ECONOMIC GEOLOGY
WYOMING–SOUTH DAKOTA
NEWCASTLE QUADRANGLE
(Sundance)
(Deadwood)
(Harney Peak)
(Edgemont)
BLACK HILLS FOREST RESERVE
NEWCASTLE
Spencer Siding
Clifton Siding
S and G Ranch
Alkali Butte
Elk Mt.
Pedro
WESTON CO.
CUSTER CO.
PENNINGTON CO.
LEGEND
(continued)
Known productive areas
Outcrop of horizon of principle coal bed in Cambria basin
Approximate area in which coal bed is over five feet thick
Area of coal workings at end of 1901
Outcrop of oil sand in Graneros formation (contains petroleum in vicinity of Newcastle and possibly elsewhere)
0–250
250–500
500–750
750–1000
1000–1250
1250–1500
Depth in feet to oil sand in vicinity of Newcastle
Gypsum (Spearfish formation which contains several beds of gypsum)
Limestone (Pahasapa and Minnekahta limestones)
Coal mine tunnels
OIL Oil springs
OIL Wells drilled for oil
SALT Salt springs
Bentonite quarries
LEGEND
SEDIMENTARY ROCKS
(Areas of subaqueous deposits are shown by patterns of parallel lines; subaerial deposits by patterns of dots and circles.)
QUATERNARY
Recent
Qal Alluvium (only the larger deposits represented)
Qt Older terrace deposits (gravel and loam)
CRETACEOUS
Upper Cretaceous series
Kl Laramie formation (sandstone and carbonaceous shale)
Kfh Fox Hills formation (sandstone and sandy shale)
Kp Pierre shale (dark-gray shale or clay with concretions)
Limestone lentils in Pierre shale (form "Tepee buttes")
Kn Niobrara formation (limy shale and impure chalk)
Benton group
Kcr Carlile formation (gray shale and thin sandstone)
Kg Greenhorn limestone (impure slabby limestone)
Kgs Graneros formation exclusive of sandstone lentil (dark fissile shale containing an extensive sandstone lentil)
Ks Sandstone lentil in Graneros formation
Kd Dakota sandstone (brownish sandstone, mostly massive)
Lower Cretaceous series
Kf Fuson formation (shale and sandstone)
Klk Lakota sandstone (massive buff sandstone with local coal bed near base)
Km Morrison shale (massive sandy shale, gray, greenish, and maroon)
JURASSIC
Jsd Sundance formation (buff sandstone and red and greenish-gray shale)
TRIASSIC ?
Ꞅs Spearfish formation (red sandy shale with beds of gypsum; "red beds")
CARBONIFEROUS
Permian series ?
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)
Mississippian
Cp Pahasapa limestone (massive gray limestone)
Sections
Legend is continued on the left margin.
E.M. Douglas, Geographer in charge.
Triangulation by Frank Tweedy and R.H. Chapman.
Topography by W.H. Herron.
Surveyed in 1899.
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION 1902.
Scale 1/125000
Miles
Kilometers
Contour interval 50 feet.
Datum is mean sea level.
Edition of Sept. 1903.
DIAGRAM OF TOWNSHIP
Geology by N.H. Darton.
Assisted by C.A. Fisher.
Surveyed 1899-1901.

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

STRUCTURE SECTIONS

WYOMING-SOUTH DAKOTA
NEWCASTLE QUADRANGLE





E. M. Douglas, Geographer in charge.
Triangulation by Frank Tweedy and R. H. Chapman.
Topography by W. H. Herron.
Surveyed in 1899.

APPROXIMATE MEAN DECLINATION 1902.

Scale 1/125000

Edition of April 1904.

DIAGRAM OF TOWNSHIP

Geology by N. H. Darton.
Assisted by C. A. Fisher.
Surveyed 1899-1901.

U.S. GEOLOGICAL SURVEY
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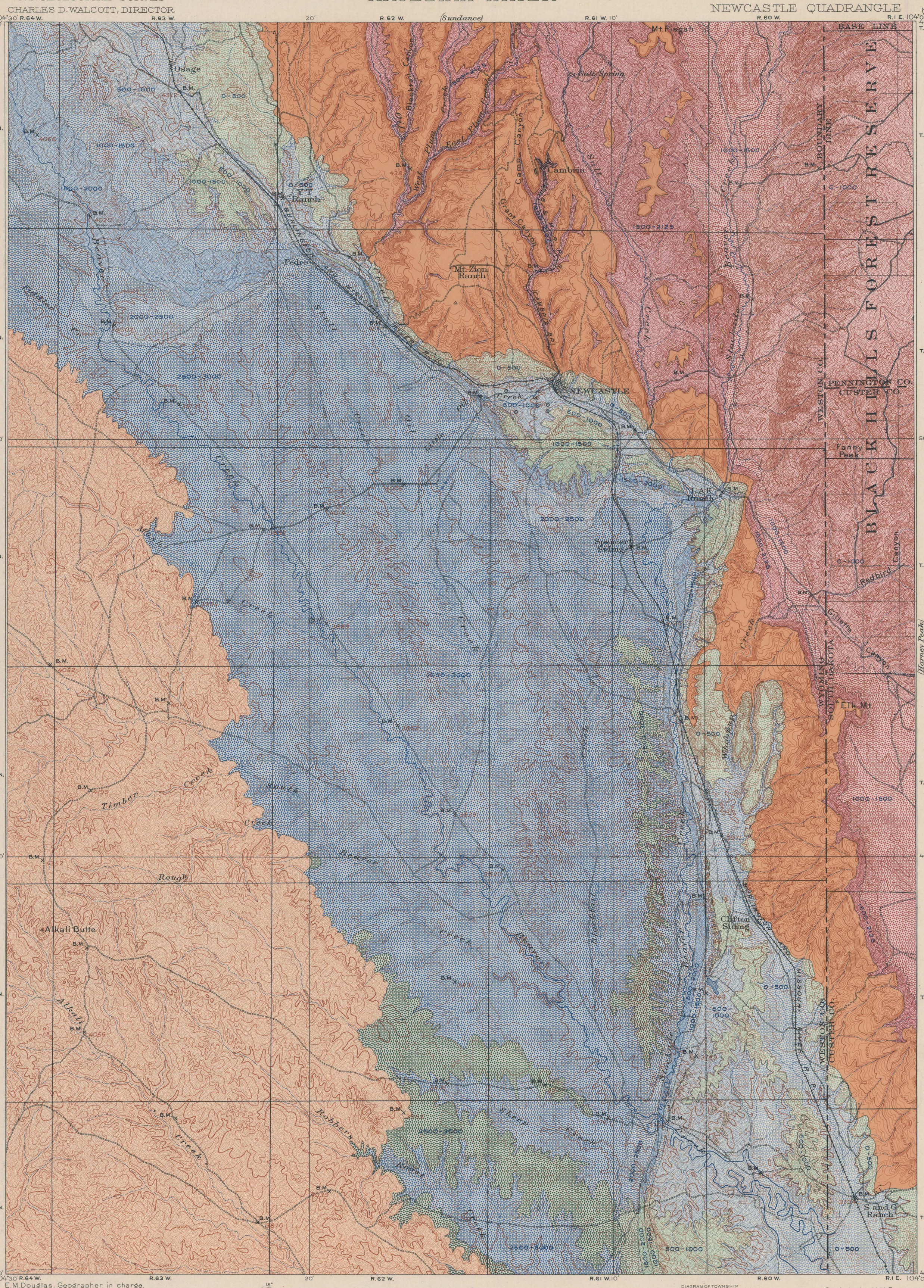
ARTESIAN WATER

WYOMING–SOUTH DAKOTA
NEWCASTLE QUADRANGLE



LEGEND

0-500
500-1000
1000-1500
1500-2000
2000-2500
2500-3000

Area of Dakota sandstone which will probably yield flowing wells at less than 3000 feet depth

(depth to top of Dakota sandstone indicated by pattern. Flowing water may be expected from 20 to 200 feet below the top of the formation)

0-500
500-1000
1000-1500
1500-2000
2000-2500
2500-3000

Area of Dakota sandstone which will probably yield pumping wells at less than 3000 feet depth

(depth to top of Dakota sandstone indicated by pattern)

Outcrop of Dakota and associated underlying sandstones

(area in which surface waters enter water-bearing strata)

Area in which Dakota sandstone is more than 3000 feet below the surface

0-1000
1000-1500
1500-2125

Depths to water-bearing horizon in Pahasapa limestone tapped in Cambria well

(the Deadwood sandstone lies from 350 to 500 feet deeper and probably also contains water)

⊙ *Wells in Dakota and associated water-bearing strata*

⊙P *Cambria well in Pahasapa limestone*

E. M. Douglas, Geographer in charge.
Triangulation by Frank Tweedy and R. H. Chapman.
Topography by W. H. Herron.
Surveyed in 1899.

APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{125000}$

Contour interval 50 feet.
Datum is mean sea level.

Edition of Feb. 1904.

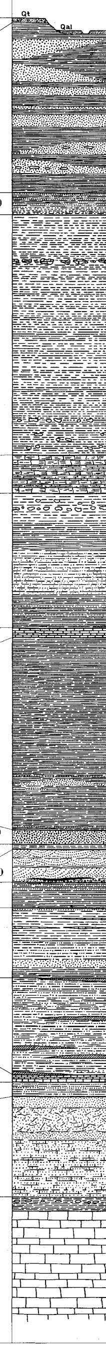
DIAGRAM OF TOWNSHIP

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

Geology by N. H. Darton.
Surveyed in 1899-1901.

COLUMNAR SECTION

GENERALIZED SECTION FOR THE NEWCASTLE QUADRANGLE.
SCALE: 1 INCH = 500 FEET.

System.		Formation Name.	Symbol.	Thickness in Feet.	Columnar Section.	Depth below Top of Pierre Shale.	Character of Rocks.	Character of Topography and Soils.
QUATERNARY		Alluvium.	Qal	20–25			Sands, gravels, and loams.	Flats and lower terraces along streams. Good soil.
QUATERNARY		Older terrace deposits.	Qt	5–25			Gravels and loams.	High terraces, deeply dissected.
CRETACEOUS	UPPER CRETACEOUS	Laramie formation.	Kl	800+			Massive, soft, buff sandstone with concretions and carbonaceous shales.	Rolling plains, with buttes capped by sandstone, and low cliffs. Thin sandy soils.
CRETACEOUS	UPPER CRETACEOUS	Fox Hills formation.	Kfh	75–150		*Water.* 0	Thin, hard sandstone in sandy shale, and soft clayey sandstone below.	Rocky or sandy slopes.
CRETACEOUS	UPPER CRETACEOUS	Pierre shale.	Kp	1250		200 400 600 800 1000 1200	Principal horizon of limestone lenses, giving rise to "tepee buttes." Dark-gray shale or clay with concretions containing many fossils.	Small sharp hills, "tepee buttes." Wide plains with shallow valleys and low ridges. Soil thin, clayey, and not very fertile. Supports fair growth of grass.
CRETACEOUS	UPPER CRETACEOUS	Niobrara formation.	Kn	200		1400	Gray calcareous shale and impure chalk, which weathers bright yellow, containing many *Ostrea congesta* near the top.	Valleys or flats. Fertile soil.
CRETACEOUS	UPPER CRETACEOUS	Carlile formation.	Kcr	700		1600 1800 2000	Light-colored shale with large oval concretions. Gray shale. Gray sandy shale Dark shale with thin beds of brown sandstone.	Low rocky ridges and bare shale slopes.
CRETACEOUS	UPPER CRETACEOUS	Greenhorn limestone.	Kg	50		2200	Thin-bedded, hard, gray limestone filled with *Inoceramus labiatus.*	Small bare ridges.
CRETACEOUS	UPPER CRETACEOUS	Graneros formation.	Kgs	1000 (0–40)		2400 2600 2800 3000	Dark shale. Hard, light-colored sandy shale. Buff to gray sandstone; "oil sand." Dark shale with hard oval concretions.	Wide valleys. Thin sterile soil, except where covered by alluvium. Some trees on its lower beds. Prominent ridges. Narrow valleys and bare shale slopes.
CRETACEOUS	UPPER CRETACEOUS	Dakota sandstone.	Kd	50–100		3200 *Water.*	Gray to buff sandstone, mostly very massive; weathers reddish brown.	Canyons and high cliffs with rocky slopes. Thin sandy soil.
CRETACEOUS	LOWER CRETACEOUS	Fuson formation.	Kf	15–30			Gray to red shales with thin sandstones.	Steep slopes below cliffs of Dakota sandstone.
CRETACEOUS	LOWER CRETACEOUS	Lakota sandstone.	Klk	150–200		3400 *Water.*	Massive, cross-bedded, coarse, gray to buff sandstone with local coal beds and conglomerate.	Canyons and wooded rocky ridges. Thin sandy soil.
CRETACEOUS	LOWER CRETACEOUS	Morrison shale.	Km	150		3600	Massive sandy shale and fine-grained sandstone of gray, buff, pale-green, and maroon tints.	Steep slopes below cliffs of Lakota sandstone.
		UNCONFORMITY						
JURASSIC		Sundance formation.	Jsd	350		3800 *Water.*	Greenish-gray shale with thin limestone layers. Reddish sandy shale. Massive buff sandstone. Dark-gray shale.	Slopes, mostly bare of soil.
		UNCONFORMITY				4000		
TRIASSIC ?		Spearfish formation. ("Red Beds.")	Ꞇrs	500			Red sandy shale and soft red sandstone with beds of gypsum.	Wide valley. Sterile soil except where covered by alluvium.
CARBONIFEROUS	PERMIAN?	Minnekahta limestone.	Cmk	40			Thin-bedded gray limestone.	Bare rocky slopes and cliffs along canyons.
CARBONIFEROUS	PERMIAN?	Opeche formation.	Co	75			Red sandy shale and red sandstone.	Steep slopes beneath cliffs of Minnekahta limestone.
CARBONIFEROUS	PENNSYLVANIAN	Minnelusa sandstone.	Cml	600+			Hard white sandstone including brecciated red sandstone. Buff and gray limy sandstone.	Rocky slopes and rolling mountain summits. Sandy soil, mostly covered by forest.
CARBONIFEROUS	MISSISSIPPIAN	Pahasapa limestone.	Cp	700+		*Water.*	Red shale with oval concretions. Massive light-gray limestone.	Canyon walls.

N. H. DARTON,
Geologist.

ILLUSTRATIONS

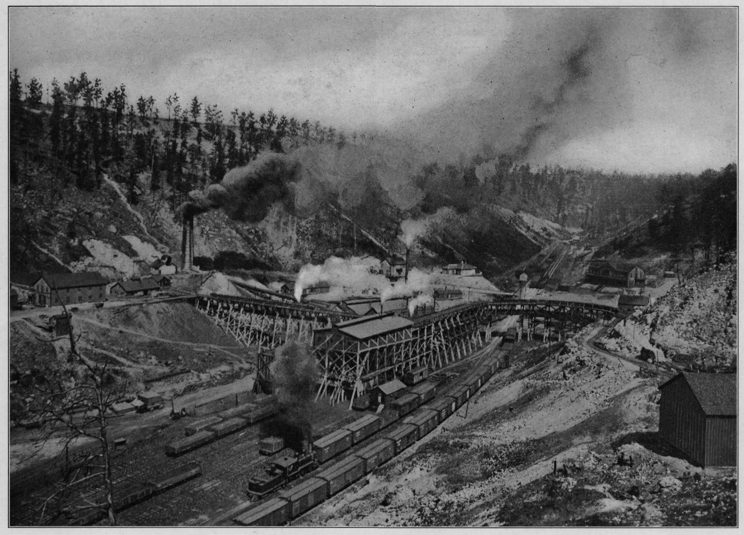


Fig. 7.—CAMBRIA COAL MINE.

The coal bed, which is near the base of the Lakota sandstone, is mined from tunnels extending under the plateau on both sides of the valley shown in this view.

Fig. 8.—WEST SLOPE OF BLACK HILLS ON THE EAST SIDE OF STOCKADE BEAVER VALLEY, EAST OF NEWCASTLE, LOOKING SOUTH.

Shows horizontal Minnekahta limestone in the foreground, sharply upturned along the foot of the mountain and underlain by Opeche red shale and steeply dipping Minnelusa sandstone on the mountain side.

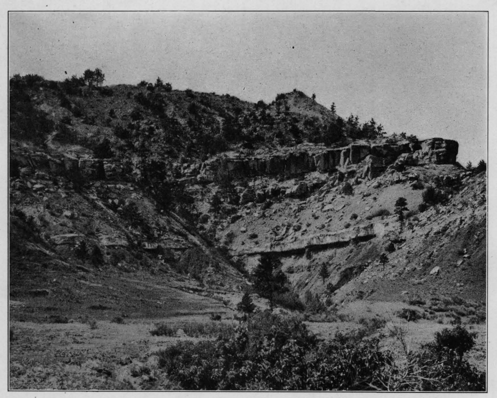


Fig. 9.—SPEARFISH, SUNDANCE, AND MORRISON FORMATIONS, WEST SIDE OF STOCKADE BEAVER VALLEY, EAST OF NEWCASTLE.

The lower hard, white bed is gypsum at top of Spearfish formation. The massive bed in middle of slope is sandstone in Sundance formation.

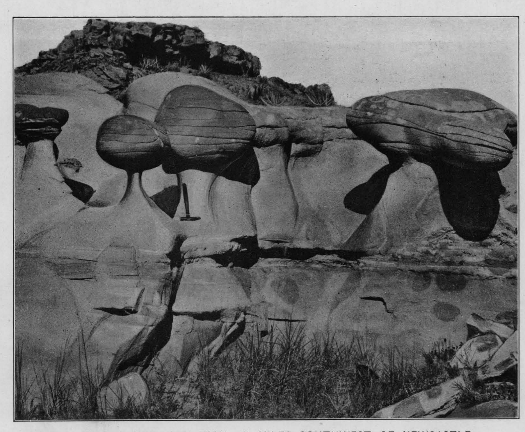


Fig. 10.—LARAMIE FORMATION, 15 MILES SOUTHWEST OF NEWCASTLE.

Showing oval concretions of harder sandstone exposed by weathering.

Fig. 11.—SMALL HOGBACK RIDGES AT RESERVOIR SOUTHWEST OF CLIFTON SIDING.

The ridge at the left is sandstone in the Carlile formation. The Greenhorn limestone forms the ridge opposite the dam.

Fig. 12.—CHARACTERISTIC FOSSILS OF NIOBRARA FORMATION (*A*) AND GREENHORN LIMESTONE (*B*), IMPORTANT GUIDES IN WELL BORING.

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

Fig. 13.—TYPICAL CLIFFS AND TALUS OF MASSIVE DAKOTA SANDSTONE ON NORTH SIDE OF GORGE OF SALT CREEK, EAST OF NEWCASTLE.

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