DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

GEOLOGIC ATLAS

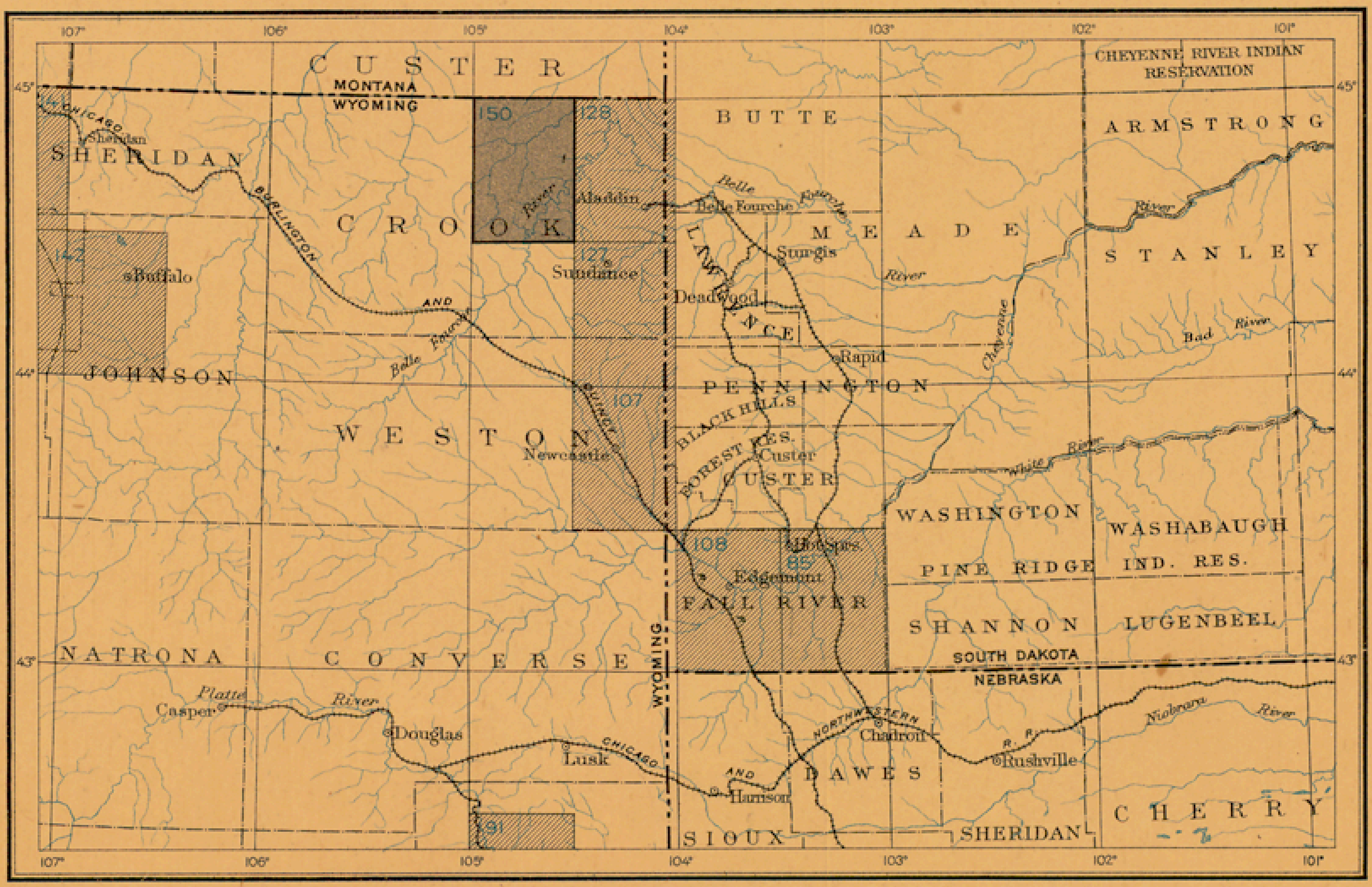
OF THE

UNITED STATES

DEVILS TOWER FOLIO

WYOMING

INDEX MAP



SCALE 40 MILES-1 INCH

DEVILS TOWER FOLIO

OTHER PUBLISHED FOLIOS

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(OLOGIC 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).

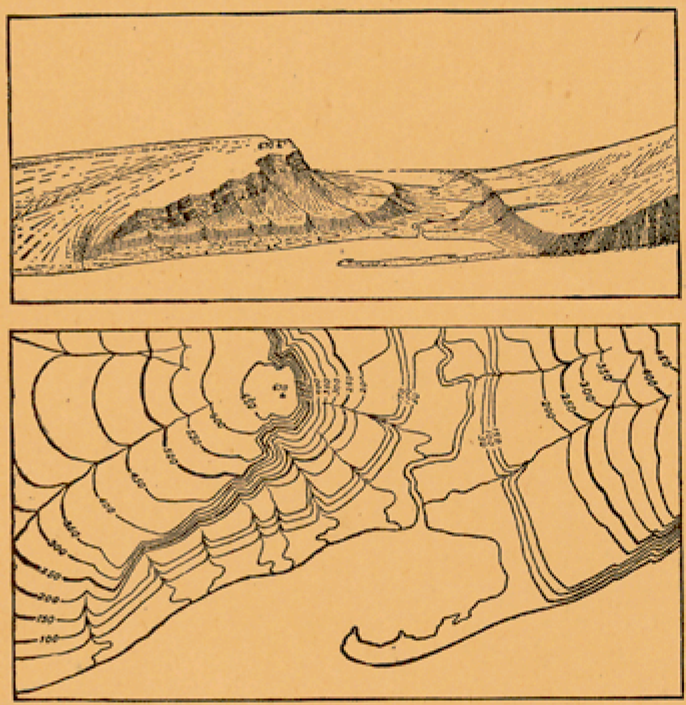

FIG. 1.—Ideal view and corresponding contour map.

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.)

DESCRIPTION OF THE DEVILS TOWER QUADRANGLE.

By N. H. Darton and C. C. O'Harra.

GEOGRAPHY.

Position and extent.—The Devils Tower quadrangle embraces the quarter of a square degree which lies between the parallels 44° 30′ and 45° north latitude and meridians 104° 30′ and 105° west longitude. It measures approximately 34½ miles from north to south and 25 miles from east to west, and its area is very nearly 850 square miles. It comprises a portion of the northeastern part of Crook County, Wyo. Its north limit is the Wyoming-Montana State line. The southeastern two-thirds of the quadrangle lies on the northern extension of the Black Hills uplift and its northwestern portion extends onto the Great Plains. It embraces a portion of the Belle Fourche and Little Missouri valleys, including the head of the latter. Being a part of the Black Hills and the Great Plains, this quadrangle exhibits many features of both, and a general account of these provinces will be given before the detailed description of the quadrangle is presented.

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 are 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 badlands. 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 very few local flexures, the region has not been subjected to folding, but has been broadly uplifted and depressed successively. During earlier epochs the surface was even smoother than at present. 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 locally 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 the 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 central 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 that 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.

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, Owl, 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 north end of the Laramie Mountains. To the south are the Rio Grande, Platte River with two large branches heading far back in the Rocky Mountains, and Arkansas River, which crosses the plains to the southeast and affords an outlet for the drainage from a large watershed of mountains 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 parklike 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 hils, 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, in places 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, parklike valleys on the plateau, they sink into deep canyons with precipitous walls of limestone, in places many hundred feet high. The limestone plateau, extending southward, 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 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 of Cheyenne River. All around the Black Hills the limestone plateau slopes outward, but near its base there is a low ridge of Minnekahta limestone with a steep infacing escarpment from 40 to 50 feet high, surmounted by a bare, rocky incline which descends several hundred feet into the Red Valley. This minor escarpment and slope are 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 already mentioned on the outer side. This valley is in many places 2 miles wide, though it is much narrower where the strata dip steeply. It 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. As a rule the larger streams flowing out of the hills cross it without material deflection, between divides most of which are so low as to give the valley the appearance of being continuous, but in its middle eastern section it is extensively choked with Oligocene deposits.

The hogback rim.—The hogback range constituting the outer rim of the hills is for the most part a single-crested ridge of hard sandstone, varying in prominence and in steepness of slope. At the north and south and locally along the middle western section it spreads out into long, sloping plateaus. It nearly everywhere 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 gaps or canyons, which divide it into level-topped ridges of various lengths. At the southern margin 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 north end of the uplift.

GEOGRAPHIC FEATURES OF THE QUADRANGLE.

Features pertaining to the Black Hills.—The Devils Tower quadrangle presents some characteristic features of the Black Hills topography, mainly of the sloping plateau of the flanking sandstone ridges. This is deeply cut by the valley of Belle Fourche River and its numerous side branches. A short distance east of the southeast corner of the quadrangle are the steep slopes of the Bear Lodge Range, a local uplift rising considerably above the general northwestern slope of the Black Hills. In this area are the highest lands of the region, the altitude being 5800 feet in the southeast corner of the quadrangle. There is a rapid descent of both ridges and valleys to Belle Fourche River, on which the altitudes are 3940 feet at the southern margin of the quadrangle and 3640 feet at the eastern margin. In the portion of the quadrangle east of the river there are long sloping ridges and outlying plateaus, the latter capped by masses of Lakota or overlying sandstones. West of the river there is rapid rise to a general plateau, capped by this same sandstone. It has an altitude of about 4500 feet at the south and 4300 feet at the north, constituting the divide between Belle Fourche and Little Missouri rivers. The front of this plateau is deeply incised by numerous canyons, and it rises irregularly from the Belle Fourche in long slopes interrupted by many local breaks due to the cutting of small streams. On the top of the plateau rise the Missouri Buttes—a mass of igneous rock, forming a small group of prominent summits, of which the highest reaches an altitude of 5372 feet. The most notable feature in the region is Devils Tower, which rises on one of the ridges west of Belle Fourche River. It has a towerlike form (see figs. 1 and 2), nearly circular, and is about 100 feet in diameter at the top. Its sides are nearly vertical and it attains an altitude of 5117 feet, or about 600 feet above the sandstone platform from which it rises. Its height above the river a short distance east of its base is a little less than 1250 feet.

Features pertaining to the Great Plains.—The southwestward dip of the uppermost sandstones of the Black Hills series carries them beneath soft shales, and in the northwestern third of the quadrangle there is a wide area underlain by soft rocks presenting characteristic topography of the Great Plains. The valleys are wide and most of the slopes are gentle or not high. Here and there a harder bed gives rise to a low escarpment, or ridge, but it is an insignificant feature as compared with the higher ridges and mountains of the adjacent Black Hills. The elevation of the plains portion of the Devils Tower quadrangle ranges from 3500 to 4600 feet in greater part, with a general downward slope to the north and east. The principal stream is Little Missouri River, which rises in the southwest corner of the quadrangle and flows northward for the first 15 miles and then northeastward, its course being closely parallel to the strike of the rocks. Its valley is wide and flat bottomed for the greater part of its length, with a declivity of about 20 feet a mile in its upper portion and of 10 to 12 feet a mile in its course northeastward. From the east the Little Missouri receives numerous branches, usually dry the greater part of the year, which rise in the shale and sandstone slopes of the Black Hills. Elkhorn Creek is the largest affluent from the east, but Hulett and T. L. creeks and Government Canyon have drainage basins 10 to 20 square miles in area. From the west the Little Missouri receives a stream known as North Fork, which gathers water from an extensive shale region in the northwest corner of the quadrangle. Thompson and Prairie creeks are smaller affluents, usually containing a small amount of water. Cabin Creek rises in the plains near the southwest corner of the quadrangle, but flows across the sandstone hogback range and empties into the Belle Fourche.

GEOLOGY.

DESCRIPTION OF THE ROCKS.

The strata coming to the surface in the Devils Tower quadrangle have a thickness of about 4800 feet. The rocks are mainly sedimentary, comprising sandstones and shales, with smaller amounts of limestone, gravel, and sand. They range in age from Triassic to Quaternary. Their general characteristics, thicknesses, etc., are given in the columnar section sheet. Igneous rocks traverse the sedimentary members, but they are of relatively slight extent. While the Spearfish red shale is the lowest formation exposed, the region is underlain by about 1500 feet of older sedimentary rocks lying on schists and granites, as shown in the structure sections. These formations appear in the higher portions of the Black Hills uplift southeast of this quadrangle and are described in other folios. Some further references to them are given in the section on "Underground waters," page 9.

Sedimentary Rocks.

TRIASSIC SYSTEM.

SPEARFISH FORMATION.

Relations and character.—The oldest exposed sedimentary rocks in the Devils Tower quadrangle are the red beds of the Spearfish formation. The entire thickness of the formation is not revealed, but the upper members are extensively exhibited in nearly horizontal position along Belle Fourche River and the lower courses of the tributary streams, particularly in Red and Barlow canyons and along Blacktail, Whitetail, and Lytle creeks. The most complete exposures in this quadrangle are in the Belle Fourche Valley near the mouth of Barlow Canyon, midway between Hulett and Devils Tower. The thickness of the Spearfish strata exposed here is approximately 200 feet. In the disturbed area near the head of Lytle Creek, in the southeast corner of the quadrangle, the thickness of the exposed beds is apparently greater than at the mouth of Barlow Canyon, but the variableness of the dips and the wooded condition of the area prevent accurate determination.

Between Hulett and Devils Tower the formation outcrops extensively in slopes, but there are cliffs where the formation is cut by the river or is protected by the massive sandstone of the overlying Sundance formation. Along the smaller valleys the exposures are for the most part in steep canyon walls, the bright-red color of which is in striking contrast to the somber tint of the Sundance slopes above.

The formation consists largely of a mixture of fine clay and sand in somewhat variable proportions, but the sand is in few places, if anywhere, in sufficient amount to give the rock the nature of a sandstone. At many horizons fresh surfaces show an indistinct nodular structure, due to incipient concretionary development.

The color of the beds varies between light pink and Indian red, the deeper shades predominating in fresh exposures. Here and there green laminæ are observed, but these, although sharply outlined, are in few places more than an inch or two thick. Several thin beds of gypsum, most of them less than 2 feet thick, occur near the top of the formation, interbedded with soft shales. Gypsum of secondary deposition occurs in thin seams and narrow veins. The line of demarcation between the Spearfish and overlying Sundance beds is distinct, owing mainly to the great difference in color, but there is no marked evidence of erosional unconformity between them, although they are separated by a long hiatus.

The formation is nearly horizontal in much of the outcrop area, but there is a prevailing low dip to the north-northwest. The highest exposure is in the southeast corner of the quadrangle, at an altitude of more than 5000 feet, due to uplift by the igneous intrusions of the central Bear Lodge area. The lowest exposure is on Buck Creek at the eastern edge of the quadrangle, at 3600 feet above sea level. Throughout the greater part of its outcrop area along Belle Fourche River the formation preserves a fairly uniform level, reaching in general a height of about 4000 feet. It passes beneath the Sundance formation and the alluvium of the river bottom at a point about 2 miles from the southern limit of the quadrangle. There is but little variation in the stratigraphy of the formation, and the following section, made on the southeastern side of the base of Devils Tower, is representative:

Section of Spearfish formation on Belle Fourche River at base of Devils Tower.

	Feet.
Red shales, mostly concealed	25
Gypsum in 1- and 2-foot beds with thin red shales between	8
Red shales, nodular and sandy in upper part	10
Massive and nearly uniform bed of red sandy shale	30
Very soft, thin, red clay shales	12
Soft, red shales with some arenaceous layers	10
Massive red sandstone layer	4
Very soft, thin, red shales, slightly green at top	½
Red sandy bed with little clay	½
Very soft, red shales, slightly nodular	5
Massive red sandstone	2½
Arenaceous red shales, inclined to nodular	3
Very soft, very thin red shales	6
Thin arenaceous red shales	½
Very soft, very thin red shales	5
Rather hard arenaceous red clay shales, slightly green near the top	4
Massive red sandstone layer	6
Arenaceous red clay shales, nodular	5
Gypsum, thin seam one-eighth inch thick.	
Soft, thin, red shales	1
Arenaceous red shales	½
Arenaceous red clay shales, nodular	2
Massive arenaceous red shales	5
Thin red shales	6
	151½

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

JURASSIC SYSTEM.

SUNDANCE FORMATION.

General relations.—The Sundance formation is exposed in a wide area in the southeastern portion of the quadrangle. The upper and middle beds are characterized by gently sloping hillsides and broadly undulating or flat surfaces. A heavy massive sandstone in the lower beds gives rise to extensive terraces near the base of the slopes and to small canyons along many of the streams. This formation affords the chief grazing lands of the region east of Little Missouri River.

Rocks.—The formation consists mainly of shales, partly sandy, and sandstones, and has an average thickness of about 340 feet. It comprises several members which are persistent throughout the region, as well as most other portions of the Black Hills uplift. There are basal shales, as a rule from 75 to 90 feet thick; buff sandstone, mostly massive, 40 to 60 feet; and at the top 150 to 200 feet of shales. The latter are in most places of reddish color in their lower portion. Limestones, nowhere more than a few feet in thickness and in many places very fossiliferous, occur abundantly in the upper part of the formation. With the exception of one sandstone bed at the top, the sandy beds are mostly in the lower part. The shales which so greatly predominate in the formation vary somewhat in purity, and at many places in the lower part of the formation they are sandy. Because of their softness they are as a rule poorly exposed. The sandstone at the top of the formation is yellowish and probably represents the Unkpapa sandstone of the eastern portion of the Black Hills. It is massive, but extremely soft, and on this account is nowhere well exposed. The greatest thickness observed is 40 feet, midway between Devils Tower and the Missouri Buttes. The thickness at other localities is given in the subjoined sections.

The most conspicuous member of the formation is a bed of sandstone, about 40 feet thick, which lies near the bottom. It consists of a massive bed of medium-coarse grained rock. In places, on weathering, it exhibits a flaggy structure, and some layers are ripple-marked. Owing to its hardness and nearly horizontal position it gives rise to prominent benches, or terraces, and outlying buttes terminated by vertical cliffs, all along the Belle Fourche Valley. It is one of the best exposed beds in the quadrangle, appearing as a rim rock along all the streams entering Belle Fourche River from the east and outcropping in the lower course of most of the streams entering from the west. The color varies, fresh surfaces being in general light pink or gray, while exposed surfaces show some shade of red, yellow, or buff. There is a certain regularity in the areal distribution of the colors. In the southeastern part of the quadrangle, along the upper portions of Whitetail, Blacktail, and Lytle creeks and their tributaries, the red is pronounced. In the vicinity of Devils Tower the red color softens to a reddish yellow, or buff, and north, northeast, and northwest of Hulett the reddish tinge is almost wholly lacking. West and south of the tower and especially along Miller Creek light yellow prevails.

Shales, in part sandy, varying from 70 to 90 feet in thickness, lie below the massive sandstone and constitute the basal member of the formation. In many places layers of sandstone are included among these shales, but with one exception they are rather soft or flaggy and inconspicuous. The exception referred to is in the vicinity of Devils Tower, where midway in the shales there is a bed of massive, sparingly fossiliferous quartzitic sandstone 4 to 8 feet thick. The best exposures of this quartzitic sandstone are along the roadside immediately north and northwest of Devils Tower.

The thick mass of shales constituting the middle and upper part of the formation is mainly of dark greenish gray color and over 200 feet thick. In portions of the area, as along Bush Canyon in the eastern part and near Miller Creek in the southern part of the quadrangle, the lowest beds, for a thickness of 20 to 30 feet or more, are of pink or red color. In Bush Canyon they are pink, but on Miller Creek they are distinctly red. These red beds resemble the red shales of the Spearfish formation, but their position above the prominent underlying sandstone indicates their true relation. Several beds of massive, platy, or shaly limestones, varying considerably in character in different localities, occur in the shales. North of lower Miller Creek some of these limestones contain numerous clay-lime concretions, or nodules. Nearly all the limestones contain considerable sand, and on well-weathered outcrops, where percolating water has had opportunity to dissolve out the lime, the sandy residue as a rule masks the original nature of the rock. The limestones are more resistant than the inclosing shales, so that in many places they outcrop prominently on the slopes, but very few of the exposures are sufficiently clear to admit of accurate measurement, and it is not everywhere practicable to determine the nature of the rocks from the weathered materials. The thicknesses vary from a few inches to 10 feet, but mostly from 5 to 6 feet, and the beds are from 5 to 40 feet or more apart. Most of them are highly fossiliferous, especially in the upper portion of the formation, but some fossiliferous layers occur throughout. The fossiliferous slabs are conspicuous features on the surface, as are also the weathered individual fossils, particularly *Belemnites*, which is in places very abundant. Locally this fossil occurs in profusion among the other fossils of the massive limestones, but its chief occurrence seems to be in thin, highly sandy beds and in nodular limy layers. Many of the fossiliferous layers show abrupt vertical passage into nonfossiliferous layers, even where no lithologic break of any character is recognized.

Local sections.—The following detailed sections show the thickness and the composition of the beds in this formation:

Section of Sundance formation 2 miles north-northwest of Hulett.

	Feet.
Morrison shale.	
Massive yellow sandstone, very soft (Unkpapa ?)	30
Shales, partly concealed	25
Highly fossiliferous limestone	6
Shales in talus	10
Fossiliferous limestone, containing belemnites, etc., but chiefly concealed	10
Highly fossiliferous limestone, many oysters, few belemnites, occasional limestone pebbles 2 or 3 inches in diameter	8
Chiefly concealed, but many fragments of limestone conglomerate	8
Highly fossiliferous limestone with few lime-clay pebbles	6
Yellowish-gray shales not well exposed, but evidently containing several layers of belemnites	12
Greenish yellow shales with lime-clay nodules	5
Highly fossiliferous blue slabby limestone	2
Chiefly concealed—apparently nearly all shales, but with some thin, highly fossiliferous limestones. Belemnites apparently in great abundance. One fragment of ammonite found	50
Massive reddish-yellow sandstone	40
Greenish-gray arenaceous shale, grayish white in lower part	80
Flaggy grayish-white sandstone	2
Gray arenaceous shale, lying on red beds	3
	297

Section of Sundance formation on north side of Bush Canyon 3 miles north of Hulett.

	Feet.
Morrison shale.	
Massive yellow sandstone, very soft (Unkpapa ?)	30
Drab soft shales	8
Fossiliferous sandy limestone, platy to nodular	1
Gray soft shales	5
Fossiliferous arenaceous limestone, platy	1
Shale, mostly concealed	20
Massive gray arenaceous limestone, fossiliferous in upper part	4
Shale, mostly concealed	18
Fossiliferous arenaceous limestone	4
Shale, chiefly concealed, but contains at least three limestone layers, each being sandy in lower part. The limestones divide the concealed rocks into three nearly equal portions	92
Fossiliferous arenaceous limestone	4
Purple and green shales, about	40
Massive yellow sandstone	40
Greenish-gray shales with thin sandstones, lying on red beds	80
	347

Section of Sundance formation north of Lytle Creek, 4 miles east-southeast of Devils Tower.

	Feet.
Morrison shale.	
Massive yellow sandstone, very soft (Unkpapa ?), about	10
Shales, partly concealed	24
Fossiliferous sandy limestone	3
Shales covered by talus	5
Flaggy nonfossiliferous limestone	4
Shales, partly concealed	30
Massive gray sandstone	5
Shales, partly concealed	25
Massive brownish sandstone	6
Shales, partly concealed	35
Nonfossiliferous limestone	3
Reddish shales, largely concealed	60
Massive reddish-yellow sandstone, thin bedded at the top	62
Thin sandstones and shales	6
Gray shales, largely concealed	14
Heavy gray sandstone	8
Gray and drab shales	14
Massive sandstone	2
Gray sandy shales and thin sandstones	25
Massive sandstones	4
Thin sandstones and shales	16
Greenish-purple shales, lying on red beds	5
	366

Section of lower part of Sundance formation on east bank of the Belle Fourche at Hulett.

	Feet.
Yellow, massive, highly ripple-marked sandstone, slight reddish tinge	45
Soft, yellow sandstone	10
Very soft, greenish shale with local thin sandstones	24
Massive but soft, yellow sandstone	8
Flaggy yellowish-gray sandstone with scattered lamellibranchs and brachiopods	3
Greenish shales	12
Buff sandy shales with a few lamellibranchs and brachiopods	1
Thin, papery gray shales	3
Gray sandstones with chalcedonic pebbles in upper part	1
Thin purplish-white soft shales	½
Gray sandstone	½
Fine white shale much resembling fire clay, lying on red beds	4
	112

Section of upper beds of Sundance formation on Cabin Creek, near southern edge of Devils Tower quadrangle.

	Feet.
Morrison shale.	
Massive yellow sandstone, very soft (Unkpapa ?)	12
Thin gray and purple shales with a few lime-clay nodules	20
Flaggy yellowish sandstone	2
Yellowish-gray sandy shales with some lime clay nodules and many small, irregular fragments of chalcedonic material	18
Slabby sandstone	4
Purple and gray sandy shales with some lime-clay concretions	16
Massive, highly fossiliferous sandy limestone	4
Concealed below.	
	76

Fossils.—Fossils are abundant in the Sundance beds, particularly in the limestone layers in the upper shales, but some occur in the basal shales also. The most characteristic species is *Belemnites densus*, represented by hard, dark-colored, cigar-shaped bodies varying in size from an inch or less to 4 inches in length and having a radiated structure when seen in transverse section. In many places these weather out on the surface and are a conspicuous feature in most of the upper shale outcrops. In the upper shales there also occur the following species: *Ostrea strigilecula*, *Avicula wyomingensis*, *Camptonectes bellistriatus*, *Astarte fragilis*, *Trapezium bellefourchensis*, *Pleuromya newtoni*, *Tancredia inornata*, *T. corbuliformis*, *T. bulbosa*, *T. postica*, *Dosinia jurassica*, *Saxicava jurassica*, *Cardioceras cordiforme*, and *Pentacrinus asteriscus*. Here and there layers of limestone and sandstone in the lower shales carry *Ostrea strigilecula*, *Camptonectes bellistriatus*, *Pseudomonotis* (*Eumicrotis*) *curta*, *Psammobia prematura*, and *Belemnites densus*.

The character of this fauna, and especially of the ammonite *Cardioceras cordiforme*, indicates a horizon in the lower part of the upper Jurassic, corresponding to a part of the European Oxfordian.

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

CRETACEOUS SYSTEM.

MORRISON SHALE.

Character and outcrops.—The slopes of the Sundance formation are in most places continued upward by those of the overlying shales of the Morrison formation, which rise to the base of the cliffs of Lakota sandstone. The outcrop zone of the Morrison is narrow, extending along the west side of the Belle Fourche Valley and around the higher sandstone ridges in the southeast corner of the quadrangle. Owing to the low dips and deeply incised creek valleys, the outcrop is very sinuous, especially on the west side of the river.

The formation consists chiefly of massive shale. The prevailing color on weathered slopes is greenish gray or yellowish gray, but pink and purple tints are not uncommon, and in a few places, particularly north of Hulett, between Bush Canyon and Burnt Hollow, the lower beds are red. Some exposures show decidedly darker shades, and in a few places the upper beds are black and somewhat carbonaceous. These were carefully examined for coal, but none was found. Thin layers of lime-clay nodules are common, and some of these in the southeastern portion of the quadrangle coalesce into fairly definite bands of soft impure limestone. Sandstones are present, but in few places do they become conspicuous. An 8-foot bed was observed in Barlow Canyon 30 feet above the bottom of the formation. The thickness of the formation at this place is 85 feet. About 3½ miles north-northwest of Hulett, between Bush Canyon and Burnt Hollow, a 1-foot bed of sandstone was observed 70 feet below the top, followed 20 feet lower by a 2-foot bed. The total thickness of the formation at this place is about 150 feet. Near the head of Bush Canyon a 2-foot bed of sandstone occurs 20 feet above the bottom of the formation, and above this for several feet there are chalcedonic nodules and a few chalcedonized fragments of saurian limb bones and vertebræ. The thickness of the formation varies considerably. The greatest thickness observed, 160 feet, is on Miller Creek near the southern border of the quadrangle, 4½ miles east of the Belle Fourche. The thinnest section observed was 40 feet, in Barlow Canyon due north of Devils Tower.

Local sections.—The formation is fairly well exposed in many places and several detailed sections were obtained. They are as follows:

Section of Morrison formation on north side of Moore Canyon 2½ miles northwest of Hulett.

	Feet.
Grayish-purple shales, underlying Lakota sandstone	20
Dark-purple shales	36
Yellowish, slightly sandy shales	4
Clay, nodular layer	1
Dark greenish-gray shales	10
Clay, nodular layer	1
Purple shales	6
Dark gray shales with lime-clay nodules	2
Drab shales	8
Very soft sandy shales, lying on Sundance formation	8
	96

Section of Morrison formation at southern edge of Devils Tower quadrangle, 2½ miles west of the Belle Fourche.

	Feet.
Lakota sandstone.	
Purple, gray, and yellowish fine shales with one or two thin sandstones	60
Flaggy to massive white sandstone	4
Purple and green shales with occasional limestone nodules, lying on Sundance formation	60
	124

Section of Morrison formation in the northwestern portion of T 52, R. 64.

	Feet.
Argillaceous limestone	2
Concealed	3
Argillaceous limestone	1
Grayish clay shales	12
Argillaceous limestone	1
Yellowish-gray shales	6
Argillaceous limestone	1
Greenish shales	40
Argillaceous limestone	½
Greenish shales	30
	96½

This is believed to be nearly the full thickness at this place, although the upper and lower contacts are not clearly exposed.

Section of Morrison formation 4 miles east-southeast of Devils Tower, north of Lytle Creek.

	Feet.
Rough nodular layer of impure fire clay, overlain by Lakota sandstone	2
Green shale	12
Sandy fire clay	1
Green shale, locally with purple tinge	70
Lime-clay shale	6
Fine green and drab shale	12
Green shale with some lime-clay nodules	16
Limestone, slightly argillaceous, lying on Sundance formation	6
	125

Section of Morrison formation near head of Burnt Hollow, 4 miles northwest of Hulett.

	Feet.
Lakota sandstone.	
Very black shales, rather fine; on weathered surface much resemble a coal outcrop, but no coal is present. (This may possibly represent the horizon of the Aladdin coal.)	10
Gray shales	32
Sandstone	1
Shales with poorly preserved plant impressions	3
Interbedded shales and thin sandstones, lying on Sundance formation	18
	64

Section of Morrison formation a short distance east of the preceding.

	Feet.
Very black shales, as in preceding section	10
Brownish-gray and purple shales	14
Sandstone	2
Brownish-red shales	8
Black shale	40
Light-gray shale, lying on Sundance formation	36
	110

Section of Morrison formation on north side of Sourdough Creek, 6 miles north of Hulett.

	Feet.
Shales, yellow at top, red at bottom, underlying Lakota sandstone	18
Black shales	14
Black shale with 4-inch sandstone near top; slight purple or pink tinge throughout and rather prominent near the middle	17
Black shale	26
Slightly sandy, green soft shale, some lime near the base	10
White sandstone	2
Green shale	5
White sandstone, carbonaceous fragments	2
Gray and reddish shales, lying on Sundance formation	40
	134

Section of Morrison formation on north side of Deer Creek near eastern border of Devils Tower quadrangle.

	Feet.
Lakota sandstone.	
Dark-purple shale, weathers to light purple	9
Massive sandstone	1
Purple shale	10
Concealed	8
Purplish-gray shale	12
Dark-purplish shale	20
Very dark shale	14
Gray shale	17
Concealed, but contains some sand	24
Green and purple shale	6
Sandy shale	4
Very white sandstone weathering to a dirty, velvety brown	1
Grayish-white shales	5
Green shales	2
Purple shales	6
Grayish-green shales with some lime nodules, lying on Sundance formation	16
	155

Fossils and age.—The Morrison shale contains many large bones, and in other areas it has yielded a varied vertebrate fauna, consisting of many genera of dinosaurs, some of which are of huge size, and of primitive forms of small mammals. This fauna, which is often called the Atlantosaurus fauna, is thought by some paleontologists to be of early Cretaceous age and by others is assigned to the late Jurassic. The invertebrate fossils are all fresh-water forms which furnish no positive evidence as to age.

LAKOTA SANDSTONE.

General relations.—The Lakota formation outcrops in a narrow zone along the higher slopes west of the Belle Fourche and constitutes portions of several high ridges on the divides in the southeast corner of the quadrangle. It consists mainly of light-colored, coarse-grained, massive sandstone which gives rise to cliffs, many of which are of considerable prominence. These cliffs surmount the rounded slopes of Sundance and Morrison shales and form the beginning of the ascent to the plateau surface of the Dakota sandstone. On the west side of the Belle Fourche they follow a very irregular course, extending eastward on the divides between the creeks and receding to the west in the valleys. Here and there outliers are isolated from the main mass of the formation, rising in buttes of various shapes and sizes.

Thickness and rocks.—The Lakota sandstone of the Devils Tower quadrangle, as in other portions of the Black Hills uplift, shows considerable resemblance to the Dakota. It is, however, not so continuously massive, and although hard in some localities, it is generally softer than the Dakota and forms a less marked feature in the topography.

The thickness of the Lakota varies considerably and in many places it is difficult to separate it from the overlying Fuson beds. Near the head of Burnt Hollow it is apparently only 25 feet thick, and near the head of Deer Creek and on Sourdough Creek it is 30 feet thick. The latter thickness was observed on Cabin Creek 2½ miles west of the Belle Fourche, while on the same creek 4 miles west of the river it is 60 feet thick, consisting of 20 feet of reddish flaggy sandstone underlain by 40 feet of nearly white massive sandstone. Near the southern limit of the quadrangle, 4 miles east of the Belle Fourche, it is 60 feet thick and consists entirely of a white massive sandstone. Midway between Devils Tower and the Missouri Buttes, and south of the Missouri Buttes near the head of Lake Creek, the thickness is 40 feet; 3½ miles northwest of Hulett, on Left Creek 3 miles south-southwest of the Missouri Buttes, and in Barlow Canyon northeast of the buttes it is 50 feet. The best detailed section was obtained on the north side of Burnt Hollow near its head, where the thickness is 47 feet, as shown in the accompanying section.

Local sections.—The following sections of the Lakota have been measured:

Section of Lakota sandstone in Burnt Hollow.

	Feet.
Fuson shale.	
Massive, gray, cross-bedded sandstone	2
Shaly sandstone	7
Massive cross-bedded sandstone, much iron stained	10
Flaggy sandstone with iron concretions	4
Massive, cross-bedded, yellowish-gray sandstone with few iron concretions	8
Shaly sandstone with considerable iron	3
Massive gray sandstone	3
Shaly sandstone, considerable iron near bottom	4
Flaggy sandstone	2
Gray sandy shale	3
Massive sandstone, lying on Morrison formation	1
	47

Section of Lakota sandstone on north side of Sourdough Creek.

	Feet.
Massive yellowish-gray sandstone, overlain by Fuson formation	10
Soft, purplish gray, shaly sandstone	1
Flaggy purplish sandstone with several bands of iron oxide	14
Massive sandstone	1
Shaly sandstone	1
Massive, soft sandstone, lying on Morrison formation	3
	30

Fossil plants.—The formation contains some petrified wood, but much less than in the eastern slopes of the Black Hills. A small amount was found 2½ miles northwest of Hulett and also 4 miles east of Devils Tower. Larger quantities, with many good-sized pieces, were observed in a rather small area in Barlow Canyon due north of the Missouri Buttes. In most portions of the Black Hills cycads have been obtained from the sandstone horizon containing the fossil tree trunks. When growing the cycad consisted of an oval trunk extending a short distance out of the ground, with leaves on long stems growing out of its surface. The fossil cycad ordinarily consists of the petrified trunk, which shows the deep scars of former sockets of the leaf stems. Some of the shales which are here and there included in the Lakota formation contain other fossil plants, mostly ferns and conifers, representing numerous species of Lower Cretaceous age. Large collections of these have been made in the Hay Creek coal field.

FUSON FORMATION.

General character and relations.—The Fuson formation consists mainly of clay or shale with thin sandstones, lying between the massive sandstones of the Lakota and Dakota formations. It is as a rule not well exposed on the slopes, but locally, where the cliffs are perpendicular, it is exhibited. Its outcrop area follows the very irregular outcrop course of the margin of the Dakota sandstone, but outliers appear along the divides adjoining Elkhorn and Tie creeks and Government Canyon. In the southeast corner of the quadrangle the sandstones of the formation are of more than usual prominence, and this in connection with the wooded condition of the region renders the separation of the Lakota and the Fuson in this vicinity a matter of uncertainty. Sandstones appear in nearly every exposure of the formation, and in general in this area the Fuson is much more sandy than in other parts of the Black Hills uplift, where it contains much soft shale and fire clay. The thickness varies from 50 to 100 feet, but some of the measurements are indefinite on account of the changeable nature of the various beds.

Local features.—The following sections illustrate the principal stratigraphic features of the formation at a number of representative exposures:

Section of Fuson formation north of Cabin Creek, 2½ miles west of the Belle Fourche.

	Feet.
Black shale, overlain by Dakota sandstone	10
Sandy shale and concealed	10
Flaggy to massive sandstone	4
Shales, thin sandstones, and concealed	30
Massive sandstones	2
Sandy shales and concealed	10
Shaly sandstone	6
Black carbonaceous shales	6
Yellowish-gray sandy shales	8
Purple shales	5
Yellowish sandy shales, lying on Lakota sandstone	4
	95

Section of Fuson formation north of Cabin Creek, 4 miles west of the Belle Fourche.

	Feet.
Yellowish-gray sandy shales, darker near top, overlain by Dakota sandstone	36
Massive yellowish sandstone	3
Yellowish sandy shales	6
Massive yellowish sandstone	5
Yellowish-gray shales, darker near the top, lying on Lakota sandstone	50
	100

Section of Fuson formation 2½ miles northwest of Hulett, between Bush Canyon and Moore Canyon.

	Feet.
Shales and concealed, at base of cliff of Dakota sandstone	12
Sandstone	4
Shales	6
Sandstone	2
Shales and concealed to top of Lakota sandstone	85
	109

Section of Fuson formation on north side of Burnt Hollow near its head.

	Feet.
Sandy shale, very dark near the top, gray below, overlain by Dakota sandstone	16
Flaggy sandstones with some iron concretions	4
Dark-gray shales	12
Massive sandstone	2
Gray sandy shales, lying on Lakota sandstone	22
	56

Section of Fuson formation on Sourdough Creek north-northwest of Hulett.

	Feet.
Flaggy sandstones and sandy shales, overlain by Dakota sandstone	32
Grayish-black shales	10
Flaggy sandstone	4
Purple sandy shales, lying on Lakota formation	5
	51

Fossils and age.—Some of the sandy clays of the Fuson formation contain fossil plants, mostly ferns and conifers, which have been collected extensively in the neighboring Aladdin quadrangle. The species are numerous and their age is Lower Cretaceous.

DAKOTA SANDSTONE.

Distribution.—The Dakota sandstone is a conspicuous member of the Cretaceous series, capping the hogback range and in most places presenting high cliffs along its eastern margin and in the canyon walls. It rises gradually on the northwesterly dip from the slopes of the overlying shales in the hills east of the Little Missouri Valley, and its main outcrop zone is an elevated table-land, terminating on the east in high cliffs from which the land drops rapidly to the bottom of the Belle Fourche Valley about 500 feet below. Most of these cliffs consist of Dakota sandstone at the top and Lakota sandstone below, surmounting long slopes of Morrison and Sundance shales. The Dakota outcrop west of this valley varies in width from 1 to 8 miles in greater part, being widest in the slopes adjoining Elkhorn Creek and Government Canyon, along which the formation is exposed nearly to the Little Missouri. Numerous canyons opening to the east cut deeply into the formation and give to its eastern margin a most irregular outline. Small areas of the formation are revealed by several valleys in the Graneros shale area near the Little Missouri Valley, notably on Hulett, Poison, Broncho John, and Gaff creeks. Small outliers of the sandstone cap the higher portions of several high ridges lying between Whitetail and Miller creeks a few miles southeast of the Belle Fourche.

Character.—The formation is chiefly a massive, hard, cross-bedded sandstone of medium-sized grain. In places deposits of shale are included, especially in the lower portion and where the formation expands in thickness. They vary from nearly pure clay to mixtures of sand and clay. In the high vertical walls of Government Canyon the shales and thin-bedded sandstones are of sufficient importance to mask in considerable measure the general massive nature of the formation. The thickness varies from 70 feet near the head of Burnt Hollow to 160 feet in Barlow Canyon. The sandstones are light gray on fresh fracture, but all prominent cliffs show a light brown or yellowish brown on exposed surfaces. The shales range from dull gray to intense black and in a few places carbonized fragments of plants were found. This phase is best shown in Government Canyon, where the carbonaceous material makes up a very considerable portion of one or two of the beds.

Local sections.—The principal features of the formation at several localities are shown by the subjoined sections. The first is on the north side of Barlow Canyon just across from the foot of the steep road leading up to the Missouri Buttes:

Section of Dakota sandstone in Barlow Canyon.

	Feet.
Thin sandstone to top of hill (approximate top of formation)	30
Flaggy to massive sandstone	10

	Feet.
Shaly sandstone	28
Massive sandstone	4
Shaly sandstone	8
Massive sandstone	6
Concealed slope	10
Massive sandstone	6
Shaly sandstone and concealed	22
Massive, highly cross-bedded, grayish-brown sandstone, lying on Fuson formation	36
	160

The next section was measured 1 mile east of the preceding, on the same side of the canyon:

Section of Dakota sandstone in Barlow Canyon.

	Feet.
Concealed slope	20
Massive sandstone, slightly flaggy at bottom	65
Shale and concealed	40
Massive sandstone with iron oxide near bottom	8
Concealed slope	5
Massive sandstone, lying on Fuson formation	8
	146

The following section is shown on the north side of Burnt Hollow, near its head:

Section of Dakota sandstone in Burnt Hollow.

	Feet.
Soft flaggy sandstone at top of formation	20
Massive yellowish-gray sandstone	5
Shaly sandstone	5
Massive sandstone	1
Shaly sandstone	4
Massive sandstone	3
Flaggy and shaly sandstone	5
Limonitic band of sandstone	½
Sandy shales	2
Massive gray sandstone with iron oxide at bottom	4
Shaly sandstone with iron-oxide bands	4
Thin gray shales	1
Massive sandstone	3
Flaggy sandstone	1
Gray shales	3
Soft black shales	2
Massive sandstone	1
Sandy shales	½
Massive yellowish-gray sandstone, lying on Fuson formation	5
	70

The following section is near the mouth of Government Canyon, 3 miles above the mouth of the creek and 3 miles west of the eastern edge of the quadrangle:

Section of Dakota sandstone near mouth of Government Canyon.

	Feet.
Flaggy sandstone at top of formation	16
Massive sandstone	6
Dark sandy shale	15
Iron concretionary band	1
Highly carbonaceous black shale	10
Massive sandstone	14
Flaggy to massive sandstone	8
Grayish shaly sandstone with iron concretions	4
Flaggy to massive sandstone with iron concretions near the bottom	10
Dark-gray carbonaceous shale	5
Shaly sandstone	6
Flaggy to massive sandstone	4
Iron concretionary band	1
Shaly to flaggy sandstone	5
Massive sandstone	4
Shaly sandstone with iron concretions	12
Flaggy sandstone	7
Yellow sandy shale with iron concretions	8
Shaly carbonaceous sandstone, lying on Fuson formation	4
	140

Fossils and age.—In this region the Dakota has yielded no satisfactory fossils, but in other portions of the Black Hills it has been found to contain remains of dicotyledonous plants of later Cretaceous age.

GRANEROS SHALE.

Components.—The Graneros formation in this quadrangle consists of four distinct members—the lower black shale, a massive sandstone, the Mowry beds, and the upper shale—the total thickness being about 1250 feet. These divisions are clearly defined lithologically and widely exposed. They are also distinct topographically, the massive sandstone and the overlying Mowry beds rising in ridges of moderate prominence from valleys of the adjoining shales. The massive sandstone is apparently identical with the petroleum-bearing sandstone of the Newcastle quadrangle.

Distribution.—The Graneros outcrop extends along the west slope of the hogback range in a zone which is narrow at the south but broadens toward the north, reaching a width of 12 miles in the north-central portion of the quadrangle. The greater part of the valley of the Little Missouri is excavated in its shales. The formation extends far eastward on some of the hogback ridges on the west side of the Belle Fourche Valley, where it rises in elevations of considerable prominence. The largest of these is Strawberry Hill, in which an altitude of about 4400 feet is attained. On the west slope of the Missouri Buttes the formation rises locally to an altitude of nearly 5000 feet.

The lower shale.—The lower Graneros shale occupies a much dissected belt of considerable width in the west-central and northern portions of the quadrangle. The member enters the area from the south as a narrow band, for here the dips are relatively steep. After crossing Cabin Creek at a point several miles west of the Belle Fourche, the dip rapidly decreases and the outcrop zone extends northward and then northeastward, with gradual increase of width. South of Mud Creek the outcrop lies wholly to the east of the Little Missouri, but northeast of that creek the western boundary extends west of the river and rises above the valley alluvium. The area thus situated on the west side of the valley gradually grows wider toward the northeast.

The rock is a fissile shale of dark-gray or intensely black color. Small deposits of sandstone and sandy shales occur near the bottom, and here and there iron-charged concretions 1 to 2 feet in diameter are scattered through the middle and upper portions, but they show at few places, except in the extensive exposures, and are nowhere abundant. They not uncommonly are inclosed by a shell of cone-in-cone structure 2 to 6 inches thick. Owing to the extremely soft nature of the shales the small streams have cut deep gullies, so that the resulting topography is for the most part one of innumerable small hills and ridges or badlands over which travel is difficult. The thickness of the shale varies considerably, but is prevailingly greater in the central and northern portions of the quadrangle. On the southern border it is 120 feet. In Barnard Canyon due north of Devils Tower it is 150 feet. On T. L. Creek it is a little more than 200 feet, but the full thickness is not revealed. It can not, however, be much greater than 200 feet. Near the head of the intervening Elkhorn Creek, where the shale is crossed by contour line 4150, its thickness is 180 feet. The amount on Hulett Creek 3 miles above its mouth is at least 190 feet, but, as on T. L. and Tie creeks, the full thickness was not observed at points where satisfactory measurements could be made. The lithologic nature of the member is nearly constant throughout the quadrangle.

Sandstone member.—The sandstone lying on the basal black shales is most extensively developed in the area drained by Hulett, T. L., and adjacent creeks. Its outcrop extends along the east side of the Little Missouri Valley as far as Mud Creek, where it crosses the river under the alluvium; thence northeastward it appears at intervals a short distance west of the stream. It crosses Cabin Creek in a zone which is rather narrow, but to the north, in the vicinity of Yeast's ranch, it extends some distance eastward up the shale slopes and caps several outlying knobs. Extensive outlying areas cap the irregular ridges adjoining and at the heads of T. L., Elkhorn, and Hulett creeks, and smaller outliers occur west and northwest of the Missouri Buttes and cap Strawberry Hill and the ridge next north.

The rock is a massive sandstone of medium to coarse grain and in a few places it becomes a conglomerate. The conglomeratic character is well developed in the two areas west and northwest of the Missouri Buttes. The rock in the outcrops nearest the buttes consists largely of pebbles about the size of a pea, while in the larger area 2 or 3 miles away many of the pebbles are 1 inch in diameter and there are some reaching 2, 3, or even 4 inches. The thickness of the sandstone varies from 8 feet, as the approximately general amount south of Poison Creek, to 50 feet in the area south and west of Elkhorn Creek. Northeast of Hulett's ranch it varies from 25 to 40 feet. East of Hulett Creek the sandstone is much the same as the Dakota sandstone in general appearance, and outcrops in many prominent cliffs. North and south of this locality the sandstone is much less distinct topographically and over considerable areas is not clearly exposed.

Mowry member.—The main outcrop zone of the Mowry member lies immediately west of the sandstone described in the preceding paragraphs and, like it, follows the general course of Little Missouri Valley. In the southern half of the quadrangle, where the strata dip rather steeply, the outcrop is narrow, in few places reaching more than half a mile. In the northern half the dip is low and in consequence the outcrop is considerably wider. From Mud Creek to the mouth of North Fork of Little Missouri River the Mowry beds give rise to a ridge of moderate prominence on the west side of the Little Missouri, and this feature also extends northeastward from North Fork to the northeast corner of the quadrangle. There are several outliers of the member on the high ridges between the Little Missouri and Belle Fourche valleys. Three of them cap portions of the high divide between Poison Creek and the head of Elkhorn Creek north-northwest of the Missouri Buttes. The fourth is of small size and lies along the granite outcrop west of the main peak of the Missouri Buttes; here the beds are steeply upturned.

The thickness of the Mowry beds is nearly constant, several measurements giving 115 to 125 feet. The material is a compact shale of dark color, containing large numbers of detached fish scales. These scales are found in all portions of the member, but vary in abundance. In places they are closely packed together, while in some beds they are somewhat widely scattered. In general they are sprinkled singly over the shale surfaces, in the proportion of one to four scales in 6 square inches. They range mostly from one-half to three-fourths of an inch in diameter.

In the hand specimen of fresh rock the shale differs little in general appearance from that of the lower Graneros except in fissility, the lower beds being thin and papery, while the Mowry scale shales are thicker or more slabby and considerably harder. Owing to the fact that the Mowry beds are much harder than the adjoining shales, they give rise to hills and ridges of moderate prominence. They afford a fairly firm hold for tree roots, and as a result the Mowry hills are generally well covered with pines and scrub oaks. The shales are dark gray or decidedly black when fresh, but, unlike the other Graneros shales, weather through drab to a distinct light gray, and this light color, together with the wooded hills and ridges, causes the Mowry outcrop to be very conspicuous. The contact of the Mowry beds with the underlying sandstone is in most places distinct, but the contact with the overlying upper Graneros shale is as a rule concealed by the mingled shales of the two members. One exceptional local feature consists in the prominent exposure near the west end of the area that lies between Poison Creek and the head of Hulett Creek, where the Mowry beds are tinged with red oxide of iron and from a distance present a most unusual bright-reddish tint, unlike the common light gray. Without close examination the rock at this place might be mistaken for the massive Graneros sandstone.

Upper shale.—The soft shale constituting the upper member of the Graneros formation is widely exposed in the north-central portion of the quadrangle. This is due chiefly to the low, undulating dip in the area northwest of Little Missouri River, where the outcrop of the upper shale, partially concealed by a broad veneer of alluvium, occupies many square miles of low, rolling grazing land. In the vicinity of Mud Creek the dip is steeper and the outcrop zone narrows to less than half a mile. It maintains approximately this width southward to a point beyond Poison Creek, where the dip lowers and the outcrop widens considerably. Near Yeast's ranch it becomes much constricted again on account of steepening dip, and continues southward across Cabin Creek and beyond the quadrangle boundary as a rather narrow belt.

This member consists of dark-gray to black shale interbedded with lime concretions, of which many are traversed by cracks filled with calcite. Most of the concretions near the bottom contain much iron and disintegrate readily into dark-brown or black chips that lie thickly strewn over the weathered surfaces in many places. Perhaps the most distinctive concretionary layer of the member is one lying near the top. The concretions of this layer contain considerable sand and many of them carry *Prionocyclus*, *Inoceramus*, and *Scaphites*.

The thickness of the upper Graneros shale midway between Mud and Driscoll creeks west of Little Missouri River is approximately 850 feet. Farther north the amount appears to be greater, but the measurements were less definite. In the accompanying section the measurements were obtained by estimate for that part of the formation which is exposed along the prominent ridge west of the margin of the alluvium of North Fork of the Little Missouri between Prickly Pear and Battle creeks. The general lithologic features are clearly exposed, but the measurements of thickness may be somewhat in error on account of irregularity of dip. Since the section does not include the portions concealed by and lying east of the alluvium, it would seem that if the measurements are approximately correct the full thickness in this locality might reach considerably more than 1000 feet.

Partial section of upper Graneros shale between Prickly Pear and Battle creeks.

	Feet.
Black shales with bands of lime-clay concretions about every 8 or 10 feet	75
Highly fossiliferous lime-clay concretions and black shales alternating in beds from 4 to 8 feet thick	60
Black shale	60
Thin sandstone lenses	1
Black shale with a few bands of sandy septarian concretions	200±
Black shale	100±
Large septarian concretions, sandy and fossiliferous	12
Black shale	40
Concretions	12
Black shale with scattered bands of sandy septarian concretions	300±
	860±

GREENHORN FORMATION.

The Greenhorn formation is not so clearly defined in the Devils Tower quadrangle as in other portions of the Black Hills uplift. It consists of alternating beds of lime-clay concretions and black shales, the shales being almost identical in general appearance with the Carlile and upper Graneros shales and the concretions not differing greatly from those of the Carlile. The concretions are of sufficient importance, however, to give a perceptible topographic effect, and with careful observations, in the absence of good exposures, the general position of these beds may be traced over the gently undulating surface. The concretions vary from a few inches to several feet in diameter, the usual size being 1 to 4 feet. They have a bluish-gray color and are spherical or ellipsoidal in shape. Here and there they show a well-developed septarian character, and a fair proportion contain fossils, chiefly *Inoceramus labiatus*, a fossil which is characteristic of this formation. The thickness of the formation varies between 60 and 80 feet, but its stratigraphic limits are somewhat indistinct. The accompanying section, as measured between Prickly Pear and Battle creeks, amounts to 78 feet. The thickness midway between Mud and Driscoll creeks is 60 feet. The outcrop of the formation occupies a narrow north-south zone that extends across the western part of the quadrangle, in the northwest corner being deflected somewhat toward the northeast and widening considerably on account of change in strike and dip.

Section of Greenhorn formation between Prickly Pear and Battle creeks.

	Feet.
Large septarian lime concretions (1 to 6 feet in diameter) with *Inoceramus*	15
Black shale	8
Shale with smaller lime concretions	2
Black shale	30
Shale with lime concretions	1
Black shale	12
Shale with large lime concretions, at supposed base of formation	10
	78

CARLILE SHALE.

The outcrop zone of the Carlile shale extends north and south in a narrow band lying entirely in range 67. From Cabin Creek to Mud Creek the width is only a few hundred yards, but it increases to the north, being about a mile north of Gammon Creek. In places the formation rises in knobs and ridges on the divides, especially on a prominent point known as Blackbank Hill, which it caps. The greater part of the outcrop is on gentle grass-covered slopes, and only one good section was obtained, at a point midway between Mud and Driscoll creeks, where the thickness is 620 feet. The formation is made up of three fairly distinct divisions. The upper division is about 300 feet thick and is nearly all shale; few concretions are present and these occur at indefinite horizons. The middle division is 125 feet thick and consists of concretions and shale, the concretions being of considerable size and in sufficient number to leave an impress on the topography in favorable localities. The lower division is 200 feet thick and, like the upper division, is chiefly shale, only a few concretions being observed. The middle series much resembles the Greenhorn formation, but lacks the distinctive *Inoceramus*.

A section measured between Mud and Driscoll creeks is as follows:

Section of Carlile shale near Mud Creek.

	Feet.
Fine light-gray shale	70
Yellow and dark-gray shale	80
Light-gray septarian lime concretions (4 to 6 feet in diameter) in dark, somewhat fossiliferous shale, much carbonate of lime in veins	6
Yellowish-gray shale with a few concretions 1 foot in diameter near the bottom	12
Fine black shale with a few septarian concretions 1 foot in diameter	25
Large septarian concretions in black shale; a few fossils in the concretions	12
Very fine black shale with a few small concretions	90
Grayish-black shale with abundant somewhat fossiliferous iron-stained lime concretions in lower part (*Inoceramus*, *Prionocyclus*, and here and there a baculite). This series forms a slight ridge	125
Grayish-black shales with a few sandy lime concretions	200
	620

Correlation.—This formation is correlated with the Carlile shale of other portions of the Black Hills uplift by continuity of outcrop, by its occurrence between distinctive Niobrara beds above and Greenhorn below, and by its fossils, especially *Prionocyclus woolgari*.

NIOBRARA FORMATION.

The outcrop of the Niobrara formation lies next west of that of the Carlile shale, extending north and south in a narrow zone across the western portion of the quadrangle. Its greatest thickness, which appears to be between Mud and Driscoll creeks, is not more than 120 feet. The width of the outcrop in the northwestern part of the quadrangle is nearly one-fourth mile. In the southern half of the quadrangle the thickness is less and the dip greater, so that the outcrop narrows to only 40 to 50 yards. Not far from the southern limit of the quadrangle the outcrop becomes indistinct, and on the slopes north and south of Cabin Creek it is wholly concealed beneath local wash. West of Blackbank Hill, in the northern part of the quadrangle, the thickness seems to be less than 80 feet, but the measurements are not conclusive. The lithologic character of the Niobrara in this quadrangle is identical with that which is so uniformly peculiar to it throughout the Black Hills region—that is, it consists of soft, light-gray, slabby shales, weathering to creamy yellow and chalky gray, finely dotted with white specks and carrying thin, irregular aggregates of *Ostrea congesta*.

In old exposures the yellow color is very conspicuous and characteristic. For this reason the Niobrara, notwithstanding its thinness and softness, is a particularly important guide to the stratigraphic succession in the western half of the quadrangle.

Section of Niobrara formation midway between Mud and Driscoll creeks.

	Feet.
Pierre shale.	
Creamy-yellow shales	12
Grayish-yellow and dark-gray shales	14
Very deep creamy-yellow, soft shales with a few thin layers of *Ostrea congesta*, lying on Carlile formation	94
	120

Section of Niobrara formation 1 *mile east of bench mark* 4036, *west of Little Missouri River, nearly due west of Hulett.*

	Feet.
Pierre shale.	
Grayish-yellow soft shales	20
Very deep creamy-yellow, soft shales with some thin *Ostrea* bands one-half to 1 inch thick	50
Yellowish-gray, soft shales with few *Ostrea*	14
	84

PIERRE SHALE.

The Pierre shale is extensively exposed along or near the western edge of the quadrangle, occupying a broad area in its northwest corner and continuing northwestward far beyond the boundary. South of Mud Creek, where the dips are steeper, the outcrop narrows to a width of 1½ to 2 miles.

Like several of the formations already described, the Pierre is largely soft dark-gray shale. It contains lime-clay concretions at many horizons, but these are of secondary importance. In much of the lower part they are small, contain much oxide of iron, and readily break up into reddish-brown chips which cover the weathered slopes much as do the somewhat darker pieces of the upper Graneros shale. Higher in the formation the concretions are larger and some of them, by decrease in clay admixture, become nearly pure limestone. The best illustration of this is 4 miles north of Yeast's ranch, where well-rounded concretions of nearly pure, bluish-gray limestone 1 to 5 feet in diameter lie in considerable numbers along the outcrop. The beds at this place dip 80° W. Highly fossiliferous concretions may be found a short distance above and below the horizon of these large concretions. Much of the shale in the lower part of the formation weathers to a dull gray, but the upper beds remain black. All of the shale produces a decided gumbo soil, nearly all of which is covered by an excellent growth of grasses.

The greatest thickness of Pierre shale within the quadrangle is in the northwest corner. Opportunities for measurement are not favorable, owing to the very low dip, but the thickness appears to be more than 1500 feet.

In the numerous concretions which occur in the Pierre shale at various horizons there are in many places 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 here and there *Lucina occidentalis*.

FOX HILLS SANDSTONE.

Along the western-southwestern border of the quadrangle the Pierre shale is overlain by buff sandstones which appear to represent the Fox Hills formation, but positive evidence of their age was not obtained. The rocks are in general massive but extremely soft and in few places well exposed. They grade into Pierre shales through a few feet of sandy shale. Some indurated beds are present, but they do not seem to have any wide distribution. On the north side of Good Lad Creek, northwest of Yeast's ranch, a rather concretionary sandstone appears in one or two places about 80 feet above the Pierre. This and the beds intervening down to the Pierre were carefully searched for fossils, but none were found. Three miles southwest of Yeast's ranch a 1-foot bed of sandy limestone was observed near the bottom of the formation. This likewise contained no fossils. One sandstone of more than usual hardness and persistence caps a number of the higher hills near the western border of the quadrangle between Prairie and Good Lad creeks. In places it reaches a thickness of 30 feet and is highly cross-bedded, and in one locality, 2½ miles south of the point where Prairie Creek enters the quadrangle, it contains turtle bones and bones of some other vertebrate, some fossil wood, and here and there *Inoceramus*. Thin beds of hard rock are included at intervals below this fossiliferous stratum for a hundred feet or more.

Concretions are present in this formation and in at least two places they have the distinctive form of "log concretions." These were best observed on a little knoll south of the Little Missouri, 200 yards west of the north-south wagon road 2 miles west of Yeast's ranch. The log concretions are near the bottom of the formation, in a soft sandstone which differs but little from the concretionary material, except that the latter is harder. Some of the concretions are spherical, as usual, but most of them are elongated and a number present excellent cylindrical forms. They are gray and some are slightly iron stained, but in general not more so than ordinary weathered sandstone of the region. The matrix sandstone is brownish yellow. It is extremely soft and the wind has carved it in an interesting manner. About 5 miles north-northwest of this locality there is another but less important exposure of log concretions, about 350 feet above the bottom of the formation. The concretions in general vary much in shape. Some are 1 or 2 inches in diameter and 1 to 5 feet in length; others are 4 to 5 feet in diameter and 15 to 20 feet in length. The spherical forms reach as much as 5 feet in diameter. Some are sharply conical and others roughly nodular as if several had been joined together. As a rule they weather free from the matrix, but some blend into hard, slabby sandstone.

The greatest thickness of the Fox Hills sandstone included in the quadrangle is apparently about 400 to 450 feet.

TERTIARY SYSTEM.

Deposits.—The Tertiary is represented by small outliers in the southeastern and south-central portions of the quadrangle. The largest is on the high flat east of Poison Creek. The deposit here consists of only a thin sheet of white clay and nodular argillaceous limestone, poorly exposed. The greatest thickness is near the south end of the area, where the amount is 8 feet. The deposit lies unconformably upon the massive Graneros sandstone in the central and southern parts of the area and upon the Mowry beds in the northern part. A similar but smaller deposit lies on a high ridge in the southeast corner of the quadrangle 1 mile north of the southern boundary and 2½ miles west of the eastern boundary. This deposit is mostly concealed, its presence being detected only by stray bits of white nodular limestone scattered over the surface. Another more important area lies just northwest of the Missouri Buttes. The southern edge begins 150 yards from the base of the northwestern butte and, curving southward, extends to a point within 250 yards of the lake at the head of Lake Creek. From this edge the area extends westward and northwestward one-half mile or more. Exposures are not good on the side next the buttes, but along the western edge from 20 to 30 feet of the deposit are shown in several places. The material is the usual fine, massive, creamy-white calcareous clay with thin bands or bunches of argillaceous limestones. There is some indication that a considerable area in addition to that mapped lies beneath the heavy grass-covered porphyry talus northwest and north of the northwestern butte. The thickness can not be determined with accuracy, but the deposit appears to have a dip of 5° or more and there is a vertical distance of about 160 feet between the lowest exposure on the west side of the area and the highest exposure near the buttes. The Tertiary lies upon the Graneros sandstone at the west, but toward the south end it rests upon the Mowry beds, while nearer the lake it appears to extend onto the lower shale of the Graneros formation. One-half mile west of the Missouri Buttes area there is another very small area. Between the two occur scattered fragments of Tertiary limestone, remnants of a connection which existed between the deposits at no distant time.

Correlation.—No fossils were found in the Tertiary deposits, and there is no basis for correlating them with beds in other regions. They may belong to the White River formation, which extends high on the eastern slope of the Black Hills.

QUATERNARY SYSTEM.

Terrace deposits.—High terrace deposits, products of an earlier drainage system, are present in various places in the quadrangle. Their thickness is nowhere great and in some areas the deposits consist of isolated bowlders and pebbles scattered over the surface. A number of areas are shown on the geologic map, but these do not fully represent the original extent of the deposits. Much of the northwest corner of the quadrangle seems to have been once covered by the bowlder deposits, as evidenced by scattered bowlders or pebbles which remain in many places; only the thicker and larger areas were mapped. The deposits lie chiefly west and northwest of the Little Missouri, although a few of small extent occur near and east of the Belle Fourche.

Alluvium.—Alluvial deposits cover areas of moderate extent in the Devils Tower quadrangle. Belle Fourche River and its tributaries are bordered by alluvial flats of considerable width, but the widest are along and to the west and northwest of the Little Missouri. These deposits, which consist chiefly of loam and fine sand, pass insensibly into the more recent wash along the upper courses of the many smaller streams. They are of local origin, having been derived from the neighboring outcropping rocks. Along the upper Little Missouri the light-colored sands from the sandstone highlands to the west have mingled with the clay from the shales of the formations below.

Igneous Rocks.

GENERAL RELATIONS.

The sedimentary rocks of the Devils Tower quadrangle are intersected by several masses of igneous rock which were intruded between the strata in early Eocene time. These igneous rocks outcrop in detached areas at the northwestern margin of the extensive zone of intrusions that extends across the northern portion of the Black Hills uplift. Most of these rocks in this quadrangle have been intruded as laccoliths between strata ranging in age from Spearfish to lower Benton, the intrusions being at progressively higher horizons to the northwest. The most notable igneous masses constitute Devils Tower and the Missouri Buttes; others occur on branches of Lytle Creek, in the southeast corner of the quadrangle, and a small laccolith is revealed in Barlow Canyon. The early Eocene age of these intrusions is indicated by the fact that they intersect or are associated with the uplift of strata as late in age as later Cretaceous, while in places they are overlapped by Oligocene deposits.

PHONOLITE PORPHYRY OF DEVILS TOWER.

Occurrence.—The mass of igneous rock known as Devils Tower is one of the most conspicuous and notable features in the Black Hills province. Characteristic views of the steep-sided shaft, which rises 600 feet from a rounded ridge of sedimentary rocks, 600 feet high, on the west bank of the Belle Fourche, are given in figs. 1 and 2 on the columnar section sheet. Its nearly flat top is elliptical in outline, with a north-south diameter of over 100 feet and an east-west diameter of about 60 feet. Its sides are strongly fluted by the great columns of the igneous rock and are nearly perpendicular, except near the top, where there is some rounding, and near the bottom, where there is considerable outward flare. The base is hidden by a talus of huge masses of broken columns lying upon a platform of the lower buff sandstone of the Sundance formation. Lower down are slopes of Spearfish red beds, which present high eastward-facing cliffs on the bank of the Belle Fourche. All the strata lie nearly horizontal, with a slight downward deflection toward the center of the igneous mass. In the narrow ridges northwest of the tower part of the beds are somewhat tilted in various directions, but apparently this is due to undermining by erosion in the adjacent gulches.

Columnar structure and talus.—The great columns of which the tower consists are mostly pentagonal in shape, but some are four or six sided. The average diameter is 6 feet and in general the columns taper slightly toward the top. In places several columns unite in their upper portion to form a large fluted column. The columns are not perpendicular, but slope inward toward the top, the angle being 4° to 5° on the west side and 10° to 12° on the east side. They are not much jointed, but are marked horizontally by faint ridges or swellings, which give the rock some appearance of bedding, especially toward the top of the tower. Near the top there is much cross jointing and more or less decomposed rock which crumbles into rounded fragments. The color at the top is brownish, mottled with dirty yellowish green, due to lichens. In the lower quarter or third of the tower the columns bend outward and merge rather abruptly into massive rock which toward the base shows but little trace of columnar structure. This massive rock circles the tower as a bench, extending out 30 to 40 feet. It is strongly jointed, in part into irregular prismatic forms and in part into rough, coarse layers. On the southwest face the long columns curve outward over the massive basal portion and lie nearly horizontal. The rugged pile of talus extends high up the lower slopes of the massive bench at the base of the tower and also far down the adjoining slopes of the sedimentary rocks. In places it rises as a low ridge a short distance from the base of the tower, the fragments falling from the higher cliffs having bounded some distance away. At one point on the platform a short distance south of the tower there is a low hill of porphyry showing a surface of 30 or 40 feet of massive rock which may possibly be in place, while a low cliff of massive porphyry a few rods southeast of the base of the tower strongly suggests igneous rock in place.

Laccolithic intrusion.—There is no conclusive evidence as to the former extent of the Devils Tower rock and location of its vent. The vertical columns indicate that the tower does not represent the conduit of a flow to higher levels, and for this reason it is believed that the mass is the remains of a laccolith which was originally much larger than the tower. It is evident that much of the laccolith has been eroded, but the original form and extent can only be conjectured. There is no evidence but that the vent is under the tower or the talus, for the materials of the associated agglomerate are of local origin and no dikes appear in the surrounding area. It has been suggested by Jaggar that the tower is a remnant of the southeast end of a laccolith extending from the Missouri Buttes, but this idea involves an improbable amount of erosion and numerous other complexities.

Petrographic description.—The rock from Devils Tower has been described as phonolite by Pirsson (Am. Jour. Sci., 3d ser., vol. 47, 1894, pp. 341–344) and as sanidine trachyte by Caswell (Geology of the Black Hills, 1880). It is here called phonolite porphyry in recognition of its porphyritic texture. The following petrographic description is by Albert Johannsen:

Megascopically the rock is coarsely porphyritic and is medium gray in color. It consists of large, white or colorless, short, thick crystals of feldspar and minute, dark-green pyroxenes, in a gray, aphanitic groundmass. The felspar crystals vary from one-eighth to one-half inch in diameter, although most of them are somewhat less than one-fourth inch.

Under the microscope the phenocrysts are found to be feldspar, pyroxene, apatite, and a very little magnetite and titanite. They vary greatly in size and are somewhat less in amount than the groundmass. No nephelite phenocrysts are found. The feldspar, a soda-rich orthoclase, is in general fairly fresh, though somewhat altered along cleavage cracks to kaolin and isotropic zeolites. The pyroxene, varying from perhaps one-fourth to one-half as much in amount as the feldspar, occurs in short, thick crystals, is very fresh, and almost invariably shows zonal structure. It is green in color and as a rule darkest around the edges. The centers are augite and the outer zones are ægirite. The apatite phenocrysts are short, thick, colorless prisms or hexagonal basal sections. Magnetite occurs only in a few irregular grains, and titanite, in rectangular or lozenge-shaped crystals, most of which are twinned, is rare. Apatite is present in small amount as an accessory.

The groundmass consists of small orthoclase laths in subparallel position and shreds and needles of ægirite, with small clouded crystals and anhedrons between. These clouded spaces are for the most part indeterminate; some of them are clear and colorless and definitely alkali feldspar, but about half of them are brownish and clouded. It is probable that they were, in part, originally nephelite, but, if so, that mineral is now entirely altered in the specimens examined. Pirsson describes some fresh nephelite and an altered mineral of the sodalite group in the material he examined. Scattered through the groundmass, in some of the rock, is magnetite in exceedingly small cubes. There is much secondary material—calcite, kaolin, chlorite, analcite, and an anisotropic zeolite. Very commonly a calcite center is surrounded by an analcite rim, the whole being a cavity filling. Some of these secondary products have definitely been derived from the feldspars, as is shown by the fact that the decomposition has taken place along cleavage cracks.

No chemical analysis was made of this rock, but the specimen analyzed by Pirsson from the same locality showed the following composition:

Analysis of phonolite porphyry from Devils Tower.

SiO	61.08
Al_2O_3	18.71
Fe_2O_3	1.91
FeO	.63
Mgo	.08
CaO	1.58
Na_2O	8.68
K_2O	4.63
H_2O (ign.)	2.21
TiO_2	.18
SO_3	Trace.
Cl	.12
MnO	Trace.
BaO	.05
	99.86
O—Cl	.03

According to the quantitative system the rock of the above analysis is a nordmarkose containing 10.5 per cent of normative nephelite. As it is probable that the specimens collected did not contain much nephelite, possibly the rock may be more correctly described as ægirite-syenite porphyry.

PHONOLITE OF THE MISSOURI BUTTES.

Occurrence.—The Missouri Buttes, which rise prominently above the plateau of Dakota sandstone on the divide between the Belle Fourche and Little Missouri valleys, 3 miles northwest of Devils Tower, consist of phonolite. There are four principal peaks, rising from 500 to 800 feet above the adjacent plateau, which is somewhat higher than the top of Devils Tower. The buttes are on the four corners of an approximately rectangular ridge about a mile in diameter, the eastern side of which is cut away by a deep draw at the head of the east prong of Lake Creek. The highest butte is on the northwest corner and rises to an altitude of 5372 feet; the next in height, on the northeast corner, has an altitude of 5218 feet; the other two are about 200 feet lower. The butte on the northeast corner is separated from its neighbor on the west by a deep saddle, but the depressions between the others are more shallow. The buttes and the adjoining ridge consist of phonolite, but in the saddle on the north side the rock is possibly not continuous. All the adjoining slopes consist of talus, which is narrow to the south, west, and east, but extends down the gentle declivity over half a mile to the north and northwest. In the depression between the two western buttes there is a low ridge of phonolite which may possibly be a dike, but its relations are not exposed.

Structure—Columnar structure, so strongly exhibited in Devils Tower, is much less developed in the Missouri Buttes, but columns appear at some of the exposures, standing at various steep angles, and on the northeastern butte they lie nearly horizontal with their pentagonal ends projecting from the face of the cliff.

The buttes are interpreted as the remains of a laccolith or series of laccoliths, of irregular oval form. Apparently the magma rose through a vent or vents, lying beneath the present igneous masses. The intrusive rock appears to lie upon a platform of nearly level Dakota sandstone, but on its west side the lower Graneros shale and an outlier of Tertiary rocks are overlapped by the talus. Probably here the igneous rock is in contact with the shale. At a few points the sedimentary beds have dips of 10° or more, but it is not apparent that these steeper dips are due to the intrusion.

Petrography.—The rock from the Missouri Buttes is of a rather dark-green color and subordinate porphyritic texture. A representative sample from the northwest side of the northwestern butte is described by Mr. Johannsen as follows:

The rock has a very fine aphanitic groundmass, full of small lath-shaped white feldspar phenocrysts from one-sixteenth to one-fourth inch in length and a few small dark pyroxene prisms. Under the microscope the texture is seen to be porphyritic, the phenocrysts exceeding the groundmass in amount. The phenocrysts vary greatly in size and are in subparallel position. They are all short, broad laths, are very regular in shape, and consist of feldspar, nephelite, and pyroxene. The feldspar is a soda-rich orthoclase. Nephelite is about equal in amount and occurs in similar form. Both the feldspar and nephelite are considerably altered to analcite in cracks and patches. The pyroxene is very much less in amount than either the feldspar or nephelite and is ægirite-augite or ægirite. Apatite occurs as an accessory in the form of long, thin needles with longitudinal inclusions. Magnetite occurs sparingly in the ægirite in the form of irregular grains.

The groundmass consists of a felt of very minute needles of ægirite with interspaces of orthoclase and a very cloudy brownish isotropic substance, probably a zeolite derived from nephelite. The character of the groundmass is the same as in the rock from Devils Tower. The phenocrysts are, however, more numerous and more uniform in size, and nephelite occurs as well as feldspar.

SYENITE PORPHYRY OF BARLOW CANYON.

Occurrence and relations.—In the bottom of Barlow Canyon, $2\frac{1}{2}$ miles northeast of the Missouri Buttes, there is a small exposure of igneous rock. It appears in a small cliff about 250 yards long north of the road. The rock is intruded immediately below the massive sandstone in the lower portion of the Sundance formation, and this bed is domed over the laccolith with dips of 7° to 10° on the west side and 5° on the east side. The base is not exposed. The sedimentary rocks show no marked evidence of alteration, and the disturbance is confined to the immediate vicinity of the laccolith.

Petrography.—Mr. Johannsen describes the Barlow Canyon rock as follows:

It is pinkish brown in color and consists of numerous small white and pink feldspar and very few biotite phenocrysts in an aphanitic groundmass which greatly exceeds the phenocrysts in amount.

Under the microscope, in the single specimen examined, the phenocrysts are not everywhere definitely determinable. An untwinned alkali feldspar and a little ægirite or ægirite-augite occur, with a small amount of biotite. Besides the fresh phenocrysts, there are areas which are entirely altered to an almost isotropic mineral which was not determined and which is very similar in appearance to the groundmass, though a little less yellow in color. The outlines remaining show that this mineral occurred in irregular rounded grains; it may have been a feldspathoid.

The groundmass is very much altered. There are numerous very small feldspar laths in subparallel position and some small rectangular areas, many of which are altered and which may represent either a feldspar or a nephelite. The greater part of the groundmass, however, is of a brownish, nearly isotropic alteration substance, and in this, besides the phenocrysts mentioned above, are a great many patches of radiating crystals, which were probably originally ægirite. Titanite and magnetite occur as accessory minerals, and analcite, calcite, kaolin, and chlorite are secondary.

The rock, in the specimen examined, is too much decomposed to permit satisfactory determination. It may have been originally an ægirite-syenite porphyry, or possibly a phonolite.

PHONOLITE OF LYTLE CREEK.

In the valley of Lytle Creek, in the southeast corner of the quadrangle, there are several areas of phonolite which project from the northwestern margin of the Bear Lodge instrusions. They cut the Sundance and Spearfish beds, following the strata to some extent, but also cutting across them, although the latter feature may be due to dikes. This phonolite was described by W. S. Tangier Smith in the Aladdin folio (No. 128), substantially as follows:

The rock is mostly massive and of a moderately light-gray to dark-gray color, in general with a slight greenish tinge. It is porphyritic, containing coarse tabular sanidine crystals, many of which have a length of 3 cm. or more. Besides sanidine (or perhaps soda orthoclase), the phenocrysts comprise anorthoclase, augite, and ægirite-augite, locally with augite centers or ægirite rims, or both. An altered and undeterminable feldspathoid or group of feldspathoidal minerals, melanite-garnet, magnetite, titanite, apatite, and here and there zircon, also occur as phenocrysts. Feldspar or the feldspathoid is most common, though locally ægirite-augite is most abundant. Brownish or brownish-yellow melanite is common in some places; magnetite is in general unimportant; while titanite and apatite are common accessories in most of the rock.

The groundmass of this phonolite is invariably fine grained, in some places granular, more commonly trachytic, and for the most part showing flow structure. It is composed mainly of alkali-feldspar laths, together with more or less ægirite or ægirite-augite, or both, locally augite, one or more feldspathoids, in many places a small amount of magnetite, and here and there a little garnet. As a rule, only one feldspathoid was noted, most commonly a second generation of the one occurring among the phenocrysts. Nephelite occurs in the groundmass of some of the rock, being locally abundant, in clear, colorless, short, hexagonal prisms.

LAMPROPHYRE DIKES.

On one of the spurs of the ridge of Lakota sandstone in the northwest corner of T. 52, R. 64, the Morrison shale is traversed by three narrow perpendicular dikes of lamprophyre. These dikes run N. 80° W., but are exposed for only a few yards. The largest is 5 feet wide and about 4 rods distant from the other two. These are each about 1 foot wide and separated by a foot of shale, which is not visibly altered and shows but slight disturbance. According to Mr. Johannsen—

the dikes consist of a dark-green, rusty-looking rock with an aphanitic groundmass containing a few small black phenocrysts. The microscope shows the texture to be obscurely porphyritic. There are numerous long, thin laths, a few of them rounded or irregular, grading into a slightly anisotropic, very clouded, and much altered groundmass, whose original character is now indeterminate. The phenocrysts consist of long laths of various sizes of pale-green diopside, crystals and irregular grains of magnetite, and rather large prisms of perfectly fresh apatite. Red iron oxide occurs in considerable amount in irregular patches, and there is a very little pyrite.

AGGLOMERATE.

Associated with the intrusions of Devils Tower and the Missouri Buttes are masses of agglomerate consisting of fragments of rocks of various kinds included in an apparently igneous matrix.

Devils Tower.—The exposures near Devils Tower are at the edge of the main talus slope on the west-southwest side of the tower, on a small, elliptical grassy hill encircled by talus. This hill is about 150 yards long and trends to the west-southwest. It consists of agglomerate, which does not appear elsewhere in the vicinity, although it may underlie some of the talus. According to T. A. Jaggar, jr., who described this rock in the Twenty-first Annual Report, the matrix appears to be a decomposed porphyry, and the rocks included comprise irregular fragments of granite, limestone, sandstone, quartzite, purplish rhyolite, slate or schist, black shale, flint, and coarse pegmatite. The most conspicuous fragments are of granite in rounded and angular masses, varying in size from small grains to bowlders 1 to 2 feet in diameter. The rounded masses have a somewhat faceted character. A bowlder of fossiliferous Pahasapa limestone a foot in diameter was noted, incased in a shell half an inch thick which could be easily stripped and appeared to be due to calcination. Some of the sandstone grains have a crust about them, suggesting fusion. The shales in the agglomerate are carbonaceous and comprise two varieties, one breaking into small blocks of dark-gray color and the other into soft, coaly flakes. Shales of this character occur at intervals in the formations from the Minnelusa to the later Cretaceous.

Monzonite.—Half a mile west of the Missouri Buttes there is a small area of granular rock the structural relations of which are not exposed. It appears in the slopes of lower Graneros shale north of the lake and extends northward about 50 yards to a point at which it disappears beneath a small area of Mowry beds and a wide area of Tertiary deposits. Its greatest width is 20 yards. One massive pile of the rock is 12 feet long, 10 feet wide, and 8 feet high. It is separated from the igneous rocks of the buttes by slopes of lower Graneros shale. Probably this body is a remnant of agglomerate from which all the finer materials have been removed by erosion, but there is a possibility that it may be a separate intrusion.

According to Mr. Johannsen the rock has the following petrographic character:

Megascopically it is a dark granular rock, showing rather large pink feldspar crystals, a greenish femic mineral, and a little quartz. Microscopically the texture is hypidiomorphic granular. The constituents are feldspar, considerably less quartz, and still less altered biotite, with accessory rutile and apatite and secondary sericite, epidote, chlorite, iron oxide, and calcite. The chief feldspar is oligoclase, which is considerably greater in amount than microcline. There is still less orthoclase. Both the microcline and the orthoclase are fresh, but the oligoclase is much clouded with many minute shreds of sericite and a little chlorite and epidote.

Missouri Buttes.—The exposures of agglomerate in the Missouri Buttes are on the eastern and south-eastern sides of the igneous area. Apparently the rock underlies the phonolite for some distance, but the relations are not exposed. It carries much coarse material, consisting largely of fragments of pink granite and sandstones of various kinds in a vesicular or highly porous matrix, the porosity being due to the leaching out of secondary minerals. Mr. Jaggar reports that, on microscopic examination, the matrix—

shows small angular fragments, reaching a maximum of 1 to 2 mm. in diameter, of quartz, orthoclase, microcline, pieces of fine-grained porphyry with ægirine, magnetite, and calcite in an earthy-brown groundmass. This groundmass, when examined under a high power, is seen to consist of a nearly isotropic base with specks of brown iron oxide. Here and there transparent portions of the base show a faint felty polarization. Ferromagnesian constituents in general are not preserved; there are one or two doubtful cases that may be idiomorphic outlines of an original hornblende or augite crystal, preserved by paramorphic masses of calcite.

STRUCTURAL GEOLOGY.

Structure of the Black Hills uplift.—The Black Hills uplift, if not eroded, would present an irregular dome at the north end of the anticlinal axis that extends northward from the Laramie Range of the Rocky Mountains. A diagram of the dome, illustrated by contours on the surface of the Minnekahta limestone, will be found in the Aladdin folio (No. 128). The dome is elongated to the south and northwest, has steep slopes on the sides, is nearly flat on top, and is subordinately fluted to a minor extent. The greatest vertical displacement of the strata, as indicated by the height at which the granite floor is now found, amounts to about 9000 feet. The subordinate flexures in the dome are mainly along the eastern side of the uplift, the most notable ones being in the ridge of Minnekahta limestone just west of Hot Springs, which may be regarded as a bifurcation of the southern edge of the dome. Another anticline of considerable prominence occurs 3 miles east of Hot Springs. The subordinate flexures are characterized by steeper dips on their western side and gentler dips to the east. They merge into the general dome to the north and run out with declining pitch to the south. On the western side of the main uplift there is a marked local steepening of dips and at the north an abrupt deflection of the dome to the northwest, which is one of its most notable irregularities. To the south the dome is separated from a small local anticline, which is the extension of the Laramie Range uplift, by a shallow syncline extending northwest and southeast. In the northern Black Hills there are numerous local domes and flexures, due mainly to laccolithic igneous intrusions, of which the most prominent is that of the Bear Lodge Range, but no similar features are indicated by the structure of the southern hills.

Faults are of rare occurrence, and none have been detected which amount to more than a few feet of vertical displacement, except where some of the igneous masses have dislocated the strata and elevated them unevenly.

Structure sections.—The sections on the structure-section sheet represent the strata as they would appear in the sides of a deep trench 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 being inferred from the position and thickness of the strata observed at the surface.

Structure of the Devils Tower quadrangle.—The principal structural features of this quadrangle are illustrated by the five structure sections on the structure-section sheet. The quadrangle embraces a portion of the northwestern margin of the Black Hills uplift, with rocks dipping to the west and northwest. There are several local irregularities in the monoclinal structure, consisting mainly of variations of strike and pitch and a few low subordinate flexures. The rate of slope in the eastern half of the quadrangle generally varies from 50 to 100 feet to the mile, but to the west and northwest the amount is much greater. West of a diagonal line passing from the northwest to the southeast corner of the quadrangle, the strike is north and south; east of that line it is northeast and southwest. Near the Belle Fourche Valley the change in strike is gradual, but in the Little Missouri Valley the change takes place abruptly near the mouth of Prairie Creek. The low dips which prevail in the region east of Little Missouri River give place within a short distance to steep dips west of that stream, in the southwestern quarter of the quadrangle. The steep dips occur in a zone of northerly strike nearly to the mouth of Prairie Creek, beyond which they diminish considerably in amount, in the region adjacent to North Fork of the Little Missouri and Thompson Creek. At North Fork the dip of the Niobrara beds is 15° W., but, entering the zone of steep dips 1 mile farther south, it increases to 60°. Midway between Driscoll and Mud creeks it is 40° in the Niobrara and 30° in the Greenhorn. About $4\frac{1}{2}$ miles north of Yeast's ranch the dip increases to 80°, but 2 miles farther south decreases to 22°. Two miles south of Yeast's ranch it increases to 45°; farther south it decreases again to 10°, but increases to 20° at Cabin Creek. The dip in the extreme southwest corner of the quadrangle is practically zero. Two miles to the north-northeast it is 4°, 2 miles west of Yeast's ranch it is 2°, and $2\frac{1}{2}$ miles northwest of this ranch it is 5° to 6°. On the western boundary of the quadrangle, midway between Good Lad and Prairie creeks, the beds are horizontal. Farther north along the western boundary and eastward through Blackbank Hill most of the area drained by Battle, Prickly Pear, Thompson, Sage, and Flat creeks has a dip of less than 5°.

Due north of the gap between the two northern peaks of the Missouri Buttes, near the head of the steep gulch leading northward to Barlow Canyon, there is a small anticline showing a dip of 5° to 7° east and west. The sharpest anticline of the quadrangle is three-fourths of a mile southwest of the lake near Missouri Buttes. So far as can be observed, this disturbance affects a very small area—a few hundred yards long at the most—but in view of the proximity of the locality to the Missouri Buttes its significance is perhaps greater than the area of disturbance might seem to imply. The axis of the anticline trends approximately northeast and southwest, the dip to the northwest being 35° and to the southeast 25°. Another sharp fold of similar character is south of Cabin Creek, on the southern boundary of the quadrangle. This is a northeast-southwest anticlinal ridge of considerable extent, the major portion of which, however, lies beyond the quadrangle. The northwesterly dip in this ridge is 12° to 30°, the southwesterly dip 20°. Farther north, near the head of Poison Creek, there is a small, rather steep dome, and still farther north, along Hulett Creek, an elongated but lower dome is exposed. In irregular areas along Elkhorn Creek and Government Canyon, as well as in smaller isolated areas on the neighboring minor streams, local doming is observed, and to this may be attributed in considerable measure the large undulating exposures in this portion of the quadrangle. The Dakota sandstone is domed in many places. This is noticed particularly on Poison Creek, on Hulett Creek, on Tie Creek, on lower Elkhorn Creek, on Broncho John and neighboring creeks, in the vicinity of Strawberry Hill near the head of Sourdough Creek, and east, northeast, and south of Government Canyon. With the exception of the Poison Creek and Hulett Creek domes, where the westerly dip reaches 15° or more, the dip is at few places more than 5° or 6° and may be calculated with fair accuracy from the topography and the areal distribution of the various formations, the thickness of each being given. There is a slight syncline 2 miles south-southeast of Anchor Reservoir, and another 2 miles north of Deer Creek near the eastern edge of the quadrangle.

In the vicinity of the Belle Fourche Valley the dips are mostly very low. North of Devils Tower the valley crosses the slope of a low dome, which causes the Spearfish red beds to rise to a moderate height in the slopes. This dome rises to the southeast mainly as a part of the Bear Lodge uplift, and with gradual increase in rate of slope approaches the great laccolith of the Warren Peaks area, which lies a short distance southeast of the southeast corner of this quadrangle. This steeper dip is a marked feature on the upper part of Lytle Creek, where the Spearfish red beds and adjoining formations rise abruptly in the vicinity of the igneous intrusions, as shown in section E–E of the structure-section sheet. There is no evidence of uplift connected with the igneous masses of Devils Tower and the Missouri Buttes, and only a slight local doming in the immediate vicinity of the intrusion in Barlow Canyon.

GEOLOGIC HISTORY.

General sedimentary record.—The rocks appearing at the surface within the limits of the Devils Tower 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 Triassic (?) time to the present, and other sediments which underlie them extend the record back into the Cambrian period. The composition, appearance, and relations of the strata indicate in some measure the conditions under which they were deposited. Sandstones ripple-marked by waters and cross-bedded by currents and shales cracked by drying on mud flats are deposited in shallow water; pure limestones suggest clear, open seas and scarcity of land-derived sediment. The fossils which the strata contain may belong to species known to inhabit waters that are fresh, brackish or salt, warm or cold, muddy or clear. The character of the adjacent land 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," as a rule result directly from the revival of erosion on a land surface long exposed to rock decay and oxidation and hence covered by deep residual soil. Limestones, on the other hand, if deposited near the shore, indicate that the land was low and that its streams were too sluggish to carry off coarse sediments, the sea receiving only fine sediment and substances in solution. The older formations exposed by the Black Hills uplift were laid down from seas which covered a large portion of west-central 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 in a general way 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. 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 west-central region. The submergence reached the Rocky Mountain province in Cambrian time, and for a while 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 offshore and partly in estuaries. Abutting against the irregular surface of the crystalline rocks which formed the shore are sediments containing much local material. Subsequently, the altitude being reduced by erosion and the area possibly lessened by submergence, the islands yielded the finer grained muds now represented by the shales that occur in the upper portion of the Cambrian in some areas. In many regions the land surface of crystalline rocks was buried beneath the sediments.

Ordovician-Devonian conditions.—From the close of Cambrian to the beginning of Carboniferous time the Black Hills area presents a scanty geologic record, the Ordovician, Silurian, and Devonian being absent in the south and only a portion of the Ordovician being present in 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 of 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 middle part of the Carboniferous the conditions were so changed that fine sand was brought into the region in large amount and deposited in thick but regular beds, apparently with much calcareous precipitate and more or less ferruginous material. The presence of the iron 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 its fossils show with a fair degree of certainty that it is a representative of the latest Carboniferous (Permian) time. It was laid down in thin layers, to a thickness now represented by only 40 feet of limestone. 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 sandy clay of the Spearfish formation was accumulated. This material probably was laid down in vast salt lakes that resulted from extensive uplift and aridity. The mud accumulated in thin layers to a thickness of 700 feet, as is now attested by the formation, and it is so uniformly of a deep-red tint that this is undoubtedly the original color. This color is present not only throughout the extent of the formation but also through its entire thickness, as 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 the 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 an epoch of little or no rainfall and consequently of temporarily suspended erosion; otherwise it is difficult to understand their nearly general purity. It has been supposed that the Spearfish red beds are Triassic, but there is no direct evidence that they are of this age, and they may be Permian. Their deposition appears to have been followed by extensive uplift, without local structural deformation but with some planation and occasional channeling, which represents a portion of Triassic-Jurassic time of unknown duration. It 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 beds. 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 the limestone layers in the upper shale of the Sundance formation indicate that deeper water followed. After this stage widespread uplift gave rise to fresh-water bodies. The first product was the thick body of fine sand of the Unkpapa sandstone, now a prominent feature along the eastern side of the Black Hills, but thinner or absent elsewhere.

Cretaceous seas.—During the Cretaceous period deposits of various kinds, but generally uniform over wide areas, gathered in a great series, beginning with such as are characteristic of shallow seas and estuaries along a coastal plain, passing into sediments from deeper marine waters, and changing toward the end to fresh-water sands and clays with marsh vegetation. The earliest of these deposits, beginning possibly in late Jurassic time, 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 the uplift which initiated the next epoch. The extent of this degradation is not known, but it has given rise to a general erosional unconformity at the base of the Lakota sandstone, the next succeeding deposit. The materials of this formation consist mainly of coarse sands spread by strong currents in beds 30 to 40 feet thick, but include several thin partings of clay and local accumulations of vegetal 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 clay of the Fuson formation. After the deposition of this clay there was a return to shallow waters and strong currents, as in Lakota time, 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, mostly in the later part of the epoch and general over the greater part of the Black Hills region. One earlier deposit was local and produced the lenses of sandstone which now underlie Mowry beds at various localities in this quadrangle 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 clay of Benton time was followed by several hundred feet of impure chalk, now constituting the Niobrara formation, and this in turn by over 1200 feet of Pierre shale, deposited under very uniform conditions. 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 the two last-named groups of sediments were deposited over any of the area now occupied by the Black Hills is not definitely known, but it is possible that they were, as they are upturned around two sides of the uplift.

Early Tertiary mountain growth.—The Black Hills dome developed early in Tertiary time—or possibly in latest Cretaceous time—to a moderate height, and the larger topographic outlines of the region were established before the Oligocene epoch, the dome being truncated and its larger old valleys excavated in part to their present depths. This is indicated by the occurrence in them of White River (Oligocene) deposits, even in some of the 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 Mississippi embayment and those of the Denver Basin.

Oligocene fresh-water deposits.—Oligocene deposits were laid down by streams and in local lakes or bayous, 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 existed, especially along the western side of the hills, but in the vicinity of Lead small outliers remain at an altitude of over 5200 feet, and on the north end of the Bear Lodge Mountains they are 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.—After the Oligocene epoch the dome was raised several hundred feet higher and was more extensively eroded. No representatives of the succeeding Loup Fork group—the Arikaree and Ogalalla formations—have been discovered in the immediate vicinity of the Black Hills but they are extensively developed in Pine Ridge to the south and remain on 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 has not been 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 places 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 which mark the southeastward 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 Missouri and Cheyenne rivers. Wide, shallow valleys have developed in the soft deposits, and canyons of moderate extent and depth in the harder rocks. Later erosion has progressed with but little deposition, but in some cases, with the shifting of channels, there have been accumulations of local deposits on small terraces at various levels.

ECONOMIC GEOLOGY.

MINERAL RESOURCES.

COAL.

At several localities on the northwestern slope of the Black Hills coal deposits occur in the base of the Lakota formation, but no coal has been observed at this horizon in the Devils Tower quadrangle. The Lakota outcrop extending across the quadrangle has been examined for coal at many localities, but as the base of the formation is commonly hidden by talus from the sandstone cliffs above, it is seldom possible to ascertain whether or not coal is present. Moreover, coal often crumbles or burns away at the outcrop and the overlying sandstone sinks down, leaving no surface indication of the presence of a coal bed. At many localities in the quadrangle the Lakota sandstone is exposed lying directly upon the Morrison shale, apparently in regular succession, indicating that no coal is present, but there is a possibility that local basins occur. Several attempts have been made to prospect for coal in the basal Graneros shale, because it is similar to the black shales often observed in association with coal, but there is not the slightest likelihood that any coal will be found at this horizon, although some of the shale is sufficiently carbonaceous to burn for a few minutes.

BUILDING STONE.

Large amounts of stone suitable for building are available from the Lakota and Dakota sandstones, but they have not as yet been utilized to any great extent. Stone also occurs in the Sundance and Fuson formations, and the sandstones and concretions in the Graneros and overlying formations can be used for rough work. Portions of the Dakota sandstone are massive, fine grained, even textured, and of a pleasant light-buff to gray tint, similar to the stone worked extensively in Buffalo Gap. At present the region is too far from railroads for this stone to be profitably worked for shipment. The igneous rocks of Devils Tower and the Missouri Buttes are so hard that there would be great difficulty in dressing them, but they could be crushed for road metal if there were any demand for it.

CLAYS.

Many of the shales above the Dakota sandstone are sufficiently soft to be classed as clays, and portions of the Fuson, Morrison, and Sundance formations could be used as clays. There is, however, no local demand for this material. Sandy clays suitable for brickmaking occur along many of the alluvial flats and they have been utilized for this purpose to a small extent at one or two points. A peculiar absorbent clay, known as bentonite, occurs in the Graneros shale, but it has not been worked in this region.

GYPSUM.

Several thin beds of gypsum are present near the top of the Spearfish formation, but their thickness in few places exceeds 2 feet and they are interbedded with soft shale. Plaster of Paris is prepared from gypsum by calcining it to drive off part of the chemically combined water, and then pulverizing it. The material is of no value, however, unless near to market.

SOILS.

Derivation.—The soils in this region are closely related to the underlying rocks, from which they are residual products of decay and disintegration, except where they are formed as alluvial deposits in the larger valleys or are spread by winds. 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 and other acids, and on its removal clay and sand remain, often forming 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 Minnelusa sandstone. If, as on the limestone plateaus, the calcareous material forms the 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 very thick in many places where the rock contains much insoluble matter. The amount of soil remaining on the rocks depends on erosion, for on many slopes the erosion is sufficient to remove the soil as rapidly as it forms, leaving bare rock surfaces. Crystalline schists and granitic rocks are decomposed mostly by hydration of a portion of their 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, thus by softening and washing giving rise to soils. If they are sandy, sandy soils result, and if they are composed of relatively pure clay a very clayey soil is the product. The character of the 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; for instance, 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 in narrow zones side by side. The only areas in which the boundaries between different varieties of soil do not coincide with the boundaries of the rock formations are in the river bottoms, in 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 below. Soils of this class are known as overplaced soils, and a special map of large scale would be required to show their distribution.

Distribution.—The arable lands of the Devils Tower quadrangle are irregularly distributed and occur in several formations. The most extensive areas available for farms are in the alluvial deposits along Little Missouri and Belle Fourche rivers and some of their branches. Many areas which have naturally fertile soils are not situated favorably for farming, notably those which are at altitudes so high that frosts are prevalent. Scanty rainfall is the principal handicap in the greater part of the area, especially in localities where there is not sufficient running water for irrigation.

The Spearfish formation is mostly bare of soil in the small areas in which it outcrops in this quadrangle. Extensive exposures of the Sundance formation are chiefly in high ridges and slopes, where ordinarily the soil is thin. Much of the formation consists of clay, and it lies in general upon dry slopes where the rainfall is seldom sufficient for raising crops. The Lakota and Dakota sandstones, although having considerable extent, yield relatively barren soils and are for the most part so dry and so situated topographically that they are not favorable for farming. The soils in the extensive shale areas in the western and northern portions of the quadrangle are mainly thin and contain a large amount of clay. They could be tilled on nearly all the lower slopes, however, if properly irrigated. The sandstones in the southwestern portion of the quadrangle disintegrate into excellent soils, but the land is not suitably situated for farming. Most of the wide alluvial bottom lands along Little Missouri River have rich and sandy loams, but in some portions of the area the percentage of clay is so large that "gumbo" results. There are many areas along the Little Missouri and its larger branches that could be farmed advantageously if they were irrigated. At many localities water could be held in reservoirs which would afford a supply for the irrigation of areas of moderate size. The alluvial flats along the Belle Fourche are in general well adapted for agriculture. At a few localities there is a predominance of sand, but in most places the soil is a sandy loam of good texture. Owing to the meander of the river from one side of the valley to the other, the alluvial tracts are cut into areas as a rule less than half a mile square. In a few places crops are raised in this valley. Small alluvial areas lie along Miller, Lytle, Blacktail, and some of the other creeks emptying into the Belle Fourche. In all of these areas the soil is of excellent quality, and water for irrigation is either available or could be easily stored in the many side draws or by damming the streams.

WATER SUPPLY.

SURFACE WATER.

The average annual rainfall in the Devils Tower quadrangle is probably somewhat less than 15 inches, but the amount of rain falling on the elevated Bear Lodge Mountains to the southeast is considerably more than this. A part 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. The Bear Lodge Mountains, which extend to a high altitude, catch many showers that do not fall on the adjacent plains and have also a greatly increased snowfall. As most of the surface of the country has a thin soil and only small areas present porous rocks, the water of rains and melting snow runs off rapidly, usually in freshets that follow storms or the rapid melting of snow, the latter taking place during warm spells in the spring. In consequence of these conditions there is but little running water in the region during the greater part of the year. Springs are few and of small volume in the lower lands.

A large amount of run-off in this region could be saved by dams and made available for irrigation. There are suitable dam sites at many localities, especially in the higher slopes. As the evaporation in the region is about 6 feet each year, a large amount of water would have to be impounded to compensate for this loss. There are many excellent dam sites along the creeks flowing into the Belle Fourche; but, to judge by the results obtained with a number of dams in the plains region farther northeast, more or less water can be held in almost all portions of the area.

Belle Fourche River carries a large volume of water at times of freshet, but is a very insignificant stream during the dry periods of midsummer. Its normal flow varies from about 2 to 15 second-feet, so far as observed, and occasionally portions of its course go dry. It drains a large area in the plains of east-central Wyoming, and the total volume of water which it carries in a year is very great. It receives numerous tributaries from the western and northern sides of the Black Hills, including some streams of considerable volume. Its waters are not used to any extent for irrigation because of the difficulty of maintaining head-gates and ditches during freshets. Its course is winding, and although there are alluvial flats within most of its bends, these are cut into small areas by the meanders, which in their outer curves as a rule impinge on the steep slopes of the valley.

Little Missouri River rises in the southeast corner of the quadrangle and flows northward to the north line of T. 55 and thence northeastward to the northeast corner of the quadrangle. Ordinarily it carries but a small volume of water, but it is subject to freshets in which the flow often is large. In dry weather the only branches from which it receives running water are Prairie Creek and North Fork of Little Missouri River, both very small streams. The flow in the river is sustained mainly by small seeps and springs in its bottom.

Lytle Creek rises on the northwestern slope of the Bear Lodge Mountains and flows northwestward, reaching the Belle Fourche a short distance east of Devils Tower. Its small flow is sustained mainly by springs which rise at intervals along its bed.

Blacktail Creek drains an inconsiderable area along the western slope of the Bear Lodge Mountains and flows in small volume to the Belle Fourche, which it joins half a mile southeast of Hulett.

Miller Creek, another small tributary reaching the Belle Fourche in the northeastern portion of T. 52, rises on the east slope of the Bear Lodge Mountains. There are numerous springs along the valley of this creek, which are important factors in sustaining the flow.

Except Blacktail, Lytle, and Miller creeks, the many small branches flowing into the Belle Fourche are dry in summer or carry only a very small volume of water, mainly in scattered pools. All the ordinary streams in the western and northern portions of the quadrangle have very scanty water supplies, and in dry weather many of them contain no water at all. Thompson Creek is an exception, for ordinarily it carries a small amount of water, mostly in pools with feeble overflow from one to another.

UNDERGROUND WATERS.

Source.—Throughout the quadrangle there are prospects of water supplies from wells of greater or less depth. The series of formations, as shown in the columnar section, includes several beds of water-bearing sandstone which receive water 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 within a short distance, owing to the relative steepness of the dip, attain considerable depth. In most of the area water-bearing beds at one horizon or another lie at a depth that is within reach of the well borer. As the region is semiarid, with surface waters inadequate or of bad quality in most localities, there is considerable need for underground waters. The principal water-bearing strata rise to the surface on the slopes of the Black Hills in regular succession, as already described. They outcrop in wide zones encircling the uplift, and receive a large amount of water not only from the rainfall on their surface but from streams which at many points sink into them wholly or in part in crossing their outcrops. The sinking of the streams in this manner is observed in almost every valley leading out of the central area. Few of the streams carry into Cheyenne River more than a small portion of the original run-off of their drainage basins, for much of it sinks underground in crossing the sandstones, particularly those of the Minnelusa, Lakota, and Dakota formations. The water thus absorbed by the sandstones passes far beneath the surface as the water-bearing beds descend on the slopes of the uplift.

Dakota-Lakota sandstones.—The Dakota and Lakota sandstones are the principal formations in which water supplies are to be expected in the western and northern, or plains portion, of the Devils Tower quadrangle. As shown on the structure-section sheet, they pass beneath the overlying shales with varying dips that carry them to a depth of about 3,700 feet along the western margin of the quadrangle. The depth to the top of the Dakota sandstone is indicated approximately on the artesian water sheet. In various portions of the country surrounding the Black Hills the Dakota-Lakota sandstones have been penetrated by wells, most of which obtain flows of greater or less volume and of satisfactory quality. The nearest wells to the Devils Tower quadrangle are those in the vicinity of Belle Fourche, a short distance to the east. Undoubtedly the same water-bearing sandstones underlie the western and northern portions of this quadrangle, and they will probably yield flowing wells in the lower lands in the valleys of the Little Missouri and its larger tributaries, as shown on the artesian water sheet.

Formations between the Lakota and Minnelusa.—In the Morrison and Sundance shales, underlying the Lakota sandstone, there are no prospects for water, although the sandstone layer in the lower portion of the Sundance formation may contain a small amount. The great mass of gypsiferous red shale of the Spearfish and Opeche formations is also not water bearing. The Minnekahta limestone is too dense to carry water, notwithstanding the fact that in some places it is cavernous.

Minnelusa formation.—As shown on the structure-section sheet, the quadrangle is underlain by the Minnelusa formation, which lies at great depth in the western and northern portions of the area but rises nearer to the surface to the southeast. In its outcrops this formation appears to consist of very porous sandstone, likely to imbibe much surface water and to constitute a water-bearing stratum available for deep wells. The numerous springs which emerge in places from the upper sandstone furnish a further indication of its properties in this regard. The formation was penetrated by a deep boring at Cambria and found to consist there of a very fine-textured rock, with the sand grains so closely cemented by lime that the interstices were filled up, without leaving room for much water. The rock appears to be of much coarser grain and less calcareous to the north, especially the upper bed of white sandstone, which would probably yield flowing water in portions of the northern Black Hills region. This upper sandstone lies at a moderate depth along the Belle Fourche and the larger confluent valleys in the southeast corner of the quadrangle. The depth to its top is shown on the artesian water sheet, from which it will be seen that along the Belle Fourche Valley from bench mark 3870, near Devils Tower, nearly to the north side of Burnt Hollow the sandstone could be reached by borings less than 600 feet deep, probably about 500 feet in T. 54 N. Above bench mark 3870 and near the eastern margin of the quadrangle the depth gradually increases to 750 feet or more. Along Lytle Creek the depth varies from 550 feet near its mouth to about 700 feet between bench marks 4146 and 4402 and 600 feet as the Bear Lodge uplift is approached, in the southeast corner of the quadrangle.

As the sandstone rises high on the slopes of the Black Hills, if it contains water the pressure or head should be sufficient to afford a flow in all the deeper valleys in the southeastern portion of the Devils Tower quadrangle.

The only attempt to obtain deep-seated waters in the vicinity of this quadrangle was in a deep boring made at Aladdin several years ago. This boring reached a depth of 1150 feet, but it was a practically dry hole. It is stated to have been abandoned in the red beds, which were entered at 400 feet. Probably it penetrated the Opeche red sandstones and was discontinued very near the top of the upper sandstone of the Minnelusa formation. It is unfortunate that this bed was not entered and tested as to its water content.

Pahasapa limestone.—As shown on the structure-section sheet, the Devils Tower quadrangle is underlain by the Pahasapa limestone, but, except in the vicinity of the Bear Lodge uplift, this formation lies at great depth. A large supply of water was obtained from it in a deep boring at Cambria, and possibly the water-bearing stratum continues to this region. Its depth in the Belle Fourche Valley ranges from 900 to 1100 feet, but toward the northwest greatly increases, so that the formation lies far below the surface in the western and northern portions of the quadrangle.

Deadwood sandstone.—Below the Pahasapa limestone is a series of shales and sandstones which probably contain a water supply, but in this quadrangle they are too deeply buried beneath the surface to be reached by ordinary boring operations.

TIMBER.

There is little merchantable timber in the Devils Tower quadrangle, but portions of the area contain abundant supplies for firewood and other local use. Scattered pines grow along the slopes of most of the canyons on either side of the Belle Fourche Valley and in moderately large bodies on the higher ridges in the southeast corner of the quadrangle. Along the Belle Fourche there is an almost continuous border of cottonwoods, many of them attaining large size. In the plains region of the western and northern portions of the quadrangle wood is very scarce. The ridge due to the outcrop of the Mowry beds is covered thinly with small pines, but farther west, in the wide shale outcrops, there are no trees, except a cottonwood here and there along the streams.

January, 1906.

COLUMNAR SECTION

GENERALIZED SECTION FOR THE DEVILS TOWER QUADRANGLE.

SCALE: 1 INCH = 500 FEET.

System	Series	Formation Name.	Symbol.	Thickness in Feet.	Columnar Section.	Depth to Top of Dakota Sandstone.	Character of Rocks.	Character of Topography and Soils.
CRETACEOUS	UPPER CRETACEOUS	Fox Hills sandstone	Kfh	250		3800 3600	Massive buff sandstone, mostly soft.	Rolling hills and rounded ridges. Sandy soil with good grass.
		Pierre shale.	Kp	1500		3400 3200 3000 2800 2600 2400 2200	Soft, dark-gray shale and clay with oval concretions.	Wide plains with shallow valleys. Thin clayey and not very fertile soil, supporting fair growth of grass.
		Niobrara formation.	Kn	80-120		2000	Light-gray limy shale; weathers straw color.	Shale slopes. Limy soil.
		Carlile formation.	Kcr	620		1800 1600 1400	Gray shale with oval concretions and thin sandstone.	Rolling hills with thin clay soil, mostly covered with grass.
		Greenhorn formation.	Kg	60-80			Shale with impure concretionary limestone.	Small bare ridges.
		Graneros shale.	Kgr	1250		1200 1000 800 600 400	Black shale with concretions.	Wide valleys containing extensive alluvial deposits.
		(Mowry member.)	(Kmr)			200 0	Hard gray shale containing many fish scales. Massive sandstone. Gray to black shale with small concretions.	Bare shaly ridges, partially wooded. Valleys with clay soil and "badlands."
		Dakota sandstone.	Kd	70-160			Gray to buff sandstone, mostly very massive; weathers reddish brown.	Plateaus, canyons, and high cliffs with rocky slopes. Thin sandy soil.
	LOWER CRET.	Fuson formation.	Kf	50-100			Shale and sandy shale with local sandstone.	Slopes below cliffs of Dakota sandstone.
		Lakota sandstone.	Klk	25-50			Light-colored, coarse, massive sandstone.	Canyons with steep cliffs. Thin sandy soil.
CRETACEOUS OR JURASSIC		Morrison shale.	Km	40-160			Massive, pale greenish-gray to maroon shale with limestone nodules.	Steep slopes below cliffs of Dakota sandstone.
JURASSIC		Sundance formation.	Jsd	340			Yellowish, soft sandstone (Unkpapa?). Greenish-gray shale with thin limestones, reddish near base. Massive, buff, ripple-marked sandstone. Dark-gray shale.	Long, gentle slopes, mostly sodded.
TRIASSIC?		Spearfish formation.	Ћs	200+			Red sandy shale and soft red sandstone with gypsum deposits.	Wide valleys with rocky slopes. Soil thin and barren.

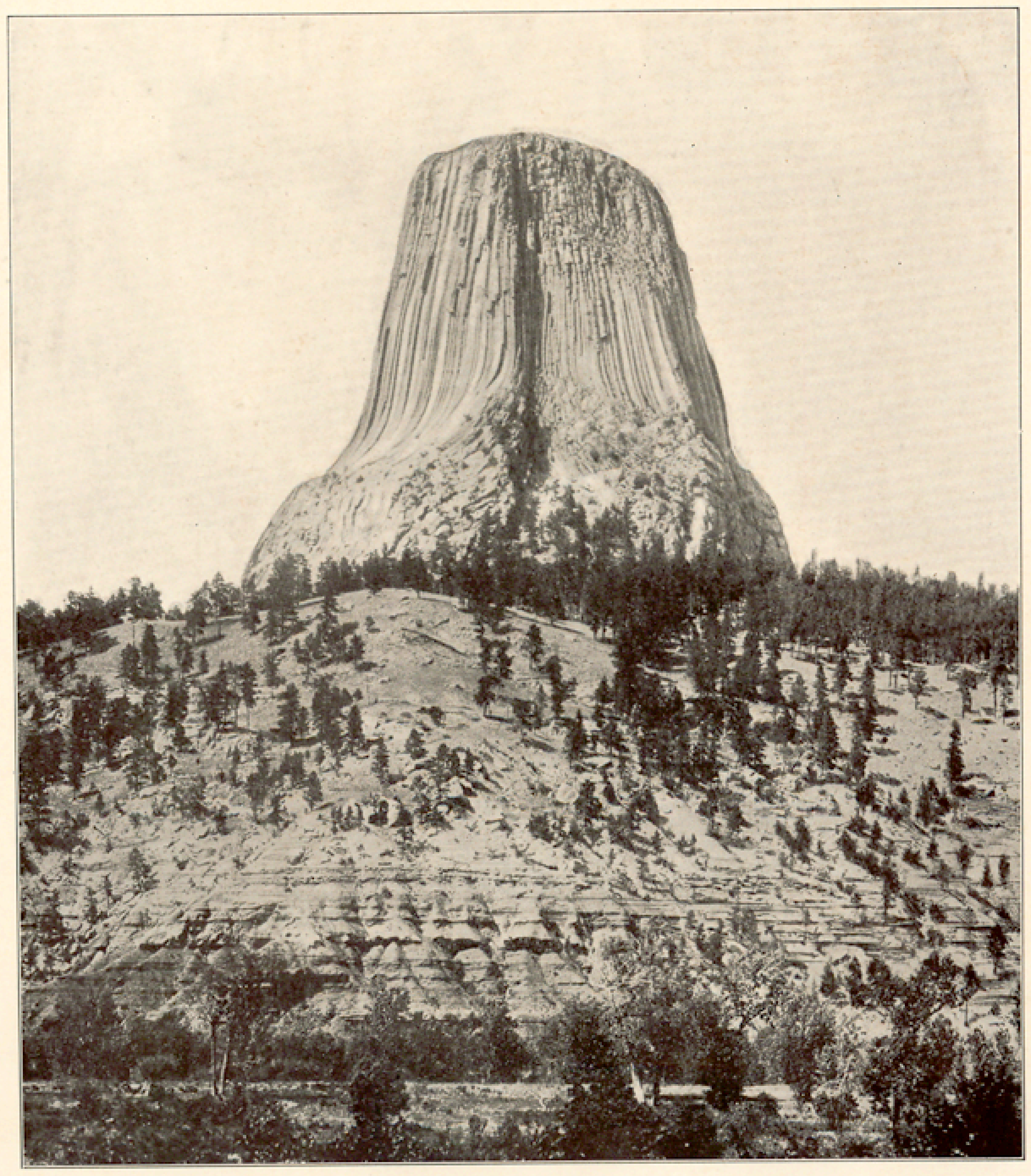

FIG. 1.—DEVILS TOWER FROM THE EAST.

The igneous rock of the tower rests on Sundance formation. The cliffs below are red shale of Spearfish formation.

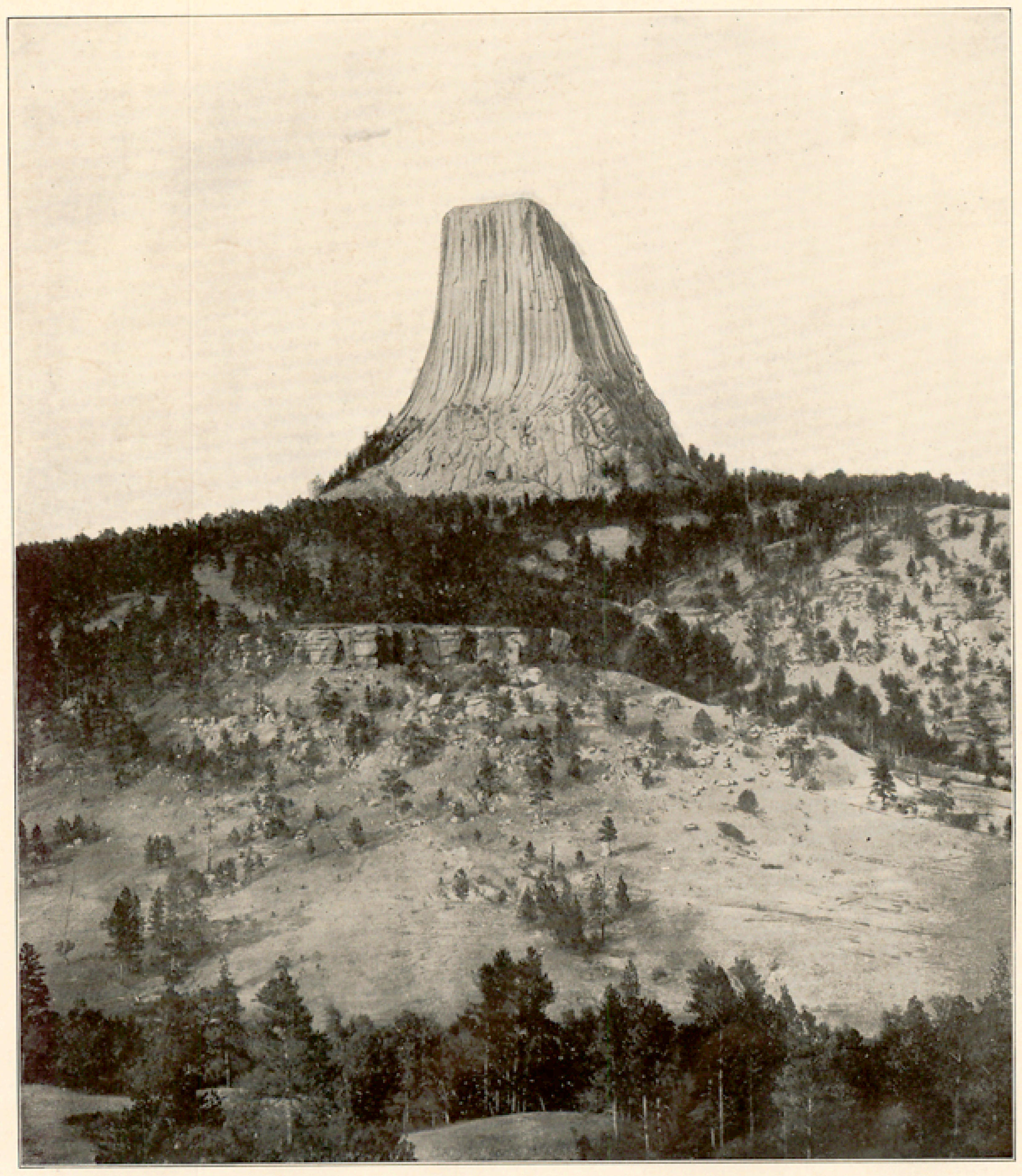

FIG. 2.—DEVILS TOWER FROM THE NORTH.

The slopes below are Sundance formation, the lower sandstone of which outcrops in the cliff near middle of view.

U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT
DIRECTOR

TOPOGRAPHY

WYOMING
(CROOK COUNTY)
DEVILS TOWER QUADRANGLE

E.M. Douglas, Geographer in charge.
Topography by W.H. Herron.
Triangulation by W.H. Herron.
Surveyed in 1902-1903.

APPROXIMATE MEAN DECLINATION 1903

Scale $\frac{1}{125000}$

Miles

Kilometers

Contour interval 50 feet.
Datum is mean sea level.

DIAGRAM OF TOWNSHIP

Edition of Mar. 1905, reprinted Dec. 1906.

U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT
DIRECTOR

AREAL GEOLOGY

WYOMING
(CROOK COUNTY)
DEVILS TOWER QUADRANGLE

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Topography by W. H. Herron.
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APPROXIMATE MEAN DECLINATION 1903.

Scale $\frac{1}{125000}$

Contour interval 50 feet.
Datum is mean sea level.

Edition of Mar. 1907.

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 C. C. O'Harra,
under the direction of N. H. Darton.
Surveyed in 1904.

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 *(sand and loam, only the larger deposits represented)*

Qtl — Talus *(of igneous rock)*

Pleistocene

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

TERTIARY

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

UNCONFORMITY

CRETACEOUS

Upper Cretaceous

Kfh — Fox Hills sandstone *(buff massive sandstone, mostly soft)*

Kp — Pierre shale *(dark-gray shale and clay, with concretions)*

Kn — Niobrara formation *(limy shale and impure chalk)*

Benton group

Kcr — Carlile formation *(gray shale and thin sandstone)*

Kg — Greenhorn formation *(black shale with limestone concretions)*

Kgr, Kmr, Kgs — Graneros shale *(dark fissile shale with sandstone bed, Kgs, and Mowry member, Kmr, composed of hard gray shale)*

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

Lower Cretaceous

Kf — Fuson formation *(shale and sandstone)*

Klk — Lakota sandstone *(massive buff sandstone)*

CRETACEOUS OR JURASSIC

Km — Morrison shale *(massive sandy shale, gray, greenish, and maroon)*

UNCONFORMITY ?

JURASSIC

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

UNCONFORMITY

TRIASSIC ?

Trs — Spearfish formation *(red sandy shale with beds of gypsum, "Red Beds")*

IGNEOUS ROCKS

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

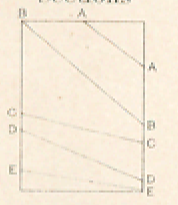
TERTIARY

Tp, Tsp, Tpp — Phonolite *(laccolithic intrusions, includes small bodies of phonolite porphyry, Tpp, and syenite porphyry, Tsp)*

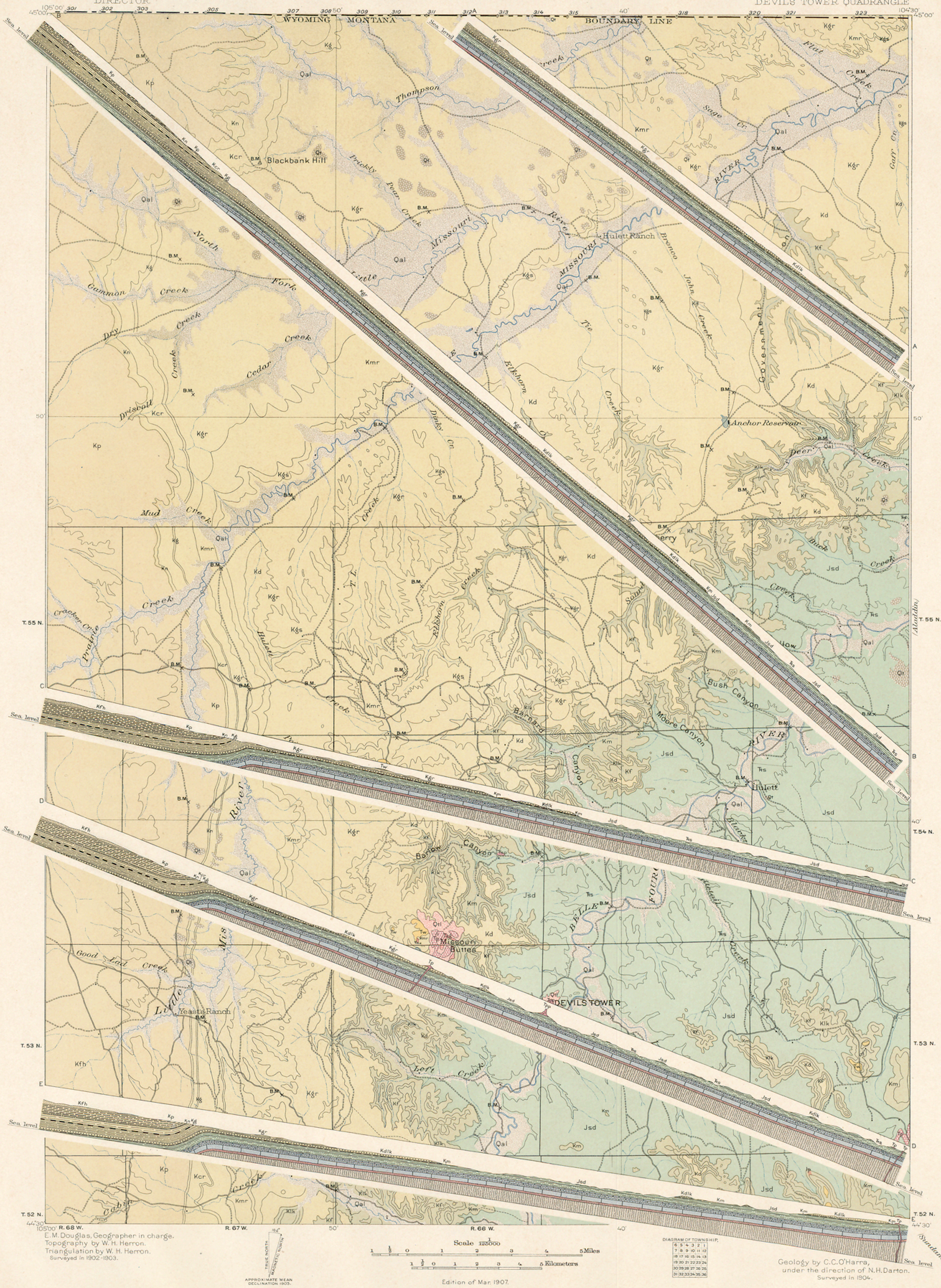
Tag, Tmz — Agglomerate *(fragments of granite, sedimentary rocks, and porphyries, in a matrix of igneous rock; a mass of monzonite, Tmz, probably an inclusion)*

lp — Lamprophyre dikes

Sections



STRUCTURE SECTIONS



LEGEND

SEDIMENTARY ROCKS

Sheet symbol	Section symbol			
Qal		Alluvium (sand and loam; only the larger deposits represented)	Recent	QUATERNARY
Qtl		Talus (of igneous rock)	Recent	QUATERNARY
Qt		Older terrace deposits (gravel and loam)	Pleistocene	QUATERNARY
Tw	Tw	Sand, gravel, and conglomerate (possibly of White River age)		TERTIARY

UNCONFORMITY

Sheet symbol	Section symbol			
Kfh	Kfh	Fox Hills sandstone (buff massive sandstone, mostly soft)	Upper Cretaceous	CRETACEOUS
Kp	Kp	Pierre shale (dark-gray shale and clay, with concretions)	Upper Cretaceous	CRETACEOUS
Kn	Kn	Niobrara formation (limy shale and impure chalk)	Upper Cretaceous	CRETACEOUS
Kcr	Kcr	Carlile formation (gray shale and thin sandstone)	Upper Cretaceous, Benton group	CRETACEOUS
Kg	Kg	Greenhorn formation (black shale with limestone concretions)	Upper Cretaceous, Benton group	CRETACEOUS
Kgr, Kmr, Kgs	Kgr	Graneros shale (dark fissile shale with sandstone bed, Kgs, and Mowry member, Kmr, composed of hard gray shale)	Upper Cretaceous, Benton group	CRETACEOUS
Kd	Kdlk	Dakota sandstone (brownish sandstone, mostly massive)	Upper Cretaceous	CRETACEOUS
Kf	Combined with Dakota sandstone on sections	Fuson formation (shale and sandstone)	Lower Cretaceous	CRETACEOUS
Klk	Combined with Dakota sandstone on sections	Lakota sandstone (massive buff sandstone)	Lower Cretaceous ?	CRETACEOUS
Km	Km	Morrison shale (massive sandy shale, gray, greenish, and maroon)		CRETACEOUS OR JURASSIC

UNCONFORMITY ?

Sheet symbol	Section symbol			
Jsd	Jsd	Sundance formation (buff sandstone and red and greenish-gray shale)		JURASSIC

UNCONFORMITY

Sheet symbol	Section symbol			
Ꞧs	Ꞧs	Spearfish formation (red sandy shale with beds of gypsum, "Red Beds")		TRIASSIC ?
		Minnekahta limestone and Opeche formation	Do not outcrop in the quadrangle	ALGONKIAN ?, CAMBRIAN, ORDOVICIAN, AND CARBONIFEROUS
		Minnelusa sandstone	Do not outcrop in the quadrangle	ALGONKIAN ?, CAMBRIAN, ORDOVICIAN, AND CARBONIFEROUS
		Pahasapa, Englewood, and Whitewood limestones	Do not outcrop in the quadrangle	ALGONKIAN ?, CAMBRIAN, ORDOVICIAN, AND CARBONIFEROUS
		Deadwood formation	Do not outcrop in the quadrangle	ALGONKIAN ?, CAMBRIAN, ORDOVICIAN, AND CARBONIFEROUS
		Schist	Do not outcrop in the quadrangle	ALGONKIAN ?, CAMBRIAN, ORDOVICIAN, AND CARBONIFEROUS

IGNEOUS ROCKS

Sheet symbol	Section symbol		
Tp, Tsp, Tpp		Phonolite (laccolithic intrusions; includes small bodies of phonolite porphyry, Tpp, and syenite porphyry, Tsp)	TERTIARY
Tag, Tmz		Agglomerate (fragments of granite, sedimentary rocks, and porphyries, in a matrix of igneous rock; a mass of monzonite, Tmz, probably an inclusion)	TERTIARY
lp		Lamprophyre dikes	TERTIARY

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APPROXIMATE MEAN DECLINATION 1903.

Scale $\frac{1}{125000}$

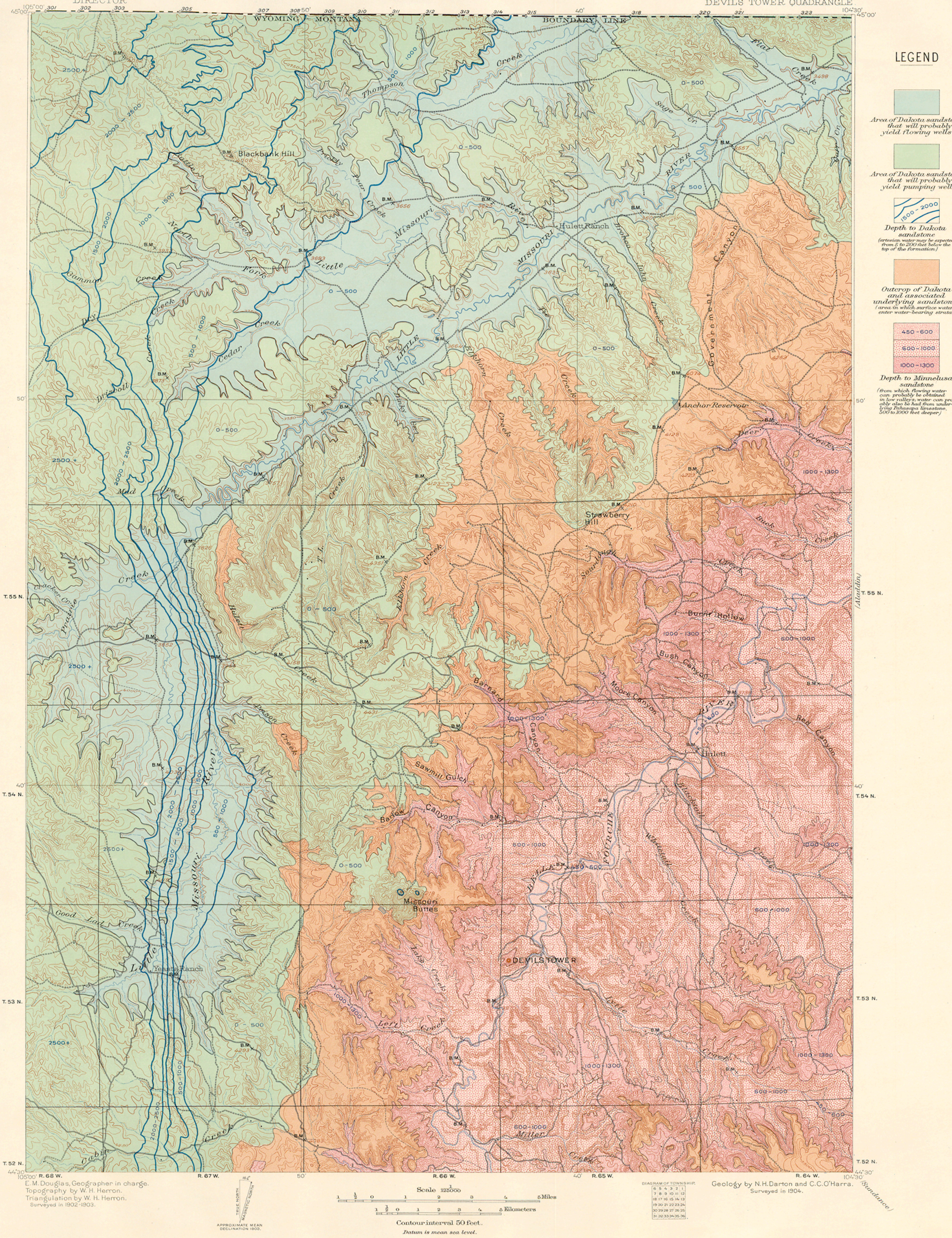
Edition of Mar. 1907.

Geology by C. C. O'Harra,
under the direction of N. H. Darton.
Surveyed in 1904.

U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT
DIRECTOR

ARTESIAN WATER

WYOMING
(CROOK COUNTY)
DEVILS TOWER QUADRANGLE



E. M. Douglas, Geographer in charge.
Topography by W. H. Herron.
Triangulation by W. H. Herron.
Surveyed in 1902-1903.

Contour interval 50 feet.
Datum is mean sea level.
Edition of Mar. 1907.

Geology by N. H. Darton and C. C. O'Harra.
Surveyed in 1904.

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.......	....	Ћ	Peacock-blue.
Paleozoic	Carboniferous.	Permian....... Pennsylvanian Mississippian..	C	Blue.
	Devonian.....	....	D	Blue-gray.
	Silurian.......	....	S	Blue-purple.
	Ordovician....	....	O	Red-purple.
	Cambrian.....	Saratogan..... Acadian....... Georgian......	Є	Brick-red.
	Algonkian	....	A	Brownish-red.
	Archean	....	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:

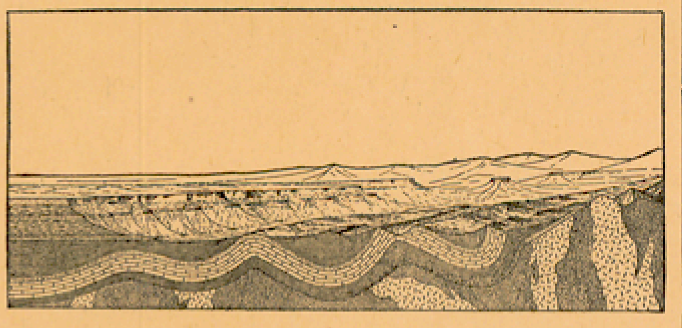


Fig. 2.—Sketch showing a vertical section at the front and a landscape beyond.

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:

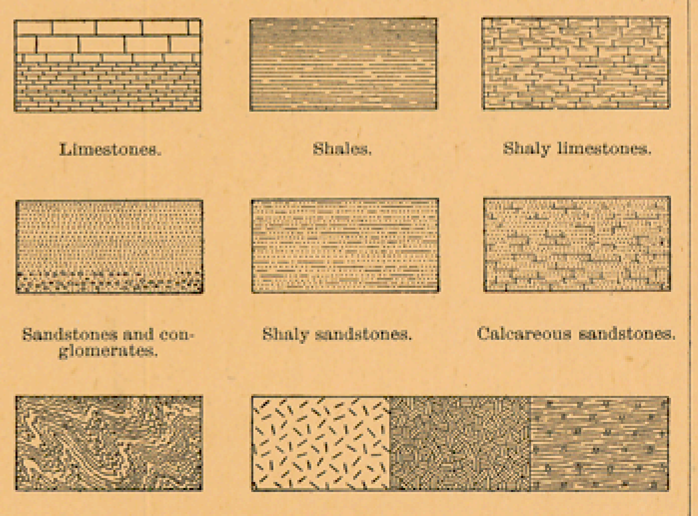


Fig. 3.—Symbols used in sections to represent different kinds of rocks.

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

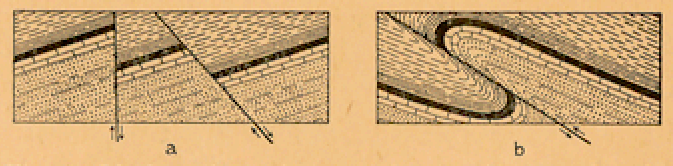


Fig. 4.—Ideal sections of strata, showing (a) *normal* faults and (b) a *thrust* fault.

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.

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