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

GEOLOGIC ATLAS
OF THE
UNITED STATES

APISHAPA FOLIO
COLORADO

BY

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GEOLOGIC ATLAS OF THE UNITED STATES.

The Geological Survey is making a geologic atlas of the United States, which is being issued in parts, called folios. Each folio includes topographic and geologic maps of a certain area, together with descriptive text.

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 of the most important ones 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 vertical interval represented by each space between lines being the same throughout each map. These lines are called *contour lines* or, more briefly, *contours*, and the uniform vertical distance between each two contours is called the *contour interval*. Contour lines and elevations are printed in brown. The manner in which contour lines express altitude, form, and grade is shown in figure 1.

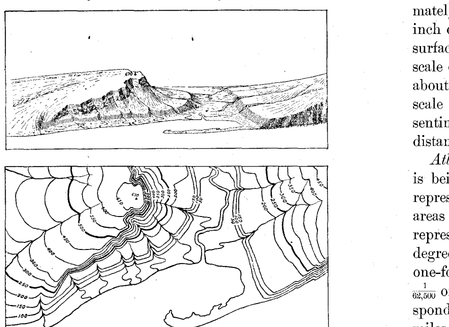


FIGURE 1.—Ideal view and corresponding contour map.

The sketch represents a river valley between two hills. In the foreground is the sea, with a bay that is partly closed by a hooked sand bar. On each side of the valley is a terrace. The terrace on the right merges into a gentle hill slope; that on the left is backed by a steep ascent to a cliff, or scarp, which contrasts with the gradual slope away from its crest. In the map each of these features is indicated, directly beneath its position in the sketch, by contour lines. The map does not include the distant portion of the view. The following notes may help to explain the use of contour lines:

1. A contour line represents a certain height above sea level. In this illustration the contour interval is 50 feet; therefore the contour lines 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 the sea—that is, this contour would be the shore line if the sea were to rise 250 feet; along the contour at 200 feet are all points that are 200 feet above the sea; and so on. In the space between any two contours are all points whose elevations are above the lower and below the higher contour. Thus the contour at 150 feet falls just below the edge of the terrace, and 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 the sea. The summit of the higher hill is marked 670 (feet above sea level); accordingly the contour at 650 feet surrounds it. In this illustration all the contour lines are numbered, and those for 250 and 500 feet are accentuated by being made heavier. Usually it is not desirable to number all the contour lines. The accentuating and numbering of certain of them—say every fifth one—suffices and the heights of the others may be ascertained by counting up or down from these.

2. Contour lines show or express the forms of slopes. As contours are continuous horizontal lines, they wind smoothly about smooth surfaces, recede into all reentrant angles of ravines, and project in passing around spurs or prominences. These relations of contour curves and angles to forms of the landscape can be seen from the map and sketch.

3. Contour lines show the approximate grade of any slope. The vertical interval between two contours is the same, whether they lie along a cliff or on a gentle slope; but to attain 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.

A small contour interval is necessary to express the relief of a flat or gently undulating country; a steep or mountainous country can, as a rule, be adequately represented on the same scale by the use of a larger interval. The smallest interval used on the atlas sheets of the Geological Survey is 5 feet. This is in regions like the Mississippi Delta and the Dismal Swamp. For great mountain masses, like those in Colorado, the interval may be 250 feet and for less rugged country contour intervals of 10, 20, 25, 50, and 100 feet are used.

Drainage.—Watercourses are indicated by blue lines. For a perennial stream the line is unbroken, but for an intermittent stream it is broken or dotted. Where a stream sinks and reappears the probable underground course is shown by a broken blue line. Lakes, marshes, and other bodies of water are represented by appropriate conventional signs in blue.

Culture.—The symbols for the works of man and all lettering are printed in black.

Scales.—The area of the United States (exclusive of Alaska and island possessions) is about 3,027,000 square miles. A map of this area, drawn to the scale of 1 mile to the inch would cover 3,027,000 square inches of paper and measure about 240 by 180 feet. Each square mile of ground surface would be represented by a square inch of map surface, and a linear mile on the ground by a linear inch on the map. 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 the inch" is expressed by the fraction $\frac{1}{63,360}$.

Three scales are used on the atlas sheets of the Geological Survey; they are $\frac{1}{250,000}$, $\frac{1}{125,000}$, and $\frac{1}{62,500}$, corresponding approximately to 4 miles, 2 miles, and 1 mile on the ground to an inch on the map. On the scale of $\frac{1}{62,500}$ a square inch of map surface represents about 1 square mile of earth surface; on the scale of $\frac{1}{125,000}$, about 4 square miles; and on the scale of $\frac{1}{250,000}$, 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, by a similar line indicating distance in the metric system, and by a fraction.

Atlas sheets and quadrangles.—The map of the United States 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 $\frac{1}{250,000}$ represents one square degree—that is, a degree of latitude by a degree of longitude; each sheet on the scale of $\frac{1}{125,000}$ represents one-fourth of a square degree, and each sheet on the scale of $\frac{1}{62,500}$ one-sixteenth of a square degree. The areas of the corresponding quadrangles are about 4000, 1000, and 250 square miles, though they vary with the latitude.

The atlas sheets, being only parts of one map of the United States, are not limited by political boundary lines, such as those of States, counties, and townships. Many of the maps represent areas lying in two or even three States. 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 are printed the names of adjacent quadrangles, if the maps are published.

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, by means of structure sections, their underground relations, so 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.—Rocks that have cooled and consolidated from a state of fusion are known as *igneous*. Molten material has from time to time been forced upward in fissures or channels of various shapes and sizes through rocks of all ages to or nearly to the surface. Rocks formed by the consolidation of molten material, or magma, within these channels—that is, below the surface—are called *intrusive*. Where the intrusive rock occupies a fissure with approximately parallel walls it is called a *dike*; where it fills a large and irregular conduit the mass is termed a *stock*. Where molten magma traverses stratified rocks it may be intruded along bedding planes; such masses are called *sills* or *sheets* if comparatively thin, and *laccoliths* if they occupy larger chambers produced by the pressure of the magma. Where inclosed by rock molten material cools slowly, with the result that intrusive rocks are generally of crystalline texture. Where the channels reach the surface the molten material poured out through them is called *lava*, and lavas often build up volcanic mountains. Igneous rocks that have solidified at the surface are called *extrusive* or *effusive*. Lavas generally cool more rapidly than intrusive rocks and as a rule contain, especially in their superficial parts, more or less volcanic glass, produced by rapid chilling. The outer parts of lava flows also are usually porous, owing to the expansion of the gases originally present in the magma. Explosive action, due to these gases, often accompanies volcanic eruptions, causing ejections of dust, ash, lapilli, and larger fragments. These materials, when consolidated, constitute breccias, agglomerates, and tuffs.

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

The chief agent in the transportation of rock débris is water in motion, including rain, streams, and the water of lakes and of the sea. The materials are in large part carried as solid particles, and the deposits are then said to be mechanical. Such are gravel, sand, and clay, which are later consolidated into conglomerate, sandstone, and shale. Some of the materials are carried in solution, and deposits of these are 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 kinds of deposit named 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*, and rocks deposited in such layers are said to be stratified.

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

Rocks exposed at the surface of the land are acted on by air, water, ice, animals, and plants, especially the low organisms known as bacteria. They gradually disintegrate and the more soluble parts are leached out, the less soluble material being left as a *residual* layer. Water washes this material down the slopes, and it is eventually carried by rivers to the ocean or other bodies of water. Usually its journey is not continuous, but it is temporarily built into river bars and flood plains, where it forms *alluvium*. Alluvial deposits, glacial deposits (collectively known as *drift*), and eolian deposits belong to the *surficial* class, and the residual layer is commonly included with them. 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 various processes, rocks may become greatly changed in composition and in texture. If the new characteristics are more pronounced than the old such rocks are called *metamorphic*. In the process of metamorphism the constituents of a chemical rock may enter into new combinations and certain substances may be lost or new ones added. A complete gradation from the primary to the metamorphic form may exist within a single rock mass. Such changes transform sandstone into quartzite and limestone into marble and modify other rocks in various ways.

From time to time during geologic ages rocks that have been deeply buried and have been subjected to enormous pressures, to slow movement, and to igneous intrusion have been afterward raised and later exposed by erosion. In such rocks the original structures may have been lost entirely and new ones substituted. A system of planes of division, along which the rock splits most readily, may have been developed. This structure is called *cleavage* and may cross the original bedding planes at any angle. The rocks characterized by it are *slates*. Crystals of mica or other minerals may have grown in the rock in such a way as to produce a laminated or foliated structure known as *schistosity*. The rocks characterized by this structure are *schists*.

As a rule, the oldest rocks are most altered and the younger formations have escaped metamorphism, but to this rule there are many important exceptions, especially in regions of igneous activity and complex structure.

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, an alternation of shale and limestone. Where the passage from one kind of rocks to another is gradual it may be necessary to separate two contiguous formations by an arbitrary line, and in some cases the distinction depends almost entirely on the contained fossils. An igneous formation contains one or more bodies of one kind, of similar occurrence, or of like origin. A metamorphic formation may consist of rock of uniform character or of several rocks having common characteristics or origin.

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

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*.

Inasmuch as sedimentary deposits accumulate successively the younger rest on those that are older, and their relative ages may be determined by observing their positions. In many regions of intense disturbance, however, the beds have been overturned by folding or superposed by faulting, so that it may be difficult to determine their relative ages from their present positions; under such conditions fossils, if present, may indicate which of two or more formations is the oldest.

Many stratified rocks contain *fossils*, the remains or imprints of plants and animals which, at the time the strata were deposited, lived in bodies of water or were washed into them, or were buried in surficial deposits on the land. Such rocks are 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. Where 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 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 many places difficult or impossible to determine the age of an igneous formation, but the relative age of such a formation can in general be ascertained by observing whether an associated sedimentary formation of known age is cut by the igneous mass or is deposited upon it. Similarly, the time at which metamorphic rocks were formed from the original masses may be shown by their relations to adjacent formations of known age; but the age recorded on the map is that of the original masses and not that of their metamorphism.

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

Patterns composed of parallel straight lines are used to represent sedimentary formations deposited in the sea, in lakes, or in other bodies of standing water. Patterns of dots and circles represent alluvial, glacial, and eolian formations. Patterns of triangles and rhombs are used for igneous formations. Metamorphic rocks of unknown origin are represented by short dashes irregularly placed; if the rock is schist the dashes may be arranged in wavy lines parallel to the structure planes. Suitable combination patterns are used for metamorphic formations 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 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 of series that have been given distinctive names, in order from youngest to oldest, with the color and symbol assigned to each system, are given in the subjoined table.

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		Ꞧ	Peacock-blue.
Paleozoic	Carboniferous	Permian; Pennsylvanian; Mississippian	C	Blue.
	Devonian		D	Blue-gray.
	Silurian		S	Blue-purple.
	Ordovician		O	Red-purple.
	Cambrian		Є	Brick-red.
	Algonkian		A	Brownish red.
	Archean		Æ	Gray-brown.

SURFACE FORMS.

Hills, 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; waves cut sea cliffs and, in cooperation with currents, build up sand spits and bars. Topographic forms thus constitute part of the record of the history of the earth.

Some forms are inseparably connected with deposition. The hooked spit shown in figure 1 is an illustration. To this class belong beaches, alluvial plains, lava streams, drumlins (smooth oval hills composed of till), and moraines (ridges of drift made at the edges of glaciers). Other forms are produced by erosion. The sea cliff is an illustration; it may be carved from any rock. To this class belong abandoned river channels, glacial furrows, and peneplains. In the making of a stream terrace an alluvial plain is first built and afterward 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. Lakes or large rivers may determine local base-levels for certain regions. When a large tract is for a long time undisturbed by uplift or subsidence it is degraded nearly to base-level, and the fairly even surface thus produced is called a *peneplain*. If the tract is afterward uplifted, the elevated peneplain becomes a record of the former close relation of the tract to base-level.

THE VARIOUS GEOLOGIC SHEETS.

Areal geology map.—The map showing the areas occupied by the various formations is called an *areal geology map*. On the margin is a *legend*, which is the key to the map. To ascertain the meaning of any color or pattern and its letter symbol the reader should look for that color, pattern, and symbol in the legend, where he will find the name and description of the formation. If it is desired to find any particular formation, its name should be sought in the legend and its color and pattern noted; then 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 names of 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.—The map representing the distribution of useful minerals and rocks and showing their relations to the topographic features and to the geologic formations is termed the *economic geology map*. The formations that appear on the areal geology map are usually shown on this map by fainter color patterns and the areas of productive formations are emphasized by strong colors. A mine symbol shows the location of each mine or quarry and is accompanied by the name of the principal mineral mined or stone quarried. If there are important mining industries or artesian basins in the area special maps to show these additional economic features are included in the folio.

Structure-section sheet.—In cliffs, canyons, shafts, and other natural and artificial cuttings the relations of different beds to one another may be seen. Any cutting that 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 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 to a considerable depth. Such a section is illustrated in figure 2.

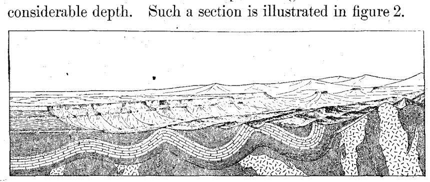


FIGURE 2.—Sketch showing a vertical section at the front and a landscape beyond.

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 patterns of lines, dots, and dashes. These patterns admit of much variation, but those shown in figure 3 are used to represent the commoner kinds of rock.

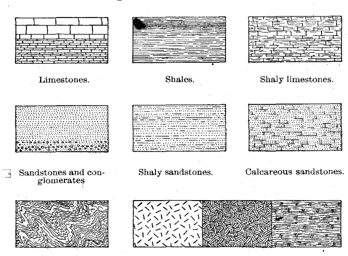


FIGURE 3.—Symbols used in sections to represent different kinds of rocks.

The plateau shown at the left of figure 2 presents toward the lower land an escarpment, or front, which is made up of sandstones, forming the cliffs, and shales, constituting the slopes. 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 of the intersection of a bed with a horizontal plane is called the *strike*. The inclination of the bed to the horizontal plane, measured at right angles to the strike, is called the *dip*.

In many regions the strata are bent into troughs and arches, such as are seen in figure 2. The arches are called *anticlines* and the troughs *synclines*. As the sandstones, shales, and limestones were deposited beneath the sea in nearly flat sheets, the fact 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 figure 4.

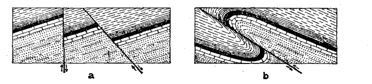


FIGURE 4.—Ideal sections of strata, showing (a) *normal* faults and (b) a *thrust* or *reverse* fault.

At the right of figure 2 the section shows schists that are traversed by igneous rocks. The schists are much contorted and their arrangement underground can not be inferred. Hence that portion of the section delineates what is probably true but is not known by observation or by well-founded inference.

The section also shows three sets of formations, distinguished by their underground relations. The uppermost set, seen at the left, is made up of sandstones and shales, which lie in a horizontal position. These strata were laid down under water but 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 uplifted. The strata of this set are parallel, a relation which is called *conformable*.

The second set of formations consists of strata that have been folded into arches and troughs. These strata were once continuous, but the crests of the arches have been removed by erosion. 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 shown at the left of the section. The overlying deposits are, from their position, evidently younger than the underlying deposits, and the bending and eroding of the older beds must have occurred between their deposition and the accumulation of the younger beds. The younger rocks are *unconformable* to the older, and the 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 folded or 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 were metamorphosed, they were disturbed by 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 figure 2 are ideal, but they illustrate actual relations. 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 that appears in the section may be measured by using the scale of the map.

Columnar section.—The geologic maps are usually accompanied by a *columnar section*, which contains a concise description of the sedimentary formations that 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 that state the least and greatest measurements, and the average thickness of each formation is shown in the column, which is drawn to scale. The order of accumulation of the sediments is shown in the columnar arrangement—the oldest being at the bottom, the youngest at the top.

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

GEORGE OTIS SMITH,
Director.

May, 1909.

DESCRIPTION OF THE APISHAPA QUADRANGLE.

By George W. Stose.[a]

GENERAL RELATIONS.

GEOGRAPHY.

Location and area.—The Apishapa quadrangle is bounded by meridians 104° and 104° 30′ and parallels 37° 30′ and 38° and includes one-fourth of a square degree, an area, in that latitude, of 944 square miles. It lies wholly in Colorado and comprises portions of Las Animas, Pueblo, Otero, and Huerfano counties. (See fig. 1.) Its northwest corner is about 20 miles southeast of Pueblo.

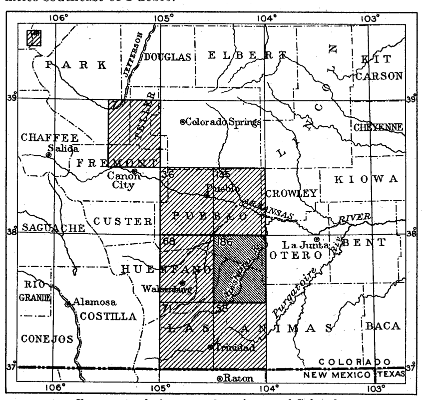


FIGURE 1.—Index map of south-central Colorado.

The location of the Apishapa quadrangle is shown by the darker ruling (No. 186). Published folios describing other areas, indicated by lighter ruling, as follows: Nos. 7, Pikes Peak; 36, Pueblo; 48, Tenmile district; 58, Elmoro; 68, Walsenburg; 71, Spanish Peaks; 135, Nepesta.

Great Plains province.—The Apishapa quadrangle lies in the west-central part of the Great Plains province, which extends from the Rocky Mountains province on the west to the Prairie Plains province of the Mississippi Valley on the east.

The Great Plains province as a whole slopes eastward at a rate of about 10 feet to the mile from an altitude of about 6000 feet at the base of the Rocky Mountains. Large tracts of its surface are smooth and gently undulating; others are characterized by hills, mesas, cliffs, and canyons of moderate dimensions; and a few high ridges would be called mountains if they stood at a greater distance from the imposing front of the Rockies. The portion of the Great Plains in which the Apishapa quadrangle is situated is one of the more rugged, abounding in hills and mesas several hundred feet in height.

The Great Plains are drained by eastward-flowing rivers, the larger of which have their sources in the mountains. These rivers are all tributary to the Mississippi and cross the higher part of the Plains in deep canyons cut in the eastward-sloping uplands. Arkansas River, which is the main artery of drainage for this portion of the Plains, heads within the mountains, receives the precipitation of an extensive mountainous area, and issues from its last mountain gorge as a large stream. Its general course on the Plains, in which it is incised to a depth of several hundred feet, is eastward. South of its canyon a number of minor streams, starting from the outer slopes of the mountains, flow northeastward in similar canyons to join the Arkansas. The Apishapa quadrangle, lying 10 to 20 miles south of the main river and 25 miles east of the mountain base, is traversed by three of these tributary streams—Huerfano and Apishapa rivers and Timpas Creek.

GEOLOGY.

The rocks of the Great Plains are chiefly sedimentary and were deposited in a great interior body of water, which was usually connected with the sea but whose waters became at times brackish and even fresh. The general attitude of the strata is approximately horizontal. Large areas are occupied by Tertiary beds, other large areas by Cretaceous formations, and smaller tracts by Jurassic (?) and Triassic rocks. Beneath these strata and not generally exposed at the surface of the Great Plains are representatives of several Paleozoic systems, the sedimentary series resting on a foundation of granitic rocks of Archean age.

The Rocky Mountains have been formed chiefly by uplift, and the uplifted mass has suffered extensive erosion, so that broad areas of the Archean basement rocks are exposed. Along the eastern base of the mountains the strata of the Plains are sharply upturned so as to stand at a steep angle. Their worn edges constitute narrow lines of outcrop, and collectively they make up a belt of peculiar character, separating the ancient rocks of the mountains from the nearly level formations of the Plains.

In a few places along the mountain front in Colorado red sandstones of Cambrian age, not over 100 feet thick, are exposed, overlain by several hundred feet of Ordovician limestones and sandstones. Silurian and Devonian rocks appear to be entirely absent along this part of the Rocky Mountain front, although they may be present beneath the Great Plains and have been eroded or overlapped by younger strata along the shore of the ancient sea. Resting on the older sedimentary rocks where they are exposed, and overlapping them at most other places along the mountain front, are Carboniferous and Triassic strata having a maximum thickness of possibly 1600 feet. The upper part of this series is composed of bright-red shale and sandstone which in places make a characteristic narrow red valley.

Marine Jurassic beds occur farther north along the mountain front but are apparently absent in Colorado. Overlapping all the older strata in most places along the mountain front is another red formation, of late Jurassic or Lower Cretaceous age. This is conformably overlain by the rest of the thick series of Cretaceous sediments. The older strata are steeply inclined or vertical, but the Cretaceous beds are so far from the uplifted mountainous area that they are less tilted. The sandstones near the base of the Cretaceous are inclined 40°–60° E. and because of their resistant character produce a line of hogback ridges with smooth dip slopes on the east and rocky precipitous slopes on the west. The softer overlying beds are still more gently inclined and are more nearly horizontal the farther they are from the mountain front.

FIGURE 2.—Relief map of south-central Colorado.

Shows the relation of the Apishapa quadrangle (outlined rectangle) to the front ranges of the Rocky Mountains.

Scale: 1 inch = 25 miles approximately.

The Rocky Mountain uplift is not simple but compound. Some of the major elements and many minor elements lap past one another along the eastern mountain front, with the result that the belt of steeply upturned strata adjacent to the mountains is not a simple one from north to south but exhibits a number of salient and reentrant angles, the reentrants pointing northwestward into the mountains and the salients southeastward into the plains. Just north of Arkansas River the south end of the Front Range thus projects into the plains, and just south of the river the end of the Wet Mountain Range marks a similar projection. (See fig. 2.)

The general evenness of the strata of the Plains is interrupted here and there by undulations or folds, most of them gentle, and some of these folds are associated with individual uplifts of the Rocky Mountains. From the south end of the Front Range a low axis of uplift continues in a south-southeasterly direction, and from a point near the south end of the Wet Mountain Range one of its axes of uplift is prolonged into the Plains in an east-southeasterly direction. From the junction of these axes a broader and somewhat higher anticlinal arch, the Apishapa anticline, extends southeastward for 40 or 50 miles and, with lower crest, somewhat farther, eventually joining a still broader uplift with more easterly trend, the full form of which is not yet known. Northeastward from the Apishapa anticline the strata descend to a shallow structural basin of great extent, and southwestward to a synclinal trough whose western limb follows the base of the Culebra Range of the Rocky Mountains.

South of the Wet Mountain Range, close to the base of the Culebra Range, is a conspicuous mountain mass called Spanish Peaks, formed largely of intrusive igneous rock. Radiating from the igneous nucleus of this mountain is an extensive system of vertical dikes. A little farther south, extending from a point near the base of the mountains eastward into the Plains, is a group of high mesas capped with extrusive lavas. The highest of these is Raton Mesa, whose crest rises 3000 feet above its northern base. The Apishapa quadrangle includes a portion of the district traversed by the dikes, and its drainage has probably been indirectly influenced by the volcanic extrusions.

TOPOGRAPHY.

RELIEF.

General features.—The Apishapa quadrangle is situated wholly in the Great Plains and in the drainage basin of the Arkansas, its surface having a general northeastward slope toward that river, which is 10 to 20 miles north of the quadrangle.

All details of topographic form in the quadrangle are the result of erosion by streams, rain, wind, and frost. The profiles of the surface features fall into three general lines—an upper level, formed by a series of mesas; a medial level, formed by terraces parallel to and at the foot of the mesas; and a lower level, that of the general plain above which the mesas rise and into which deep canyons are cut. These levels or benches are made more evident by a growth of trees along their rims, the surface back from the rims and the slopes below each bench being treeless or but sparsely wooded. (See Pls. I and IV.) The benches are due to successive nearly horizontal layers of more resistant rocks that form projecting ledges in the midst of soft beds that are more readily removed by erosion and occupy slopes below the ledges. As shown in figure 3, the upper

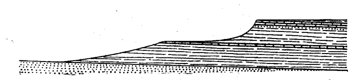


FIGURE 3.—Typical profile of the mesa escarpment capped by Timpas limestone, the medial bench capped by Greenhorn limestone, and the lower plain composed of Dakota sandstone.

bench or mesa is formed by the Timpas limestone, the medial terrace by the Greenhorn limestone, and the lower plain by the Dakota sandstone.

The quadrangle may be divided topographically into three parts—the northeastern mesa, the central upland, and the southern mesas—and each division has a characteristic topography determined chiefly by the attitude and nature of the rocks at the surface.

Northeastern mesa.—The northeastern third of the quadrangle is occupied by a rolling northeastward-sloping plain crossed by broad valleys draining in the same direction. The streams generally lie in shallow box canyons in the alluvium-filled valley bottoms, making travel across them difficult.

The mesa is bounded on the southwest by a steep zigzag escarpment facing southwestward and cut through by the streams, so that the valleys occupy deep reentrants separated by high promontories. The upper part of the escarpment is in most places a cliff 20 to 50 feet high, with steep slopes below.

[a] The principal geologic field work in the Apishapa quadrangle was done in 1894 by G. K. Gilbert, assisted by G. W. Stose and F. P. Gulliver. The accurate topographic survey on which the maps in this folio are based was not executed until two years later. The geologic boundaries and other data were transferred from the old base to the new in the office, and it is probable that some minor details of geologic boundaries are less exactly portrayed than they would have been if the geologists had had the use of an accurate topographic base in the field. In 1903 C. A. Fisher verified the mapping of formations along the northern boundary of the Apishapa quadrangle, adjacent to the Nepesta quadrangle, and afterward revised the mapping along the eastern boundary of the quadrangle. Mr. Stose traversed the quadrangle again in 1910 primarily to study the Purgatoire formation and separate it from the Dakota sandstone, thus mapping the boundary between the Lower and Upper Cretaceous. He readjusted to the new sketch of the topography such other boundaries as were observed in the field to be inaccurately located. The new drawing of the map and deformation contours and the descriptive text are by G. W. Stose.

Midway on the slope there is generally a bench, referred to previously as forming the medial level. In the stream reentrants the escarpment gradually diminishes in height and disappears at the stream crossing. The promontories have altitudes ranging from 5200 feet to over 5500 feet, the highest one, 4 miles from the north edge of the quadrangle, reaching 5514 feet. These promontories no doubt have local names not given on the map, for they stand out above the surrounding lowland like mountains.

From the escarpment the surface of the mesa has a general northeastward slope to an altitude of 4450 feet at the lowest point in the quadrangle, in its northeast corner. This surface is in general a part of a broad planation surface which formerly covered the whole region, probably rising above the tops of the Rattlesnake Buttes in the western part of the quadrangle, and below which the present surface has been eroded by means of the revival of the streams by uplift and warping of the old planation surface. (See fig. 4.) The surface slopes with the dip of the rocks but not so steeply, so that older

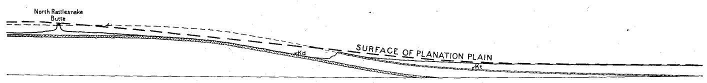


FIGURE 4.—Profile along a line running northeastward from North Rattlesnake Butte to the edge of the quadrangle, and the hypothetical position of the Tertiary planation surface which formerly covered this area.
Kd, Dakota sandstone; Kt, Timpas limestone.
Horizontal scale: 1 inch = 4 miles. Vertical scale five times the horizontal.

formations outcrop successively southwestward. The present rim of the mesa is approximately along the line where the hard limestones at the base of the Timpas were beveled by the old planation surface, as shown in figure 4, and the bounding escarpment has been cut in the softer shales of the Benton group. The position of the mesa rim is brought out more prominently on the geologic than on the topographic map by the line between the patterns representing the Timpas limestone and the Carlile shale.

The soil of the mesa is derived from limy shales, and where water for irrigation is available has proved to be fertile. The present attempt to cultivate the gentler slopes ought to be successful if sufficient water can be confined in the reservoirs on the streams and distributed by ditches without too much loss by evaporation and absorption.

Central upland.—The central and western portions of the quadrangle are occupied by a high interior plateau sloping from the Rattlesnake Buttes northward, eastward, and southeastward and drained in the same directions through deep box canyons. The altitude of the surface increases from about 5000 feet at the base of the escarpment on the northeast and about 5400 feet along the southeast side to about 6100 feet in the culminating area about the base of the Rattlesnake Buttes.

The upland surface is in general a broad, flat half dome, the margins of which are several hundred feet lower than the rims of the surrounding mesas, whereas the central part is much higher than the mesa rims. This surface is formed almost entirely of the uppermost hard beds of the Dakota sandstone, which dip northward, eastward, and southeastward with the slope of the surface. It is generally barren and the soil is scant and infertile because of the resistant nature of the rock from which it is derived.

A few hills of shale and limestone rise above the surface, the most conspicuous of which are the Rattlesnake Buttes, which surmount the culminating point of the upland, attaining an altitude of 6442 feet. (See Pl. V.) These tops are probably remnants, somewhat reduced in altitude by erosion, of the planation surface of which the northeastern mesa was a part, the rest of the central upland area having been eroded below that plane. Into the upland surface are cut canyons of various sizes, some as much as 400 feet in depth, arranged more or less radially about the summit. The deeper canyons are cut through the hard beds of the Dakota sandstone into the Purgatoire formation and are consequently very rocky and precipitous.

Southern area.—The southern area comprises several large separate mesas of Timpas limestone, including Cordova Mesa, Tyrone Flats, Poitrey Arroyo Hills, and Big Arroyo Hills. These larger mesa masses are separated by the valleys of Apishapa River and Timpas Creek and their main tributaries and are highly dissected along their margins by smaller ravines and arroyos. The mesas range in elevation from 5700 feet in Tyrone Flats to about 6480 feet near the western boundary of the quadrangle. The larger valleys in this part of the area are broad and open, but the usual small box canyons occur in the alluvial bottoms. The mesas are arid, and as they are disconnected no water can be gathered and stored on them for irrigation.

DRAINAGE.

General features.—Most of the stream channels in the quadrangle are arroyos, being dry during the larger part of the year. At almost any time, however, water can be found at favorable places in the deeper canyons in the Dakota sandstone in the central upland area, where the water flowing beneath the surface of the gravel in the stream bed emerges from place to place as a thin stream or stands in a rock-bound water hole.

During heavy rains the water rapidly runs off from the almost impervious baked clay and shale slopes and eats deep, precipitous ravines into the hills. The arroyos and canyons temporarily hold torrents of water that carry the waste products down toward the Arkansas, the flat valley bottoms being silted up as the storm waters recede.

Most of the drainage of the quadrangle flows to Arkansas River by way of Apishapa and Huerfano rivers and Timpas Creek. A small area in the northern part is drained by Chicosa Creek and its tributaries directly into the Arkansas, and a few small ravines in the southeast corner of the quadrangle discharge into Purgatoire River, also a tributary of the Arkansas.

Apishapa River.—Apishapa River heads on the east slope of Spanish Peak, 25 miles southwest of this quadrangle. It enters the southern part of the quadrangle in an open valley in which its many small branches head in reentrants in the mesa cliffs on both sides. On reaching the central upland region it enters a deep, winding canyon at the edge of the exposures of Dakota sandstone. (See Pl. VIII.) In this part of its course it receives few tributaries from the east, but three long branches, Jones Lake Fork and the streams in Bass Canyon and South Canyon, enter it from the west. These streams also flow in deep rock canyons. The headwaters of most of these streams and their many branches converge in a general way toward Rattlesnake Buttes. The Apishapa emerges from its canyon at the point where the Dakota sandstone dips beneath overlying soft strata and there enters another open valley, which leads through the mesa front to the sloping plains beyond, on which the stream meanders in a broad, open valley. Its main branches in this part of its course are Saunders Arroyo and Mustang Creek. These streams have open valleys in the plains portions of their courses, but their numerous nearly parallel tributaries, which head on the northeastward-sloping Dakota sandstone surface, have cut deep, rugged canyons. On passing out of the sandstone area, however, these streams also enter open valleys, which lead through the mesa front out upon the plains beyond. Other smaller tributaries of the Apishapa head on the slopes of the limestone mesa.

Two peculiar features in the course of the Apishapa across the quadrangle require explanation. The river cuts through a broad anticline, at the axis of which it has become deeply incised in the Dakota sandstone; and, like all the other streams that flow northeastward down the slope of the Dakota sandstone, it flows toward and through a break in the mesa front. (See fig. 5.) Such courses could not have been estab-

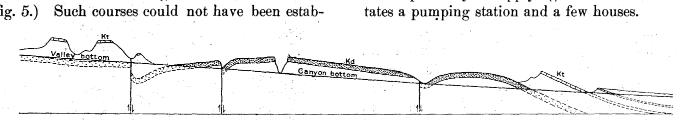


FIGURE 5.—Profile along Apishapa River in the Apishapa quadrangle.
The river's canyon in the arched Dakota sandstone in the middle is flanked at both ends by open valleys in the softer overlying strata.
Kd, Dakota sandstone; Kt, Timpas limestone.
Horizontal scale: 1 inch = 4 miles. Vertical scale ten times the horizontal.

lished on the present surface and must have been inherited from an older higher surface. This matter is discussed under "Geologic history."

Huerfano River.—Huerfano River heads in the Rocky Mountains and for only a few miles of its course passes through the northwest corner of the quadrangle, where it occupies a very deep, precipitous canyon in the Dakota sandstone and underlying formations. It has several short tributaries in the quadrangle, which also have rugged canyons, and also a larger tributary, Doyle Arroyo, which heads on the north slope of the Rattlesnake Buttes and, after passing through a canyon in the Dakota sandstone, cuts through the mesa front in a very deep reentrant before leaving the quadrangle and joining the Huerfano.

Timpas Creek.—Timpas Creek heads within and drains the southeastern portion of the quadrangle, its branches reaching back in ramifying arroyos into the limestone mesas on both sides. At Delhi it enters a short deep canyon in the Dakota sandstone and a mile or two to the west a tributary, Poitrey Arroyo, occupies a parallel canyon.

Lakes and ponds.—Scattered over the quadrangle are depressions which, during most seasons, contain ponded rain water and furnish one of the sources of water for stock. One of these lakes is shown in Plate III. A few of these lakes are on the surface of the Dakota sandstone and on the limestone mesas, but most of them are on the shales of the Benton group. During seasons of drought these temporary lakes diminish in size and many of them completely dry up. The origin of the lake basins is discussed under the heading "Geologic history."

VEGETATION.

The Apishapa quadrangle is largely a prairie that sustains a thin growth of grass, small flowering plants, sagebrush, cane cactus, and other small shrubs. Cottonwood or aspen trees line the flood plains of Huerfano and Apishapa rivers and occur more sparingly along other drainage lines. Juniper (commonly called cedar) and piñon grow on rocky tracts, especially on the benches of Greenhorn limestone, at the mesa escapments of Timpas limestone (see Pl. I), and at the brinks of canyons in the Dakota sandstone. Gilbert noted that the piñon does not grow below altitudes of about 5100 feet or the juniper below 4900 feet, and that below 5200 feet the mesa crests are mostly bald. Yellow pine grows sparingly on the Dakota sandstone and prefers the most rugged places. It is a straggler at altitudes of 5200 feet but is more abundant at 5600 to 6000 feet. The highest parts of the area—mesas of Timpas limestone about 6500 feet in elevation—are covered with juniper and piñon.

The timber has no commercial value but is used locally for making log cabins and corrals and for fire wood. All the region within reach of the newly settled agricultural tract in the northeastern part of the quadrangle has recently been stripped of its timber.

CULTURE.

The most important cultural feature in the quadrangle is the main line of the Atchison, Topeka & Santa Fe Railway, which crosses its southeast corner. Until recently the quadrangle had very few permanent residents. Many of the houses shown on the topographic map, which was surveyed prior to the establishment of White Rock settlement and scattered ranches on the northeastern mesa, are the temporary abodes of stock raisers and herders or are old, abandoned ranch houses. The McDaniel, Yellowbank, English, Pittinger, Reynolds, Bonito Cordova, and Elmore ranches, shown on the map, and the Redtop and two or three others not shown, are the chief permanent residences outside of the village of White Rock and the small settlements about the railroad stations at Delhi and Thatcher. These ranches are chiefly stock farms, having the low adobe houses typical of the plains, and most of them inclose in wire fences large areas of grazing land. The largest inclosed tract, known as the Ben Butler ranch, embraces several thousand acres in the northwest corner of the quadrangle, reaching southward to the Huerfano County line and eastward to Black Ridge. The buildings of this ranch lie just north of the quadrangle. Small patches of land around some of the ranch houses are cultivated and Mexican beans are raised in some larger tracts by dry farming.

The railroad settlements each comprise a station, a post office, one or two stores (generally abandoned or temporarily closed), a few temporary dwellings, and one or two large ranch houses where accommodations can be had. At Thatcher a reservoir in Timpas Canyon supplying water for the locomotives necessitates a pumping station and a few houses.

The settlements on the northeastern mesa are made up of quarter-section homesteads, in part fenced and under cultivation by irrigation. The houses are mostly small frame dwellings, but a few are more substantial and some are of brick.

DESCRIPTIVE GEOLOGY.

SEDIMENTARY ROCKS.

STRATIGRAPHY.

SYSTEMS REPRESENTED.

The sedimentary rocks exposed in the quadrangle belong to three systems—Cretaceous, Tertiary, and Quaternary—and possibly a fourth, Jurassic. The Cretaceous strata occupy the surface of nearly the whole quadrangle. The rocks of possibly Jurassic age directly underlie the known Cretaceous and are exposed only in the deepest canyons. The Tertiary and Quaternary strata rest unconformably upon the Cretaceous, having been deposited after a long interval of time during which there were important physical changes. The summary of the consolidated rocks of the quadrangle is given in the columnar section forming figure 6.

JURASSIC OR CRETACEOUS ROCKS.

The oldest rocks exposed in the Apishapa quadrangle are heterogeneous nonmarine sediments of the Morrison formation, which are of either Lower Cretaceous or Jurassic age.

MORRISON FORMATION.

Character and thickness.—The lowest formation exposed in the area consists of blocky clay shale or argillite, with thin layers of limestone and beds of arenaceous shale, and soft sandstone. The argillaceous rocks are of brilliant colors, ranging from white to chocolate and red and to green and drab. They are usually nonfoliated and compact, having a tendency to crack in weathering into cuboid blocks instead of shaly fragments, and can not properly be called shale. The term "argillite," which has been used to some extent for rock of this character, will be employed in this sense throughout this report. The thickness in neighboring areas ranges from 100 to 300 feet. Within the quadrangle the exposures are poor and are limited to the upper 120 feet of the formation. The following composite section measured in the Huerfano Canyon, on the western border of the quadrangle, is only approximate:

Partial section of the Morrison formation in Huerfano Canyon.

	Feet.
Sandstones of the Purgatoire formation.	
Variegated shale and compact argillite, green, drab, and dull maroon in color, largely covered	37
Massive gray sandstone having ocher-colored spots, with soft fine-grained chocolate-colored sandstone above and red layers toward the top. Largely covered. Exact relation not known	58±
Greenish-gray shale and compact argillite with 6-inch beds of impure limestone and short lenses of sandstone. The limestones contain small fresh-water gastropods and lamellibranchs	25±
	120±

Scattered outcrops of red shale and compact green to drab mottled argillite in the débris-covered slope are generally all that is seen of the formation. The impure limestones near the base (see Pl. VI) were observed at only one place and are believed to be the lowest beds outcropping in the quadrangle.

Two miles above the mouth of Jones Lake Fork, at the axis of the Apishapa anticline, at least 100 feet of the formation is exposed. The uppermost beds are here largely concealed by talus, but about 30 feet is composed of reddish shale with small yellow calcareous concretions. Below this is 8 to 10 feet of purple limestone with white calcite seams and blebs. At the base is compact green argillite, mottled with purple, weathering in part to shale, and greenish sandstone containing a 6-inch bed of dark-green and red jasper. A section measured by Gilbert at the mouth of Jones Lake Fork showed 77 feet of the formation, as follows:

Partial section of Morrison formation at mouth of Jones Lake Fork.

[By G. K. Gilbert.]

	Feet.
Thin sandstone and gray shale [Purgatoire formation].	
Chocolate-colored shale	16
Soft pale-gray sandstone freckled with brown, weathering pale brown	10
Variegated compact blocky shale, red, chocolate, green, and white, with bands of fine sandstone, some tough and brown. The lowest sandstone is a fine-grained white rock freckled with pale yellow	51
	77

The top of the formation is generally defined by the massive beds of purer light-buff sandstone of the Purgatoire formation, although at one place in the Jones Lake Fork canyon a conglomerate with red matrix was observed at the base of the Purgatoire. The base of the Morrison is not exposed in this quadrangle, but elsewhere in the region it is defined by red gypsiferous shales of the underlying "Red Beds," called the Badito formation in the Huerfano Canyon in the adjacent Walsenburg quadrangle by R. C. Hills and the Fountain formation along the mountain front in the Pueblo quadrangle by Gilbert. The following section of the formation in a branch canyon of Purgatoire River, 20 miles east of the Apishapa quadrangle, was measured by Lee:[a]

Section of Morrison formation in Red Rocks Canyon, branch of Purgatoire Canyon.

[By W. T. Lee.]

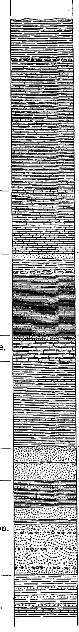
	Ft.	in.
Massive sandstone [Purgatoire formation, called Dakota by Lee].		
Brick-red arenaceous shale, containing bands of hard fine-grained sandstone	25	
Reddish limestone, very brittle and having a conchoidal fracture	3	
Soft dark clay shale	30	
Light-brown clay shale	11	
Argillaceous limestone		6
Brown shale	7	
Concretionary limestone	1	
Variegated clay shale with joint structure	7	
Fine yellow paper shale	3	
Argillaceous limestone, finely laminated		6
Fine shale	1	6
White limestone	1	
Variegated clay shale	15	
Argillaceous limestone, finely laminated		8
Yellow shale	4	
Sandstone containing agate either in concretionary masses half an inch or more in diameter or disseminated generally throughout the mass	1	
Sandstone, easily crumbling; made up of thin layers	8	
Massive sandstone, poorly indurated	2	
Fine paper shale	2	
Massive sandstone, poorly indurated	7	
Gypsum interstratified with clay, underlain by red sandstone ("Red Beds," of supposed Triassic age).		
	130	2

The agate layer near the base of the section is probably the jasper layer seen in the Huerfano and Apishapa sections. The supposed Triassic age of the red sandstone beneath the gypsum beds is based on the identification of a bone collected by Darton[b] in the Purgatoire Valley and of teeth and other bones collected by Lee in the same region as fragments of a belodont, a characteristic saurian of the Triassic. Lee's inclusion of the gypsum with the "Red Beds" is in keeping with the treatment of pre-Morrison rocks in other areas by previous writers.

The pre-Morrison rocks in the Walsenburg quadrangle were regarded by R. C. Hills as probably Carboniferous (Badito formation), and recent studies of the rocks along the Rocky Mountain front by R. D. George,[a] State geologist of Colorado, has demonstrated the Permian age of the "Red Beds" there exposed beneath the Morrison.

[a] Lee, W. T., The Morrison formation of southeastern Colorado: Jour. Geology, vol. 9, 1901, p. 347.

[b] Darton, N. H., Geology and underground waters of the Arkansas Valley in eastern Colorado: Prof. Paper U. S. Geol. Survey No. 52, 1906, p. 20.



System.	Series.	Group.	Formation.	Section.	Thickness in feet.	Character of rocks.	Character of topography and soils.
Cretaceous.	Upper Cretaceous.	Niobrara.	Apishapa shale.		500±	Light-gray calcareous papery shale with concretions containing barite in upper part.	Plains with gentle valleys. Fertile soil.
			Timpas limestone.		175	Thin-bedded light-gray chalky limestone at base, light-gray calcareous shale above, and thin cream-colored limestone at top.	Flat plains forming tops of mesas and mesa cliffs. Fertile soil, generally sparsely wooded at edges of mesas.
		Benton.	Carlile shale.		200–230	Gray to black shale, with large septarian concretions in upper part and thin fossiliferous sandstone at top containing numerous fish teeth.	Steep upper slopes of mesa escarpments, deeply gullied in places. Soil thin and barren.
			Greenhorn limestone.		25–50	Alternating layers of blue-gray fine-grained blocky limestone and darker-gray shale.	Benches on the slopes below mesas. Rocky fertile soil, generally sparsely wooded.
			Graneros shale.		210	Dark bluish-gray shale containing a few thin beds of impure limestone.	Gentle slopes, deeply gullied in places. Soil thin and barren.
			Dakota sandstone.		63–83	Massive gray sandstone, weathering rusty brown, generally in two ledges with variable thin dark shale parting.	Rocky slopes and uplands and deep rocky canyons. Soil thin and arid, wooded in places.
	Lower Cretaceous.		Purgatoire formation.		220	Chiefly light-buff cross-bedded sandstone with scattered quartz pebbles; upper third black shale with thin sandstone beds.	Cliffs and slopes of canyon walls.
Jurassic or Cretaceous.			Morrison formation.		120±	Red, green, and drab blocky shale or argillite, soft sandstone, and thin beds of limestone.	Lower slopes of canyon walls.

FIGURE 6.—Columnar section of the sedimentary rocks exposed in the Apishapa quadrangle.

Scale: 1 inch = 200 feet.

In the Walsenburg folio (No. 68) R. C. Hills describes the Morrison formation in Huerfano and Cuchara canyons, just west of the Apishapa quadrangle, as a variegated shale and clay, 100 feet thick, with bands of limestone containing vermilion cherts. Hills further states that still farther west, at the foot of Greenhorn Mountain, the south end of the Wet Mountain Range, the formation thickens to 270 feet and has a basal member 60 feet thick of soft white sandstone with conglomerate layers, which he regards as littoral deposits close to the old shore.

Distribution.—The Morrison formation occurs in only three areas in the Apishapa quadrangle. A narrow strip, exposed in Huerfano Canyon near the northwest corner, passes out of the quadrangle and reenters 2 miles to the north, where the Huerfano swings into the area again. The third outcrop is in the Apishapa Canyon, where the formation is exposed for about 4 miles along the Apishapa and for more than a mile up Jones Lake Fork, to the west. As it occurs at the base of the canyon walls, its outcrops are mostly covered by débris from the overlying sandstones. Its extent as represented on the map was determined by the position of the top of the formation as calculated from scattered outcrops.

Fossils and age.—Only a few fresh-water shells, *Valvata scabrida*, were found in this formation in the quadrangle. These were obtained from limestones which are believed to be the lowest beds exposed in the Huerfano Canyon within this area. This species is reported by Stanton to be characteristic of the Morrison formation elsewhere. The formation also closely resembles in lithologic character the Morrison of other areas, being composed largely of red and purple argillite or clay, with thin layers of limestone and segregations of characteristic red jasper or agate. Occurring immediately beneath sandstones formerly regarded as part of the Dakota, the formation occupies the position of the Morrison mapped in the adjoining Pueblo and Walsenburg quadrangles, and although its base is not exposed, it may safely be called Morrison.

At its type locality, Morrison, Colo., near Denver, and elsewhere along the Rocky Mountain front, especially at Garden Park, near Canon City, west of the Apishapa quadrangle, the Morrison contains abundant dinosaur remains, from which it early received the name *Atlantosaurus* beds. Vertebrate remains, including *Morosaurus* and *Diplodocus* vertebræ identified by Barnum Brown and *Brontosaurus* bones identified by C. W. Gilmore, have also been obtained south and east of the Apishapa quadrangle in beds corresponding in position and character to those here described and similarly exposed in deep canyons in the plains. Abundant bones were collected by Stanton and Lee in the adjacent Timpas quadrangle and similar remains would probably also be found in the Apishapa quadrangle if the exposures there were more extensive.

The fossils so far obtained from the Morrison formation comprise bones of terrestrial animals, (including mammals, dinosaurs, crocodiles, turtles, lizards, and birds) and of fresh-water fishes, and shells of land mollusks. The exact age of these fossils has not yet been determined. Some paleontologists assign the beds to the Cretaceous; others consider them to belong in the Jurassic. The fresh-water invertebrates are of modern types, not distinctive of either age, and the dinosaurs and other vertebrates, although they were formerly regarded by Marsh and others as Jurassic, are considered by such authorities as Lull[b] and Williston to be of Cretaceous age, and the beds containing them to be equivalent to the Wealden of Europe. The weight of evidence at hand at the present time is in favor of the latter view.

CRETACEOUS SYSTEM.

In the Apishapa quadrangle the Cretaceous system includes the Purgatoire formation, representing the Comanche or Lower Cretaceous series, and the Dakota sandstone, Graneros shale, Greenhorn limestone, Carlile shale, Timpas limestone, and Apishapa shale, representing the Upper Cretaceous series. The Graneros, Greenhorn, and Carlile formations constitute the Benton group, and the Timpas and Apishapa formations the Niobrara group. The thickness of the whole is about 1300 feet, of which 330 feet is sandstone, 50 feet limestone, and the remainder shale.

It may be stated with confidence that the next higher Cretaceous formation, the Pierre shale, was originally deposited over this area and has been eroded away, and it is not improbable that the Laramie formation, the highest member of the system in this region, was also once present.

LOWER CRETACEOUS SERIES.

PURGATOIRE FORMATION.

Name and definition.—The Purgatoire formation, which is composed largely of sandstone, was formerly regarded as part of the Dakota sandstone and is so mapped in the Pueblo and

[a] Personal communication.

[b] Lull, R. S., Dinosaurian distribution: Am. Jour. Sci., 4th ser., vol. 29, 1910, pp. 1-39.

Walsenburg folios. The discovery of fossil leaves of Lower Cretaceous age in the middle and lower portions of what had been previously regarded as the Dakota sandstone in South Dakota led to the suspicion that other areas of so-called Dakota sandstone included rocks of Comanche age. In 1905 Stanton[a] and Lee discovered a marine Comanche fauna in the shales between the two sandstone beds previously called Dakota in the canyons of Purgatoire, Cimarron, and Canadian rivers southeast of the Apishapa quadrangle, and similar Comanche strata were recently found by Stanton and the present writer between the Morrison and the upper portion of what had been regarded as the Dakota sandstone in the Apishapa area. Upon this discovery rests the separation of the Purgatoire from the Dakota. The formation takes its name from Purgatoire Canyon, in the Mesa de Maya quadrangle.

Character and thickness.—The upper third of the formation is composed largely of shale and minor thin, platy sandstone beds, but the lower two-thirds is almost wholly sandstone. A section of the formation in the west wall of Huerfano Canyon just beyond the western border of the quadrangle, measured by T. W. Stanton and the writer, is as follows:

Section of Purgatoire formation in Huerfano Canyon.

	Feet.
Thick massive sandstone, with brown surface (Dakota).	
Black shale, at top fissile with thin flaggy sandstone marked by trails; lower portion sandy and lumpy, forming a sand-mud agglomerate	10
Dark shale and thin sandstone, largely covered; black shale at the base containing *Lingula*, fish bones, and fine wavy sandstone lenses	50
Largely cross-bedded light-buff sandstone, with rusty upper surface apparently marked by worm tubes. Near base, thin quartz-pebble conglomerate containing teeth, vertebræ, and other bones of fish, with some maroon shale just below	40
Light-buff cross-bedded open-textured sandstone containing layers with scattered small quartz pebbles. Weathers pitted and cavernous	120
Soft green shale (Morrison).	
	220

A bed similar to the peculiar "sand-mud agglomerate" in the upper 10 feet of the section was observed in most sections in the quadrangle and helped to distinguish the shale of the Purgatoire from somewhat similar shales in the Dakota. It is a lumpy, knotty mixture of black argillaceous material and white sand grains, resembling a deposit of partly reworked unconsolidated materials. The sandstone is also to be distinguished from that of the overlying Dakota by its lighter color in the cliff (see Pl. VIII), its open texture and cavernous appearance on weathering, and its contained scattered quartz pebbles. Its open texture makes this sandstone an excellent water-bearing stratum or reservoir, and most of the artesian water obtained in this region comes from it, although generally reported as coming from the Dakota.

A more detailed section of the upper part of the Purgatoire formation, measured in the east wall of Huerfano Canyon at the western edge of the quadrangle, is as follows:

Section of Purgatoire formation in east wall of Huerfano Canyon.

	Feet.
Massive sandstone (Dakota).	
Sandstone in 2 to 6 inch beds, with thin layers of shale, in part black. The shale has a white alum efflorescence on its outcrop. The sandstones are pitted by casts of plant fragments, and 5 feet from the top is a thin slabby sandstone bearing numerous trails and other peculiar markings. Hard 3-foot bed of sandstone at base	30
Thin black shale with 2-inch layers of interbedded sandstone. White slabby sandstone at base, with numerous pits and casts of twigs and bones	20
Soft white sandy shale, some mottled purple, and thin white slabby sandstone with small quartz pebbles, fish bones, casts of twigs, and other markings	10
Covered, probably largely soft sandstone	40
Black hackly shale with *Lingula* in upper part, black and white sandy shale or sandy agglomerate, with conglomerate of 2-inch quartz pebbles in black shaly matrix which contains teeth, vertebræ, and other bones of fish	10
White crumbly sandstone with hard upper surface	100±
	210±

The alum efflorescence is probably alunite, hydrous aluminum sulphate, resulting from the action of sulphuric acid, formed by the decomposition of pyrite, on the aluminous shale.

In the Jones Lake Fork and Apishapa canyons the firmer buff sandstone of the formation is divided by a shaly band into two massive cliff makers, each about 40 feet thick, distinctly lighter colored than the cliffs of Dakota sandstone and showing the characteristic cavernous and porous weathering. At the base of the formation was seen at one point a conglomerate of quartz pebbles in red sand or clay matrix and a red sand-mud agglomerate, probably derived from the erosion of red strata of the underlying Morrison formation.

The section in Christian Canyon given in figure 7 shows not only the details of the upper 30 feet of the formation but also its variability within a few feet horizontally. The section also shows the presence of a 4-inch bed of blocky coal, which is the only coal bed observed in the quadrangle, although highly carbonaceous shale is not uncommon.

[a] Stanton, T. W., The Morrison formation and its relations with the Comanche series and the Dakota formation: Jour. Geology, vol. 13, 1905, pp. 657-669.

A carefully measured section in the right wall of Apishapa Canyon just below the mouth of Jones Lake Fork is as follows:

Section of Purgatoire formation in Apishapa Canyon.

	Feet.
Very massive sandstone (Dakota).	
Black shale, sand-mud agglomerate, in places reddish, and blue compact argillite interbedded with slabby quartzitic sandstone marked by numerous trails	5
Largely covered. Includes white sandstone freckled with rusty spots and marked by rust-stained joints, some dark quartzitic slabby sandstone bearing trails and markings, and soft buff sand-mud agglomerate	44
Light-buff homogeneous open-textured sandstone. Contains scattered small spherical concretions and specks of iron pyrite which weather to rust-colored freckles, rust-stained joints, and iron bands. Somewhat cross-bedded in upper part and shaly at the top. Cavernous at base, making a reentrant in the cliff	45
Massive light-buff homogeneous sandstone	33
Covered with talus below sandstone cliff. Portion estimated as belonging in Purgatoire formation	75±
	202±

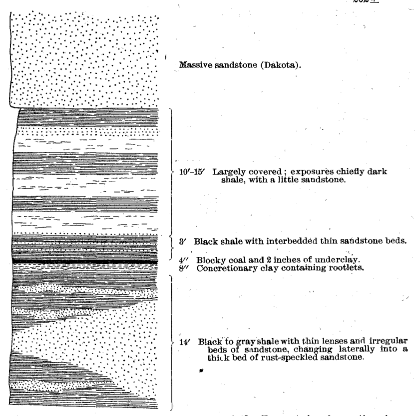


FIGURE 7.—Section of the upper part of the Purgatoire formation in Christian Canyon.

Scale: 1 inch = 10 feet.

Distribution.—The Purgatoire formation is exposed in the walls of all the deeper canyons in the central upland, and in Christian, Devils, and Timpas canyons, in the southeastern part of the quadrangle. Its largest areas are in the four deepest canyons, Huerfano, South, Apishapa, and Jones Lake Fork.

In the walls of Huerfano Canyon the massive white beds of the Purgatoire are conspicuous, generally making the lower cliffs, which extend up about two-thirds of the height of the walls and at the top of which is the bench of sloping talus that covers the upper, softer shaly part of the formation. Soft black shale at this horizon is in places exposed in undercuts or caverns beneath the massive sandstone ledges of the Dakota. The formation here dips northeastward and passes below the surface at the northern boundary of the quadrangle.

The Purgatoire formation was not seen in Karrick and Horse Pasture canyons, which have been cut almost if not quite through the Dakota sandstone. Although it was not observed in Doyle Arroyo and is kept largely below the surface by a sharp synclinal fold that follows the arroyo, it probably outcrops in the deepest part of that gorge and is so shown on the geologic map. Black Ridge, forming the east wall of Doyle Arroyo, is a broken monoclinal fold with minor transverse folds at the line of fracture, and here the Dakota, though deeply dissected, is apparently nowhere entirely cut through. In the deeper part of Beardsley Arroyo, on the headwaters of the same stream, the black shale of the Purgatoire formation crops out.

In the deeper parts of the Madden, Lone Jack, Crossbars, and unnamed canyons northeast of North Rattlesnake Butte the Dakota sandstone, which forms the general sloping surface of this upland, is cut through to the black shale and massive light-buff sandstone of the Purgatoire. These narrow inliers are limited to parts of the canyons in which the monoclinal strata have a convex surface, due to an increase in dip, and which are far enough down the slope to be corraded in deep gorges by the streams. The formation of inliers is illustrated by the profiles of the rock surface and of the stream channel of Crossbars Canyon, shown in figure 8.

The Purgatoire formation occupies the bottom and forms the lower walls of South Canyon for about 10 miles, disappearing below the surface near its junction with Apishapa River. In Bass Canyon its light sandstones are exposed at several places, and in Almagre Canyon only the black shales of the upper part of the formation appear, in two small lens-shaped areas. A small exposure of the black shale is seen at the mouth of Dripping Spring Arroyo. In parts of Tejano Arroyo the sandstones make prominent ledges near the stream bed, but in most places the outcrop of the Purgatoire is concealed by the talus from the cliffs above.

On Apishapa River and Jones Lake Fork the full thickness of the Purgatoire is exposed in the canyon walls, and where the Dakota has receded from the brink or is weakened by shaly character the light-buff sandstone of the Purgatoire is the principal cliff maker. In places the cliffs are so precipitous that they can not be scaled. A small area of the formation is cut off in the Apishapa Canyon by the Cross Canyon fault. Downstream it is again terminated by the Almagre Canyon fault but reappears in two lens-shaped areas in the deep gorge below.

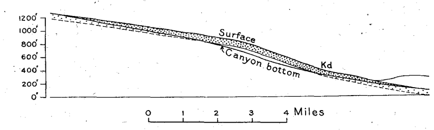


FIGURE 8.—Profiles of bottom of Crossbars Canyon and of surface of Dakota sandstone upland.

Shows how inliers of the Purgatoire formation are formed in valley bottoms by streams cutting through the bowed-up portion of the overlying Dakota sandstone where its dip steepens.

Three small isolated inliers of the Purgatoire occur in the southeastern part of the quadrangle in Christian, Devils, and Timpas canyons. Timpas Canyon contains only the uppermost black shale of the formation, which has been prospected for fire clay.

Fossils and age.—The few fossils obtained from the Purgatoire formation in the quadrangle conclusively determine its age to be Comanche (Lower Cretaceous).

In the black carbonaceous shale in the upper half of the formation, within 5 feet of the base of the Dakota sandstone, undetermined species of *Lingula* may generally be found. In the Huerfano Canyon numerous fish teeth, vertebræ, and other fish bones were collected from a conglomerate 100 to 110 feet below the Dakota sandstone. Although the species of fish have not been determined, Stanton reports that they are clearly of the same types that are found in the upper beds of the Comanche series in southern Kansas.

In Apishapa and South canyons and Tejano Arroyo the invertebrate fossils named below were collected from slabby sandstones about 90 feet below the base of the Dakota and just above the massive beds of buff sandstone:

Avicula sp.	Trigonia ? sp.
Pecten ? sp.	Protocardia ? sp.
Pholadomya cf. sancti-sabæ Roemer.	Tapes ? sp.

These were identified by Stanton, who reported that they are all species which occur in rocks of recognized Washita age in Kansas, Oklahoma, northern Texas, and southern Colorado.

Stanton[a] collected the following species from beds at this horizon in the Purgatoire Canyon and its branches 15 miles east of the Apishapa quadrangle:

Inoceramus comancheanus.	Pholadomya sancti-sabæ Roemer.
Trigonia emoryi.	Protocardia texana.
Cardium kansasense.	Leptosolen conradi.
Cyprimeria sp.	

Stanton further states that at this locality and in adjacent areas in southeastern Colorado and New Mexico these forms are associated with *Gryphæa corrugata*, and that the horizon is no doubt the equivalent of some part of the Washita group and should be correlated directly with the Kiowa shale of Kansas.

UPPER CRETACEOUS SERIES.

DAKOTA SANDSTONE.

Name.—The name Dakota sandstone has long been in use and was taken from Dakota City, Nebr., where the formation bears the typical flora of this horizon. Until relatively recently the sandy beds here called the Purgatoire formation and in the northern Great Plains called Lakota sandstone were included in the Dakota in the belief that they were of the same age, but on the discovery of Lower Cretaceous fossils in the lower beds, which are also readily separable lithologically from the upper beds carrying an Upper Cretaceous flora, the name Dakota was restricted to these upper strata. This practice is in accord with the usage at the type locality in Nebraska, where the lower (Purgatoire) sandstone is not present.

Character and thickness.—The Dakota, the lowest formation of the Upper Cretaceous, is composed almost wholly of sandstone. The individual beds are generally thick except near the top and show cross lamination. The rock is of uniform and moderately fine grain and is more compact and dense than the open-textured sandstone of the underlying Purgatoire. The original color, seen on fresh surfaces, is white or pale gray, but weathering produces various shades of yellow and brown. This discoloration affects only the surface and joint planes and is spoken of as "desert varnish." It was used by the

[a] Stanton, T. W., Jour. Geology, vol. 13, 1905, p. 662.

Indians as a means of communication and record, for in many of the canyons, especially near the water holes, are preserved their pictographs chipped into the "varnished" cliffs. (See Pl. II.)

The contact with the Purgatoire formation beneath is one of apparent conformity but is generally marked by an abrupt change from carbonaceous shale to clean sandstone, indicating a decided change in physiographic conditions. At the top the formation is conformable with the overlying Graneros shale, having a transition zone of alternating sandy and shaly layers.

In many places the uppermost thin-bedded sandstone weathers to turrets, domes, and fantastic forms. This is most interestingly displayed on the slopes of the southern part of Black Ridge, just north of the Reynolds ranch, on Streeter Arroyo (see Pl. X), but may be seen in many other outcrops where erosion has not scoured too deeply. At the point north of the Juan Baca ranch dome-shaped knolls of this bed resemble Spanish ovens. (See Pl. IX.)

The formation as exposed in the canyon walls is generally divided into two massive layers by shaly beds that form a small reentrant between the two cliff makers or a minor sloping shelf less prominent than the bench at the shale horizon of the upper part of the Purgatoire. These sandstone layers vary in fineness and in resistance to weathering (see Pl. VII), and in some places the upper and in others the lower bed makes the more prominent cliff in the walls, the change to soft shaly or friable rock being rather abrupt. The beds also vary in thickness, swelling and thinning in plain view along the canyon walls. The shaly beds separating the massive sandstones consist in places of a compact white blocky clay or argillite, but elsewhere they are largely blue or black carbonaceous shale.

A section of the formation in the east wall of Huerfano Canyon at the west edge of the quadrangle is as follows:

Section of Dakota sandstone in east wall of Huerfano Canyon.

	Feet.
Thin-bedded sandstone, worn back from edge of canyon	10
Massive fine-grained light-gray sandstone, weathering pink to yellow; upper cliff maker	20
Black shale, weathering blue (slight reentrant)	3
Hard vitreous coarse-grained gray sandstone, weathering rusty	25
Light-gray sandstone, weathering to thick rusty-brown coating	25
Shale and shaly sandstone (Purgatoire).	
	83

Probably several feet more of sandstone and interbedded shale at the top of the formation have been entirely removed from the Dakota surface at the canyon brink. A comparison of the above section with the published descriptions of the composition and thickness of the Dakota sandstone in the Walsenburg and Pueblo quadrangles will show at a glance that the Dakota here described is only the upper third of what was formerly called Dakota, the lower two-thirds being here separated as the Purgatoire formation.

At another point farther south in the canyon the massive sandstone is in one ledge, as shown by the following section:

Section of Dakota sandstone in Huerfano Canyon.

	Feet.
Thin-bedded sandstone, shelving back from cliff	15
Massive gray to rusty sandstone, with few bedding planes; lower portion especially massive; upper surface very rough, irregular, and rust stained. Broken by great rust-stained joint planes into sheer cliffs and immense detached blocks	60
	75

East of Huerfano Canyon layers of black shale are intercalated at several horizons in the upper portion of the sandstone, and in Streeter Arroyo thin beds of hard sandstone are interstratified with the black and blue shales at the base of the Graneros shale, showing a gradual transition. In Beardsley Arroyo a clean exposure of the upper 30 feet of the Dakota permitted the measurement of the following detailed section:

Section of upper part of Dakota sandstone in Beardsley Arroyo.

	Feet.
Massive cliff-making light-buff sandstone, weathering with brown stain. Very irregularly cross-bedded and weathers into fantastic shapes and finally into thin irregular plates. Some of the bedding surfaces on which the laminæ have exfoliated have a fan-shaped appearance resembling *Cauda galli*. Plant impressions are numerous and a large tree trunk 18 inches wide, 9 inches thick, and 6½ feet long was observed	10
Bluish-gray argillite or mud rock, irregularly bedded, containing scattered round quartz grains more numerous at base. Varies in thickness from 5 to 8 feet within a few feet, and thin layers of the same material are intercalated in the overlying sandstone	5–8
Homogeneous massive-bedded softer white sandstone	4
Black shale with carbonized plant remains and thin layer of hard blue, finely sun-cracked argillite	1
Hard light-buff sandstone with irregular upper surface	5

The two divisions of the Dakota sandstone are clearly shown in most outcrops in the Apishapa Canyon and its larger branches, where it generally makes the two upper cliffs. (See Pl. VIII and fig. 9.) The following sections were measured on the right wall of the canyon just below Jones Lake Fork.

Sections of Dakota sandstone in Apishapa Canyon just below Jones Lake Fork.

1.

		Feet.
Sandstone fragments back from cliff		10
Massive sandstone, weathering to fantastic shapes at top	Upper cliff maker	16
Thin dark shale parting	Upper cliff maker	
Massive sandstone	Upper cliff maker	10
Thin dark shale partings.		
Massive rusty-surfaced sandstone	Second cliff maker	30
Soft sandy and black shales (Purgatoire).		
		66

2.

		Feet.
Thin-bedded sandstone back from cliff, weathered to fragments		20
Thin-bedded sandstone	Upper cliff maker	15
Thin dark shale parting	Upper cliff maker	
Thin-bedded sandstone	Upper cliff maker	8
Thin dark shale parting.		
Very massive homogeneous sandstone, irregularly bedded	Second cliff maker	20
Black shale and sandy beds (Purgatoire).		
		63

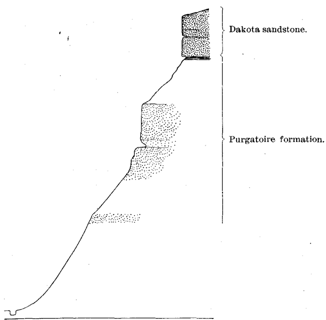


FIGURE 9.—Typical profile of wall of Jones Lake Fork canyon.

Showing upper cliff of Dakota sandstone, generally divided into two ledges; shale slope below with reentrant at its top; second cliff maker of lighter-colored sandstone of the Purgatoire formation, with a reentrant generally in its midst; and a long talus slope below, with scattered sandstone ledges. Vertical scale: 1 inch = 100 feet.

The following record of a well at Delhi can not be positively interpreted, but the most appropriate assignment of strata to their respective formations gives the Dakota a thickness of 86 feet.

Record of well at Delhi.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay (Graneros)	75	75
Dakota, 86 feet:		
Dark-gray sand	35	110
Light-gray sand	10	120
Dark-gray sand	21	141
Light-gray sand	20	161
Shaly beds of Purgatoire, 57 feet:		
Dark-gray sand	15	176
Black shale	9	185
Dark-gray sand	20	205
Shale	13	118
Sandstones of Purgatoire:		
White sand	87	305
Water-bearing sands	17	322

In Timpas Canyon, 2 miles below Thatcher, Gilbert measured 70 to 80 feet of Dakota sandstone as follows:

Section of Dakota sandstone near Thatcher.

	Feet.
Cross-bedded sandstone, weathering to thin shaly beds	30–40
Massive gray to rusty sandstone	40
	70–80

Distribution and surface form.—The Dakota sandstone constitutes the surface of about one-third of the quadrangle and underlies all the remainder, with the exception of the small tracts occupied by the Purgatoire and Morrison formations. Its great breadth of outcrop is determined largely by the fact that it is much more resistant to erosion than the shales overlying it. Its principal areas of outcrop are uplands, partly dissected by many narrow, steep-walled canyons. The surfaces of the uplands exhibit chiefly the upper thin-bedded layers of sandstone, which eventually weather into a sandy soil; the lower beds are exposed almost exclusively in the walls of the canyons.

The largest area occupies the middle of the quadrangle. It extends northwestward and, except for a thin covering of Graneros shale over a part of the area, occupies the surface of the northwest corner, whence it passes into the Walsenburg quadrangle. Other areas are near Delhi, at Thatcher, in the upper valley of Apishapa River, at Rocky Hill, and in Little Dome. Four very small exposures occur in the bottoms of arroyos on the south side of the Rocky Hill fault in Smith Hollow.

Fossils and age.—The Dakota sandstone contains numerous casts of unidentifiable fragments of wood, and near Beardsley Spring an unidentified tree trunk 6 feet long was observed. Near Smith Ranch good specimens of leaves were collected, identified by F. H. Knowlton as *Sterculia lugubris*. Fragments of an indeterminable dicotyledon and of a conifer that, according to Knowlton, suggests *Sequoia reichenbachi* were also obtained in the quadrangle. In Kansas and Nebraska the Dakota sandstone has yielded a flora, mostly dicotyledons, comprising several hundred species that are generally considered to belong in the Cenomanian, the lower part of the Upper Cretaceous.

BENTON GROUP.

The Benton group is composed of two shale formations separated by a thin limestone named Greenhorn. The lower shale is named Graneros and the upper Carlile.

GRANEROS SHALE.

Name, character, and thickness.—Next above the Dakota is a body of clay shale 200 to 210 feet thick. Its color is bluish gray, ranging from medium to dark, the middle part being darker than the upper and lower. The name Graneros shale for this formation has been in use over 15 years, since Gilbert recognized the threefold division of the Benton and named the lower formation from Graneros Creek, which traverses the formation 25 miles southwest of Pueblo.

On fresh exposures, seldom seen in this area, it is a compact argillite with little tendency to split into shale, and its lamination appears chiefly as delicate markings. Exposure to the weather causes it to divide into thin, shaly flakes and eventually reduces it to a clay.

In the lower half are a few layers of white clay, which are in places associated with thin layers of concretionary limestone. A bed of impure, sparingly fossiliferous limestone, 12 to 14 inches thick, lies from 65 to 75 feet above the base, another thinner layer occurs directly beneath, and a 6-inch bed of hard sandstone occurs a few feet above. The limestone weathers to cobble-size fragments, which are stained ocher yellow by the contained iron, as are also the fragments of the associated thin sandstone. These harder rocks together form a persistent bench.

There is a very thin but persistent fossiliferous platy sandy limestone about 45 feet below the top of the Graneros, which in places also makes a bench but generally is merged into the larger bench of the Greenhorn limestone. Concretions, most of them small, occur sporadically at several horizons. Selenite crystals, some large and roughly twinned, are formed in the basal shales apparently by the action of decomposing pyrite on calcareous layers, and the crystals are strewn over the surface of these beds where they thinly mantle the Dakota upland.

The general section of the Graneros shale in this quadrangle is as follows:

General section of Graneros shale.

	Feet.
Blue blocky limestone (Greenhorn).	
Gray argillaceous shale	43
Thin hard fossiliferous sandy limestone, weathering shaly	1
Dark-gray to black argillaceous shale with thin hard sandstone bed near base	92
Tough gray impure limestone, weathering to rusty blocks	1
Gray argillaceous shale, with some thin nearly white beds	73
Thin sandstones with shale interbedded (Dakota).	
	210

The transition zone at the base varies greatly from place to place but usually consists of several beds of shale of irregular thickness interstratified with the topmost sandstones of the Dakota. The top of the formation is sharply defined by the beds of pure bluish limestone of the Greenhorn.

Distribution and surface form.—The Graneros shale, being easily eroded, is found chiefly in valleys or on gentle slopes. Where the strata lie nearly level it constitutes slopes below bluffs of the Greenhorn limestone. Where the dip is considerable the formation rests against slopes of the Dakota sandstone. On account of its soft character it washes badly and its surface in many places is deeply trenched by vertical-walled arroyos cut into the otherwise gentle slope of its surface. In the main its outcrops constitute rather broad belts, encircling areas of Dakota sandstone.

The main outcrop surrounds the rudely elliptical central area of the Dakota. In the regions of gentle dips around the Rattlesnake Buttes and west of Hog Ranch Canyon it forms rather broad elevated tracts culminating in hills of Greenhorn limestone and higher rocks. In the southern third of the quadrangle its areas are intricately entwined with the narrow bands of Greenhorn limestone, but in the main they surround the uplifts of Dakota sandstone of Christian and Devils canyons, Thatcher, the Apishapa Valley south of the Rocky Hill fault, Rocky Hill, and the Little Dome.

A few outliers of Graneros shale rest on the upland surface of Dakota sandstone. The largest one, northwest of Jones Lake Fork canyon, is protected from erosion by faulting. Three small outliers at the head of Doyle Arroyo are infolded in a sharp syncline associated with the Doyle Arroyo fault. Besides the two small areas east of North Rattlesnake Butte there are probably other thin remnants of shale mantling the broad Dakota surface, which were not distinguished from the arid soil of the sandstone.

Fossils.—The Graneros shale in general is not very fossiliferous, but the sandy limestone near its top is everywhere full of shells of a small simple oyster somewhat larger and more regular in form than *Ostrea congesta*, which it otherwise resembles. Associated with the *Ostrea* are fragments of undetermined species of *Inoceramus* and *Prionotropis*. A zone of concretions lower in the shale is locally fossiliferous and has yielded a number of species, most of which are undescribed. The following list of fossils obtained from the formation is furnished by T. W. Stanton:

Pecten sp.	Prionotropis sp.
Inoceramus fragilis H. & M.?	Acanthoceras sp.
Leda sp.	Turrilites sp.
Turritella whitei Stanton.	

GREENHORN LIMESTONE.

Name, character, and thickness.—The Graneros and Carlile shales are separated by about 30 feet of interbedded thin limestone and shale named the Greenhorn limestone. This name was introduced over 15 years ago for the thin limestone in the midst of the Benton group, and was derived from Greenhorn Creek, a branch of St. Charles River in the Pueblo quadrangle, where good exposures of the limestone are exhibited. The repeated alternation of shale and limestone is clearly expressed in the section given below and in Plate XII. The limestone beds are from 3 to 12 inches thick and the intervening shale beds from 10 to 20 inches. Although the shale predominates the limestone resists weathering so strongly that its fragments cover the surface of the outcrop, concealing the shale and giving the impression of a thick sheet of limestone. The limestone is bluish gray, weathering to lighter shades, and is of fine grain. Most of the layers are divided by vertical cracks into rectangular blocks or smooth plates. The shale is bluish gray, darker than the limestone, and is calcareous. There are also some interbedded thin layers of white shale. Both the shale and limestone contain abundant fossil shells, especially the concentrically marked oval *Inoceramus labiatus*. At the top are 5 or 6 feet of very fossiliferous arenaceous limestone interbedded with shale, forming a transition into the overlying Carlile shale.

The measured thickness varies from 30 to 50 feet, the detailed section given below measuring only 30 feet.

Section of Greenhorn limestone in northwest corner of quadrangle.

	Ft.	in.
Arenaceous limestone		6
Shale	1	
Hard limestone		2
Shale	1	10
Hard arenaceous limestone		5
Shale		8
Hard limestone		2
Shale		8
Hard limestone		1
Shale		5
Arenaceous limestone		6
Shale	2	5
Hard limestone		5
Shaly limestone		7
Shale		1
Hard limestone		6
Shale	1	7
Hard limestone		1
Shale		2
Hard limestone		2
Shale	1	6
Hard limestone		4
Gray and rusty shales	1	6
Hard limestone		6
Gray and rusty shales	1	6
Hard limestone		5
Gray and rusty shales	1	2
Hard blue limestone		7
Blue shale		10
Hard blue limestone	1	5
Blue shale weathering gray with rusty bands	8	1
	30	3

A section of the Greenhorn limestone at the dike ridge northeast of North Rattlesnake Butte, measured by F. P. Gulliver, has a 5-foot massive cliff maker near the middle and a smaller one near the top, with a total thickness of 60 feet, but the greater thickness is probably due to the fact that shales hardened by contact metamorphism were erroneously included with the limestone.

Distribution and surface form.—The cedar-clothed bench of Greenhorn limestone fringes the base of the mesas of Timpas limestone throughout the quadrangle. From the northwest corner to the eastern edge of the quadrangle near Devils Canyon it forms a scalloped band at the foot of the mesas, its wooded bench merging into the general slope at the stream reentrants and spreading out into broad elevated tables at the salients. Two outlying masses of the formation form low wooded mesas on opposite sides of Hog Ranch Canyon. Inliers of the formation in the overlying Carlile shale are uncommon, but one occurs in the valley forming the reentrant in the mesa front east of Horse Pasture Canyon and another in Saunders Arroyo.

The Greenhorn limestone entirely surrounds the Rattlesnake Buttes with a wooded terrace and fringes the Timpas limestone mesas, on the western border of the quadrangle, with minor breaks where it is faulted out. South of the Bonito Cordova ranch it has a tortuous course, following the outline of the Timpas limestone mesas in general to the southern boundary of the quadrangle west of Apishapa River. It is repeated north of the Rocky Hill fault, first following the northern foot of the hills of Dakota sandstone near the western edge of the quadrangle and then partly surrounding the low buttes of Timpas limestone southeast of the Bonito Cordova ranch, extending to Apishapa River. A very narrow band encircles the central area of Dakota in the Little Dome, where the rocks are steeply tilted in all directions away from the center of uplift. A rather large outlier of the formation occurs near the center of the quadrangle in the midst of the Dakota upland, protected and preserved from erosion by its relatively low position due to faulting.

In the southeastern portion of the quadrangle the Greenhorn entirely surrounds the Poitrey Arroyo Hills, fringes the Tyrone Flats, Big Arroyo Hills, and adjacent Timpas limestone mesa, except where offset by faults, and passes out of the quadrangle on the east near Devils Canyon.

Fossils.—Fossils are abundant though not of great variety in this formation. The most common form is the oval, concentrically marked *Inoceramus labiatus* Schlotheim, which may be found at almost every exposure of the limestone. Among the rarer forms Stanton reports the following from Arkansas Valley in Colorado:

Ostrea sp.	Helicoceras corrugatum Stanton.
Acanthoceras coloradoense Henderson.	Pachydiscus sp.
Prionotropis sp.	Metoicoceras whitei Hyatt?
	Baculites sp.

CARLILE SHALE.

Name, character, and thickness.—The Carlile shale, the uppermost formation of the Benton group, was named by Gilbert after Carlile Spring, on Arkansas River 20 miles above Pueblo, which is located on the shale in the upper part of the Benton. It is from 200 to 232 feet thick and consists chiefly of argillaceous shale. In the lower 50 feet it is medium gray; then comes 25 feet of dark-gray beds, including bands that are nearly black, above which the color is again medium gray. About 60 or 70 feet below the top of the formation the shale is sandy and contains lenses of friable sandstone. In most places yellow sandstone 10 to 20 feet thick occurs at the top. The sandstone is calcareous in fresh exposure, and is generally very fossiliferous in the upper part, its fragments being marked by casts of a large, strongly ribbed coiled ammonite *Prionocyclus wyomingensis*.

The sandy shale contains many calcareous concretions, more or less globular in form, which range from a few inches to 4 or 5 feet in diameter. The outer layers have what is called cone-in-cone structure, seeming to be made up of a system of interlocking cones with apices all pointing toward the middle of the concretion. The inner parts are of even, fine texture and gray color. The larger concretions are traversed by ramifying cracks, which are partly or wholly filled by crystalline calcite, and are called septaria. The first-formed calcite, adjacent to the walls of the cracks, is usually of a rich dark brownish color, but the last formed is white or transparent, and in some specimens large flat rhombohedrons or "nail-head" crystals of this calcite stand in relief on the botryoidal surface of the wine-colored interior. There is also present with the calcite some translucent to chalk-white crystalline barite. Although the cleaved fragments of the barite closely resemble the calcite in color and form, it may be readily detected by its greater weight.

A section measured in the northern part of the quadrangle is as follows:

Section of Carlile shale in scarp of mesa in northwest corner of quadrangle.

	Feet.
Chalky white limestone beds (Timpas).	
Brown arenaceous shale, upper portion gray and apparently calcareous. Contains abundant fish teeth	2
Hard yellowish granular sandstone	4
Thin-bedded, somewhat shaly loose-textured sandstone	7
Gray shale with yellow bands, containing numerous large concretions in lower portion, many of which have septarian structure	54
Black shale; weathers to soft clay	159
Arenaceous and calcareous shales containing numerous fossils beds of transition (into the Greenhorn limestone, included with that formation).	
	226

Distribution and surface form.—The Carlile shale occupies gentle slopes and steep escarpments below the cliffs of Timpas limestone. As it lies high on the slopes and is composed of soft shale it is in general deeply trenched by the streams and forms badland topography. Its outcrop follows the mesa front in a narrow scalloped band from the Ben Butler ranch, just beyond the northwest corner of the quadrangle, to the eastern edge of the quadrangle near the mouth of Devils Canyon. It has many long minor reentrants and some inliers in the Timpas limestone which forms the cap of the mesa. An irregular elliptical area surrounds the Rattlesnake Buttes, and semicircular belts outline the mesas on the western border of the quadrangle. South of the Bonito Cordova ranch it largely occupies valleys between the isolated hills and mesas of Timpas limestone. In the southeastern part of the quadrangle it again follows the edges of the mesas in an irregular wavy band, entirely surrounding the Poitrey Arroyo Hills.

Fossils.—The fossils collected in this formation come mostly from the upper sandstone, with the exception of *Inoceramus labiatus*, which is common in the transition beds at the base and is found at some localities ranging to the top of the formation. Fish teeth, in places associated with *Prionocyclus wyomingensis* Meek and *Scaphites warreni* Meek and Hayden, are abundant in the uppermost bed. The following species from the upper part of the Carlile shale in the Apishapa and Pueblo quadrangles have been identified by T. W. Stanton:

Ostrea lugubris Conrad.	Veniella mortoni M. and H.
Exogyra suborbiculata Lamarck.	Pugnellus fusiformis (Meek).
Anomia subquadrata Stanton.	Turritella whitei Stanton.
Inoceramus fragilis H. and M.	Prionocyclus wyomingensis Meek.
Trigonarca obliqua Meek.	Prionotropis woolgari Mantell.
Cardium pauperculum Stanton.	Scaphites warreni M. and H.

NIOBRARA GROUP.

The Niobrara group is in general calcareous and comprises the limestones and calcareous shales named Timpas limestone at the base and the more shaly formation, the Apishapa shale, above.

TIMPAS LIMESTONE.

Name, character, and thickness.—The Timpas limestone was named by Gilbert from Timpas Creek, which crosses the southeast corner of the quadrangle and exposes the limestone of the formation both to the south and to the east of this area.

It may be characterized as a series of soft limestones and calcareous shales with prevailing pale colors. Its general thickness is 175 feet. At the base is a series of limestone beds about 50 feet thick, the capping rock of most of the mesas and buttes in the region. (See Pls. I, III, IV, and V.) As a rule these beds are well exposed at the top of the mesa cliffs. The individual limestone beds range in thickness from a few inches to 3 feet, the average being about a foot. They are separated by layers of light-gray calcareous shale, usually 1 or 2 inches thick. The limestone has a light-gray color, which becomes creamy white on weathered surfaces. It is compact but chalky in texture and rather fine grained. Where exposed to the weather it breaks up into rough shaly flakes, and this characteristic ordinarily serves to distinguish it from the Greenhorn limestone, which cleaves into blocks or into rectangular plates.

In its lower layers are small nodules of oval or cylindrical form composed of iron sulphide, whose surfaces are set with angular projections of crystals. These iron concretions oxidize at the surface to limonite and acquire a dark-brown color. The formation is characterized by a thick fossil shell (*Inoceramus deformis*), the outer surface of which is usually covered by the shells of a very small oyster (*Ostrea congesta*). The interior cast of the *Inoceramus*, which is most commonly found, is suggestive of the hoof of a horse.

The limestone passes gradually upward into a light-gray limy shale, which contains a few thin beds of limestone and terminates at the top in one or two layers of faint-pinkish chalky limestone. This upper bed contains scales and other fish remains and numerous fragments of a large flat *Inoceramus* also covered by small *Ostrea congesta*.

The section in the bluff south of the Yellowbank ranch, although it does not exhibit the whole formation, furnishes details of the upper beds as follows:

Section of upper part of Timpas limestone in bluff south of Yellowbank ranch.

[By G. K. Gilbert.]

	Feet.
White chalky limestone with same fossils as in lower beds	6+
Gray calcareous shale alternating with creamy limestone beds. Fossils same as in lower bed but more abundant	20
Dark-gray shale, weathering at first blue, then pale blue-gray, and finally cream-yellow. Harder layers weather yellow. Contains pyrite concretions, mollusks, and fish scales	50+

Distribution and surface form.—The Timpas limestone caps most of the mesas in the quadrangle. All the sloping mesas in the northeast for a width of 3 or 4 miles back from the salient escarpments are composed of this formation. The harder limestone at the base of the formation forms the cliffs of the mesa fronts and the fish scale bed at the top forms a low ridge on the mesa plain where the formation passes beneath the Apishapa shale. At the valley reentrants the formation outcrop is generally not over a mile in width. An inlier of the Timpas in the Apishapa shale, brought to the surface south of the Yellowbank ranch by a local uplift, is about $2\frac{1}{2}$ square miles in area. At the eastern margin of the quadrangle the formation outcrop has the unusual width of over 5 miles, which is due to a change in strike and decrease in the dip of the beds.

In the other mesas of Timpas limestone in the quadrangle the formation is so nearly flat that it does not pass under cover of the Apishapa shale except in a very small area let down by the Rocky Hill fault on Tyrone Flats. Tyrone Flats, the largest of these mesas, is very nearly level, as the name implies. It has a long tapering arm stretching northeastward parallel to the Rocky Hill fault and connects by low hills at its northern extremity with the more irregular narrow area of the Poitrey Arroyo Hills. Big Arroyo Hills and the adjacent mesas on the eastern border of the quadrangle form the divide between the Timpas and the Purgatoire drainage. Cordova Mesa and numerous smaller isolated mesas in the southwestern part of the quadrangle, as well as the two extending into the quadrangle from the west, are also capped by Timpas limestone.

The most prominent and best-known outcrops of the formation are two mesas called Rattlesnake Buttes, which are not only prominent because of their isolation but are landmarks for miles around because of their height above the surrounding plateau. (See Pl. V.) Along the mesa fronts are numerous knolls, buttes, and hills capped with Timpas limestone that are distinctly lower than the adjacent mesas. These are great blocks that have become detached and moved down the slope a short distance as landslides but have been so modified by erosion that they appear to be in place. Their strata, however, generally dip strongly toward the mesa, which is characteristic of landslide masses. Such areas are not mapped as outcrops of the Timpas. A few of the smaller mesas have lost their former capping of Timpas limestone through erosion and are now capped by the sandstone or concretion zone at the top of the Carlile.

Fossils.—The fossil shells found in this formation are abundant in certain layers near the base and at the top but represent only a few species. Fragmentary fish remains are common, especially in the upper hard shaly layers, shiny brown scales being conspicuous in some outcrops. T. W. Stanton has furnished the following list of invertebrates:

Globigerina and other Foraminifera.
Ostrea congesta Conrad.
Inoceramus deformis Meek.
Inoceramus undulatoplicatus Roemer.
Inoceramus umbonatus M. and H.
Baculites sp.

APISHAPA SHALE.

Name, character, and thickness.—The Apishapa shale was named by Gilbert over 15 years ago, from its exposures on Apishapa River in this and adjacent quadrangles. It is chiefly a laminated calcareous shale of gray color when freshly exposed, but atmospheric action has changed it everywhere for a considerable depth to a rock of yellowish color and rough texture. Gypsum in thin plates and films between the shale is somewhat abundant. It was probably chemically produced by the action of decomposing pyrite, disseminated in the formation, on the aluminous shale. Oval fish scales from one-third of an inch to an inch in diameter are common in the shale.

Well up in the formation, about 100 feet below the top, are calcareous concretions, usually of considerable size and of ellipsoidal shape. At a few places they coalesce with one another so as to form a continuous bed several rods in extent. Some have internal cracks filled with minerals similar to those of the concretions in the Carlile shale, but containing, in addition to calcite, large crystals of translucent barite of faint bluish color, which may be distinguished from calcite by their greater weight. At the top of the formation are calcareous beds sufficiently resistant to make ridges and escarpments. They do not outcrop in the quadrangle but a scarp of these beds forms the bluffs of Apishapa River 3 miles to the northeast. The entire thickness of the formation is approximately 500 feet but the upper 80 feet or so is not now present in this quadrangle.

Distribution and surface form.—The formation occurs only in the northeastern part of the quadrangle, except one small area. It occupies all of the triangular area northeast of the low line of hills made by the hard fish-scale bed at the top of the Timpas, except the inlier of Timpas limestone at the Yellowbank ranch and the scattered patches of thin gravel and sand. The base of this triangular area is about 24 miles long and its sides about 16 miles. The concretionary layer near the top of the formation outcrops on the plain in the northeastern part of the quadrangle 9 or 10 miles from the outcrop of the base of the formation and its fragments cover the prominent mesa just east of Apishapa River.

The only other area of the formation in the quadrangle is a very small outlier on the top of Tyrone Flats, let down, and thus preserved, by the Rocky Hill fault. Here for a short distance the rocks slope somewhat steeply south, toward the fault, and the upper yellowish limestone of the Timpas makes a low bench on which a thin remnant of Apishapa shale is preserved. Undoubtedly the shale once extended over the remainder of the quadrangle but has been removed by erosion.

Fossils.—The formation has yielded few fossils in this quadrangle except fragmentary fish remains. According to Stanton the fauna apparently does not differ from the Timpas fauna. *Globigerina* and other Foraminifera are locally abundant and *Ostrea congesta* attached to fragments of a thick-shelled *Inoceramus* like *I. deformis* is common. There are also specimens provisionally referred to *Inoceramus confertim-annulatus* Roemer.

TERTIARY SYSTEM.

PLIOCENE (?) SERIES.

The only representative of the Tertiary system in the Apishapa quadrangle is the Nussbaum formation, comprising certain unconsolidated gravels of supposed Pliocene age.

NUSSBAUM FORMATION.

Name, character, and distribution.—On the mesa slope in the northeastern portion of the quadrangle are scattered deposits of coarse gravel and sand. Some of these apparently were part of the great sheet of wash which was deposited by the antecedent of Arkansas River and by other streams issuing from the Rocky Mountain front during Tertiary time and mantling the plains to great distances and which is now left in elevated remnants capping mesas and table-lands. These gravels were named the Nussbaum formation by Gilbert because they cover the large mesa in the vicinity of Nussbaum Spring, east of Pueblo. In the type region the formation is largely sand with layers of pebbles and at the base a thick gravel composed of well-rounded, unassorted heterogeneous material including granitic rocks, basic lavas, quartzite, and much quartz. The lower 2 or 3 feet of gravel at that region is generally hardened into firm rock by calcareous cement.

The few scattered deposits in this quadrangle that are referred to this source occupy the gentle crests of the inter-stream ridges on the sloping upland of Apishapa shale, which may once have been continuous with the large gravel-capped mesa east of Apishapa River in the Timpas and Catlin quadrangles and with the Hooker Hills, 10 miles north in the Nepesta quadrangle.

Other gravel terraces of equal extent and height, such as that north of Snowden Lake, were apparently not part of a great sheet of Nussbaum wash but may have been deposited at a little later time in channels of streams not far from those now in existence. They are included with the high terrace gravel.

Age.—Fossils have not been obtained from these gravels in this general region, and their age must therefore be determined by other means. The floor on which rests the great sheet of wash of which these remnants are supposed to be a part is an old planation surface that bevels the latest Cretaceous sediments. It declines northward from an elevation of 4700 feet in the northern part of the Apishapa quadrangle to 4500 feet at Arkansas River and rises to 5300 feet in the mesa east of Pueblo, and to a much greater height on the high plain east of Colorado Springs. This irregularity probably does not represent the original shape of the basin or valley in which the gravel was deposited, for this surface was probably a plain sloping gently eastward, with faint drainage depressions, which has since been slightly folded by uplift along certain axes. This old planation surface is therefore of post-Cretaceous age and its formation preceded a minor tilting and warping of the surface that led to Pleistocene sculpturing. The deposit is regarded as of late Tertiary age, probably Pliocene.

QUATERNARY SYSTEM.

The only deposits of the Quaternary system in the Apishapa quadrangle are terrace gravels, dune sand, landslides, and stream alluvium. The terrace gravels and dune sand are regarded of Pleistocene age.

PLEISTOCENE SERIES.

HIGH TERRACE GRAVEL.

Character and distribution.—Some high terrace gravels in this area, not regarded as part of the sheet of Nussbaum formation, are probably of somewhat later and more local origin than the Nussbaum and are therefore mapped as of Pleistocene age. Many of them were deposited by the streams to which they are adjacent when the channels were higher than they are at present.

Most of these gravels are on the mesa plain in the northeastern part of the quadrangle, adjacent to the streams. Those on the north side of Mustang Creek were probably deposited by that stream when its floor was about 100 feet higher than it is at present, and similarly those adjacent to Apishapa River were probably deposited by that stream or its tributaries during an earlier stage. The large area of high gravel north of Snowden Lake and two smaller areas to the south are directly in line with a sharp gap in the mesa east of the Juan Baca ranch, which is now occupied by a small stream but apparently was once the course of a larger stream, possibly either the Apishapa or the Timpas.

Patches of high gravel have been mapped also in places southwest of the Timpas limestone escarpment, especially near Mustang Creek and its tributaries, where they rest in part on the Dakota sandstone. Scattered pebbles of quartzite, basalt, other volcanic rocks, and gneiss are distributed over the Dakota upland in the vicinity of the Apishapa Canyon, 300 feet above the present watercourse, and three small areas of this gravel are mapped.

Apishapa River above its canyon is bordered by extensive gravel-covered terraces that have not been mapped. These include deposits that are probably younger than those of the uplands, as they occupy benches near the stream level. They are composed of well-rounded bowlders and pebbles of the harder rocks, largely quartz and sandstone, but include many fragments of dark basaltic volcanic rock derived from the great lava flows of Mesa de Maya and Raton Mesa.

DUNE SAND.

On the eastern border of the quadrangle an area of about 10 square miles is covered by dune sand, overlying a deposit of high gravel from which it was apparently derived by wind action. The sand of this old alluvial deposit has been segregated by the wind and has been given a more or less dunelike topography of low hillocks and depressions. The sand is fine, is of a buff color, consists mostly of quartz, and closely resembles the much larger barren wastes of sand of similar origin north of Arkansas River in the Nepesta quadrangle. Its distribution indicates that it was mostly spread by wind action before the dissection of the upland surface on which the high terrace gravels were deposited and it is, therefore, chiefly of Pleistocene age.

RECENT SERIES.

LANDSLIDES.

Small landslide masses are common along the edge of the mesas of Timpas limestone. The cliffs of harder rocks in the mesa escarpments are undermined, the soft shale of the upper part of the Carlile being washed away by the rains, aided no doubt by the scouring of the winds. Large blocks become loosened and slip down from the mesa front, forming in places prominent detached knobs of slightly lower elevation than the mesa. The strata of these landslide masses usually dip toward the mesa from which they were derived. These blocks have fallen during all stages of the mesa erosion, but most of those now forming prominent knobs are probably of recent occurrence.

ALLUVIUM.

In the larger stream channels are narrow areas of recent alluvium, composed chiefly of gravel and fine silt, in process of transportation. These are not shown on the map because of their small size, but they are of interest in interpreting the terrace gravels. The recent alluvium is composed of local material except along Huerfano and Apishapa rivers, which rise in the mountains and bring down material of great variety. Large quantities of sandstone débris are derived from the canyons in the Dakota and Purgatoire formations, and the fragments become smaller and smaller as they are gradually moved downstream toward the Arkansas. The adobe soil and shale are washed into the streams by the heavy rains and floods, and this fine silt remains so long in suspension that most of it is carried to the Arkansas, but each receding flood leaves large quantities of the silt as alluvium to form a flood plain.

STRUCTURE.

GENERAL STRUCTURE.

All the sedimentary rocks occurring at the surface of the Apishapa quadrangle except the surficial gravels were nearly or quite horizontal when deposited and were below sea level. They are now far from horizontal and lie 5000 to 6000 feet above the sea. The deformation of the strata was brought about in part by internal earth forces during the elevation of the land to its present position and possibly in part by the intrusion of deep-seated igneous masses. The rocks of the quadrangle have been uplifted in a general way into a domelike fold with minor plications, which has in places been broken into large blocks that have settled down and been tilted, causing displacements of the strata between the blocks, some of them amounting to several hundred feet. The study of adjacent areas on the west shows that the domelike structure is the plunging end of an anticline which is the extension of the Wet Mountain salient of the Rocky Mountain uplift. It has been named the Apishapa anticline.

The structure of the quadrangle is shown on the structural-geology map by deformation contours on the top of the Dakota sandstone and by a cross section.

INDIVIDUAL STRUCTURAL FEATURES.

Apishapa anticline.—The Apishapa anticline, considered as a feature of geologic structure, is more than 2500 feet high, but its topographic expression is comparatively faint, all the higher parts of the arch having been removed by erosion. By this erosion a considerable tract of the Dakota sandstone is brought to view, and within the Apishapa quadrangle are many small exposures of the two underlying formations, of Lower Cretaceous age and possibly of Jurassic age. The Dakota sandstone area is completely surrounded by outcrops of shales belonging to the overlying Benton group, dipping away from the arch. The limestone and shales of the Niobrara group, next in order above the Benton, do not entirely surround the central tract but form broad belts on the flanks of the arch.

The plunging end of the Apishapa anticline is well shown by the structure contours on the structural-geology map. The highest point of the anticline lies just east of the Rattlesnake Buttes, where the surface of the Dakota sandstone, which is the datum used in the construction of the deformation contours, is 6100 feet above sea level. The sandstone dips rather uniformly northeastward, passing beneath higher Cretaceous strata, but to the south and southwest the descent is interrupted by faults and folds. In the Walsenburg quadrangle it again slopes rather uniformly southwestward and passes under a thick cover of higher Cretaceous and Tertiary strata. Along the axis of the anticline toward the northwest, in the Walsenburg quadrangle, its crest is broad and nearly level, but toward the southeast it has a notable pitch, which is not uniform, however, because of faulting. A bird's-eye view of the domelike structure may be had from the top of the Rattlesnake Buttes, which are remnants of the Timpas limestone on nearly the highest point of the axis. Seen from this point the inward-facing cliffs of the surrounding rim of mesas capped by the Timpas limestone, dipping away from the observer in all directions, with the terraces of Greenhorn limestone fringing their bases, are strikingly brought out by the growth of trees that accompanies these features. (See fig. 10.)

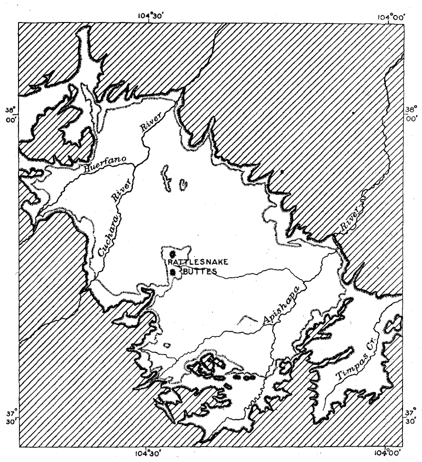


FIGURE 10.—Map of the Timpas limestone and Greenhorn limestone escarpments surrounding the Rattlesnake Buttes, which are at the crest of the Apishapa anticline.

The Timpas limestone escarpment is the darker cliff at the margin of the shaded mesa areas. The Greenhorn limestone escarpment is the inner lighter one. The Apishapa quadrangle is delimited by meridians 104° and 104° 30' and parallels 37° 30' and 38°. Scale: 1 inch = 10 miles approximately.

From the axis of the anticline the Dakota sandstone at first descends in a northeast direction at the rate of about 100 feet to the mile from an altitude of 6100 feet to about 5700 feet. At this altitude the descent steepens, increasing to about 200 feet to the mile to an altitude of 4300 feet. Farther northeast the dip becomes flatter again and in the northeast corner of the quadrangle, where the altitude of the sandstone is below 3600 feet, the dip is less than 50 feet to the mile. The difference in elevation of the Dakota sandstone at the top of the dome near the Rattlesnake Buttes and in the extreme northeast corner of the area is over 2500 feet.

On this general northeastward slope there are minor structural depressions and ridges, the depressions seemingly being in accord with the larger canyons that descend the slope in this direction and probably having determined the location of the streams that cut the canyons. Such structural depressions can be seen in Madden, Lone Jack, and Crossbars canyons. One of these synclines near Blue Hill becomes a deep, sharp fold as it passes out of the Dakota sandstone in Buffalo Arroyo, and remnants of the infolded Greenhorn limestone preserved in synclinal hills form the divide between branches of the arroyo, as shown in the section in figure 11.

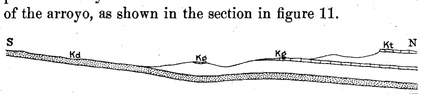


FIGURE 11.—Section across the minor fold of Buffalo Arroyo, 3½ miles west of Pittinger ranch.

Kd, Dakota sandstone; Kg, Greenhorn limestone; Kt, Timpas limestone.
Horizontal scale: 1 inch = 1 mile. Vertical scale: 1 inch = 1500 feet.

A low oval uplift at the base of the steeper descent in the vicinity of the Yellowbank ranch brings the Timpas limestone to the surface in an area about 2 miles long within the large tract covered by the Apishapa shale. This local anticline, which rises abruptly on the otherwise uniform monoclinal slope, is about 75 feet high.

Doyle Arroyo flexure.—West of Black Ridge the northeastward dip of the strata is disturbed by a sharp flexure along the line of Doyle and Streeter arroyos. (See fig. 12.) This feature is a fold of monoclinal type accompanied by faulting and minor folding. It begins east of the Rattlesnake Buttes as a minor drop fault with downthrow on the west, increasing in intensity northward. A branch fault, also with downthrow on the west, joins the main fault at Beardsley Arroyo, where the total displacement of the Dakota sandstone is over 200 feet. This displacement is accomplished chiefly by faulting and monoclinal folding but in part by a minor sharp syncline on the west. The sharp minor syncline adjacent to the fault may be regarded as the bottom of the flexure with the strata dragged up into a syncline. The open syncline farther west is less closely associated with the flexure.

There is nearly everywhere more or less bending or dragging of the strata adjacent to the fault. Near Cottonwood Spring the drag increases and the fault gradually diminishes

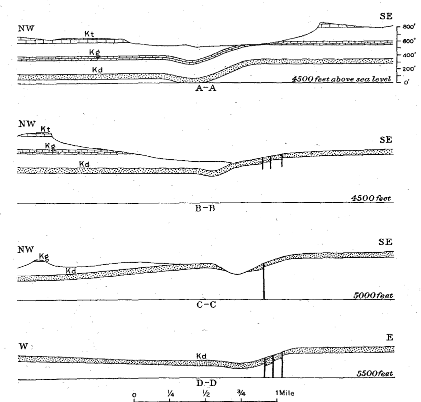


FIGURE 12.—Sections across Doyle Arroyo flexure.

Kd, Dakota sandstone; Kg, Greenhorn limestone; Kt, Timpas limestone.
A–A, 2 miles north of Cottonwood Spring; B–B, at Cottonwood Spring; C–C, 3½ miles south of Cottonwood Spring; D–D, 1 mile north of Reynolds ranch.

and passes into a sharp monoclinal fold, the strata striking northwest and southeast on opposite sides of the flexure. Near the north border of the quadrangle the flexure broadens and its effect is not so apparent.

Rocky Hill fault.—The Rocky Hill fault, which crosses the southern part of the quadrangle from the vicinity of Rocky Hill nearly to the eastern edge, is the longest fault in the area. It is a drop fault crossing the generally southeastward-dipping strata diagonally, the block to the south being elevated. Beginning several miles to the west, it enters the quadrangle with a displacement of about 300 feet, the Greenhorn limestone resting against the foot of the Dakota sandstone ridge.

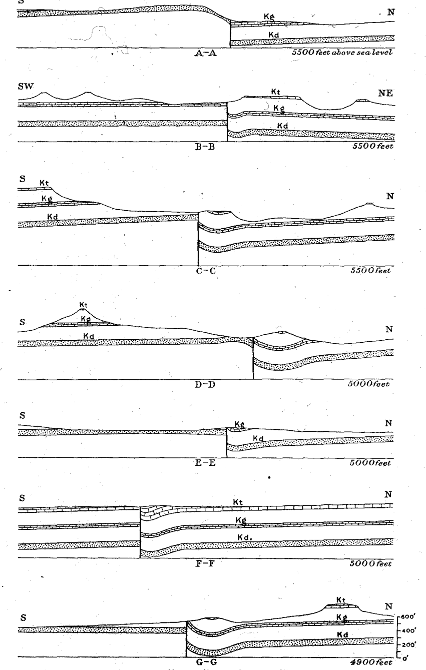


FIGURE 13.—Sections across Rocky Hill fault.

Kd, Dakota sandstone; Kg, Greenhorn limestone; Kt, Timpas limestone.
A–A, North point of Rocky Hill; B–B, on the divide 2 miles east of Rocky Hill; C–C, due south of Mica Butte; D–D, 3½ miles west of Apishapa River; E–E, at Apishapa River; F–F, on the divide 4 miles east of Apishapa River; G–G, due north of Thatcher.

At Rocky Hill it is crossed by the Bonita Cordova fault, which has a northeast trend and a downthrow to the northwest. The Rocky Hill mesa, lying at the intersection of these crossed faults, is the elevated end of an inclined block of Dakota sandstone, and the same strata north of the fault intersection have been dropped vertically 500 feet, but the drag along the fault plane has bent the Dakota strata down the slope of Rocky Hill.

To the east, on the mesa divide, the Timpas limestone north of the fault has been let down nearly to the level of the Greenhorn limestone on the south, so that the two form mesas of about the same altitude. Farther east, on the south side of Smith Hollow, small remnants of Timpas limestone north of the fault are brought very low in a sharp syncline accompanying the fault nearly to the level of the Dakota sandstone, which is exposed in several of the side streams south of the fault. This sharp syncline is more than the turned-up bottom of a monoclinal fold, and its effect on the position of the strata may be observed all along this part of the fault. In the Apishapa Valley, where the Greenhorn limestone is brought down to the level of the Dakota in the valley bottom, the drag along the fault is finely shown by the limestone standing vertical for over a mile along the fault on both sides of the river.

On Tyrone Flats a small outlier of the Apishapa shale has been preserved in the depression in the Timpas limestone on the north side of the fault. In the Timpas Valley small outliers of the Timpas limestone are brought very low in the syncline north of the fault, and the drag of the Greenhorn limestone along the fault is again marked. To the northeast, beyond Timpas Creek, the fault passes into a fold and swerves to the north, the low-lying mesa of Timpas limestone east of Delhi occupying the depression of the syncline.

Figure 13 represents sketch sections of this fault and associated fold at several points along its course. In figure 14 are sketched minute details of structure that accompany the faulting, as observed by Gilbert.

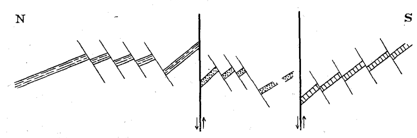


FIGURE 14.—Details of structure accompanying the Rocky Hill fault.

By G. K. Gilbert.

The strata shown are minor harder beds in the Graneros shale. That at the right is the 1-foot ferruginous limestone 75 feet from the base of the formation. The offsets of the beds, which are from 1 to 4 feet, are in the opposite direction from the main displacements of the Rocky Hill fault shown by the heavy lines.

Bonita Cordova fault.—Where the Bonita Cordova fault enters the quadrangle from the west the Timpas limestone mesa on the north is brought close to the Dakota sandstone outcrop in the valley south of the fault, showing a displacement of about 400 feet. This break culminates in Rocky Hill at the crossing of the Rocky Hill fault, as previously mentioned, and declines rapidly toward Tejano Arroyo, where it fades into other displacements.

Cross Canyon fault.—The fault in Cross Canyon is marked by a northward-facing escarpment of Dakota sandstone forming the south wall of the canyon, which is approximately parallel with the Rocky Hill fault. The valley itself is floored with Graneros shale, preserved on the steeply tilted dropped block in the narrow depression. In the Apishapa Canyon the Purgatoire formation is faulted down on the north farther below the stream bottom. Eastward the Dakota south of the fault is bowed up in a broad anticline, as shown in figure 15.

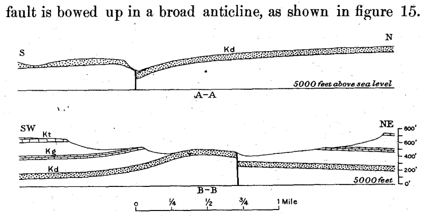


FIGURE 15.—Sections across Cross Canyon fault.

Kd, Dakota sandstone; Kg, Greenhorn limestone; Kt, Timpas limestone.
A–A, three-fourths mile west of Apishapa Canyon; B–B, 2½ miles east of Apishapa Canyon.

At the divide farther east the outlying buttes of Timpas limestone are 150 feet lower than the mesa top of the same limestone south of the fault. The fault passes into a fold in Poitrey Arroyo where its effect is shown by the broad area of Dakota sandstone brought to the surface in the uplift of Christian and Devils canyons.

Jones Lake Fork and Tejano Arroyo faults.—Several faults occur in the vicinity of Jones Lake Fork and Tejano Arroyo. The Jones Lake Fork fault enters the quadrangle southwest of the Rattlesnake Buttes. It causes a conspicuous disturbance in the Greenhorn limestone benches and brings a small mesa of Timpas limestone on the north down to the level of the Greenhorn. In the Dakota sandstone area the upthrown south side of the fault presents a rocky escarpment which grows higher down the valley until it meets the Tejano Arroyo fault, beyond which the throw is less.

The Tejano Arroyo fault starts in the Graneros shale west of the Bonito Cordova ranch and uplifts the Dakota on the south, forming the long straight sandstone escarpment along the north fork of Tejano Arroyo, shown in Plate XIII. After crossing the Jones Lake Fork fault it brings the Dakota sandstone against an outlier of Greenhorn limestone preserved in the depression north of the fault. Two parallel minor faults to the north, which offset the Graneros and Dakota, probably join the main Jones Lake Fork fault to the west as indicated on the map. The short parallel fault heading just south of the Rattlesnake Buttes is the only known fault in the quadrangle that has a downthrow to the south.

Almagre Canyon fault.—There is an uplift or minor dome in the Dakota sandstone between Almagre and Cross canyons, west of Apishapa River. This area is conspicuously higher than the surrounding Dakota sandstone surface and its anticlinal structure is exhibited in the Jones Lake Fork canyon.

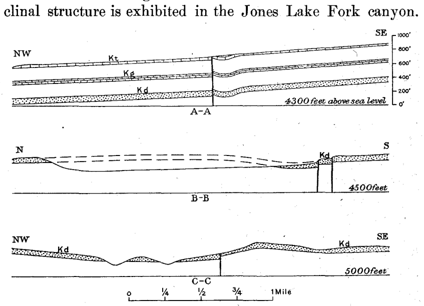


FIGURE 16.—Sections across Almagre Canyon fault and fold.

Kd, Dakota sandstone; Kg, Greenhorn limestone; Kt, Timpas limestone.
A-A, Along mesa front 3 miles east of Apishapa Canyon; B-B, along Apishapa Canyon below Juan Baca Canyon; C-C, near mouth of Almagre Canyon.

It is limited on the northwest by a faulted monoclinal downfold which makes a rugged escarpment and wooded slope from its south end at the Cross Canyon fault northward and is plainly traceable in the bench along the southeast side of Almagre Canyon. After crossing Apishapa and Juan Baca canyons it passes into a fold which, in the Timpas limestone mesa beyond, is seen to be accompanied by minor faulting. Figure 16 illustrates details observed along this fault.

Little Dome.—The Little Dome, west of Cordova Mesa, is a very interesting structural feature. In the midst of the mesa of Timpas limestone with the usual gentle southeastward dip an elliptical area of Dakota sandstone has been pushed up, with dips on its periphery so steep that the Graneros shale, Greenhorn limestone, and Carlile shale outcrop in very narrow concentric bands around the Dakota core. The Dakota sandstone surface is as high as the mesa of Timpas limestone to the east and south, showing an abrupt displacement of over 500 feet. On the north side the bands of Graneros and Greenhorn are broken by a fault which brings the Dakota and Greenhorn into contact.

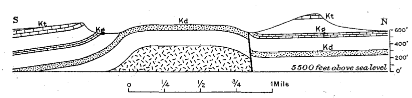


FIGURE 17.—Section across the Little Dome.

Kd, Dakota sandstone; Kg, Greenhorn limestone; Kt, Timpas limestone.
The strata beneath the Dakota are shown as having been intruded by a mass of igneous rock, which is believed to have domed up the overlying strata.

The abruptness of this dome is not in keeping with the other structures in the area but the dome so closely resembles in structure the laccolithic hills in the Rocky Mountains and similar occurrences in the plains, such as Twin Buttes, 80 miles east of the quadrangle, that it is believed that a body of igneous rock, probably coming from the same source as and composed of material similar to the dikes of the area, was intruded beneath and domed up the strata now at the surface of the Little Dome but has not itself been exposed by erosion. (See fig. 17.)

ORIGIN OF THE STRUCTURES.

As previously stated, the Apishapa anticline is a continuation of the Wet Mountain fold of the general Rocky Mountain uplift, which reaches a local climax at the Rattlesnake Buttes, in the Apishapa quadrangle, giving the effect of a dome, and pitches beyond to the southeast. Around this pitching end occur the puckerings and breaks that have been described above as folds and faults. These faults are situated chiefly on the south and southeast sides of the anticline and at all that have been observed except one the block on the north or arched side has dropped and the outer block has been relatively raised. The settling seems to have been in the nature of a partial collapse of the arch due to lack of support while the sides of the arch remained intact.

This process may be illustrated by an ideal arch composed of blocks settling, when the support is removed, by adjustment between the blocks, as shown in figure 18. A generalized north-south section through the faults and folds in the southern part of the quadrangle and a theoretical restoration of the arch from which the blocks were derived are presented in figure 19.

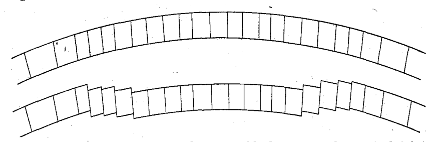


FIGURE 18.—An ideal arch broken into blocks by nearly vertical joint planes (upper figure) and the same arch as it would appear if the central part collapsed by displacement of the blocks along the joint planes, due to lack of support (lower figure).

When the rocks were pliable the settling took place by bending or by breaks so minute that the effect is that of folding rather than faulting. Thus the faults are accompanied by and pass into monoclinal folds. The cause of the sharp synclines that are closely associated with the downthrown side of many of these faults is not clear under this hypothesis and can not be satisfactorily explained with the data in hand.

The Little Dome, as previously stated, evidently is not a structure of this class. It is oval in outline and is isolated from and has no apparent connection with the Apishapa anticline. The local doming of its strata is probably due to the intrusion of molten igneous rock from some deeper source, possibly the same as that of the dikes of the region, which spread out between the rock strata at some horizon below the Dakota and domed up the overlying beds. The laccolith, as such an igneous mass is called, has not been exposed at the surface but probably does not lie deeply buried. The laccolith at Twin Buttes, which domes up the same strata in the Great Plains 80 miles to the east, has been exposed by erosion and is seen to penetrate the red strata of the Morrison and underlying formation and to dome up the Purgatoire and Dakota formations. The theoretic laccolith of the Little Dome is shown in the section (fig. 17) at about the same horizon.

IGNEOUS ROCKS.

OCCURRENCE.

General character.—The 42 recorded dikes in the quadrangle are of various composition but may be classed for the purposes of this report into two groups, basalt and lamprophyre. The dikes are mostly narrow bodies, 4 to 10 feet thick, but some are 20 feet or more wide. They represent clefts or cracks in the stratified rocks into which molten material was forced from deeper sources during the eruption of lava now forming Spanish Peaks, 25 miles southwest of the quadrangle, and Raton and other lava-capped mesas to the southeast of those peaks. The molten magma ascending in these narrow fissures and cracks became cooled and solidified into firm rock, the various minerals in the magma segregating into more or less crystalline forms, some of which can be detected by the unaided eye. The wall rock is generally indurated by the heat of the injected mass and its attendant vapors, soft shales being cemented to hard argillite, and crumbly limestone to hard porcelain-like rock. The hardening effect, or baking, is observed in some places as far as 20 feet from the dike.

Some dikes include fragments of wall rock that have been brought up from deeply buried beds. Although usually hardened and altered in appearance, some of these fragments are from older sedimentary rocks and granite, indicating that rocks similar to those which form the Greenhorn Mountains, west of the Apishapa quadrangle, deeply underlie the surface here.

The dikes that are inclosed in walls of Dakota sandstone and generally those in the Timpas limestone are attacked more readily by the agents of weathering than the inclosing rock and are therefore decomposed and washed away or dissolved faster, leaving crevices or channels in the wall rock partly filled with iron-stained clay. In the dikes cutting other formations, however, the intruding material is the more resistant and its fragments remain on the surface and retard erosion. Shale and limestone of the wall rock are hardened by the heat and by hot liquids or vapors emanating from the injected molten rock and aid in resisting erosion, so that the dikes in shale generally form straight, narrow ridges, protected by fragments of the dike and of the hardened wall rocks. The most conspicuous of these dike ridges in the area are Mica Butte, 4 miles east of the Bonito Cordova ranch, and Blue Hill, 7 miles northeast of North Rattlesnake Butte. The dike hill just east of North Rattlesnake Butte and the one on the mesa 3 miles south of English Spring are about as large but are less conspicuous because not so isolated.

Age.—The dikes cut the latest Cretaceous strata now remaining in the Apishapa quadrangle. In the Spanish Peaks region they cut the Huerfano formation, which is of Eocene age. As fragments of the volcanic rocks are found in the oldest terrace deposits derived from this region, the dikes are undoubtedly of Tertiary age, probably late Eocene or early Miocene.

Distribution.—Dikes are most plentiful in the southwestern part of the quadrangle, the portion nearest to the Spanish Peaks intrusive mass. The most thickly intruded tract is an elliptical upland area southeast of the Bonito Cordova ranch, where 12 dikes occur within an area about a mile wide. The dikes all trend in a westerly direction, toward the eruptive center in the Spanish Peaks. In several places in the quadrangle there are intersecting dikes, generally of slightly different composition, but as the points of intersection were so poorly exposed the relative age of none of the dikes was determined.

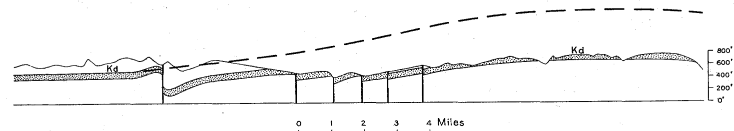


FIGURE 19.—North-south section across the faults in the southern part of the quadrangle, and the arch of the Dakota sandstone (Kd) restored as it is believed to have stood before displacement of the blocks by faulting along joint planes, as illustrated in the ideal arch in figure 18.

On the Timpas limestone hills south of Mica Butte a vogesite dike and a tinguaite dike cross, also a diabase dike and a vogesite dike. In the dike hill east of North Rattlesnake Butte a long basalt dike and a short vogesite dike intersect, but the details are on too small a scale to be shown on the map. Figure 20 shows the relation in the field as sketched by Gulliver.

The longest dike in the area is the one south of English Spring, which has been traced 4 miles. This dike is nearly the farthest in the area from the source of intrusion, the one south of Snowden Lake, at the eastern edge of the quadrangle, being slightly more remote.

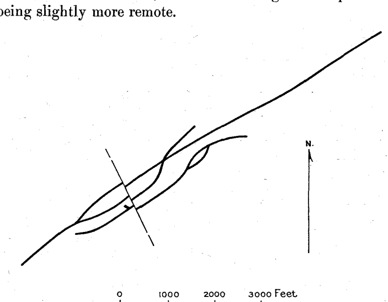


FIGURE 20.—Plan of dikes 2 miles northeast of North Rattlesnake Butte.
By F. P. Gulliver.
Shows branching and crossing of the dikes, and slight offset by faulting.

Certain of the igneous masses have a rounded shape like volcanic necks. Gilbert observed that the dike near the Reynolds ranch, in Streeter Arroyo, spread out at one point into a mass 25 feet in diameter which formed a detached butte suggesting a neck. Another in a valley of the dissected mesa east of the Bonito Cordova ranch also expands at one spot to 50 feet in diameter. The only necklike intrusion of sufficient size to be mapped as such is the vogesite mass southeast of Haystack Butte, which covers an oval area about 80 by 180 feet. Such necklike rock masses are of similar composition to the dikes and generally contain many similar inclusions of extraneous rock.

PETROGRAPHIC DESCRIPTION.

By WHITMAN CROSS.

General character of the rocks.—With few exceptions the dike rocks of the Apishapa quadrangle are dark-gray or black aphanites with few mineral grains recognizable in the hand specimen, even with a magnifying glass. The rock called minette has abundant leaves of brown biotite, and two described as diabase are clearly granular in texture, the lens revealing feldspar and augite. Several very dark rocks are porphyritic in subordinate degree through the presence of olivine crystals, fresh or altered, and locally augite has a corresponding development. Biotite of rich brown color occurs sporadically in some dikes in tablets reaching rarely a breadth of 1 centimeter. The rocks generally have a hackly or subconchoidal fracture.

A number of the specimens are characterized by white grains of analcite, which appear like primary phenocrysts but are believed to be the secondary filling of small vesicles or irregular cavities. This analcite is commonly associated with calcite and chlorite and in one specimen round pores are partly filled by a fibrous zeolite.

All these rocks belong to the unsystematic but useful group of the lamprophyres, which includes a great many dark fine-grained rocks rich in one or more of the ferromagnesian silicates—biotite, hornblende, augite, and olivine—generally with subordinate feldspars of a very wide range of composition. Basalt is not commonly included among the lamprophyres, but it clearly belongs to this series of dike rocks by occurrence, habit, and direct gradation through intermediate forms into some typical lamprophyres. That lamprophyres are not restricted to actual dike form is illustrated by numerous sills or small laccoliths in the Spanish Peaks and Walsenburg areas.

The rocks mapped as lamprophyre will be described under the headings minette and tinguaite, olivine-bearing augite vogesite, augite-hornblende vogesite, and diabase, and those mapped as basalt, under the heading olivine-plagioclase basalt.

Minette and tinguaite.—Highly micaceous rock of the minette type is represented in two dikes of the Apishapa quadrangle. This rock and a tinguaite associated with one of these dikes are the only types of the great series connected with the Spanish Peaks center that are peculiar to this quadrangle. The more typical minette forms a dike more than a mile long on the divide at the head of Buffalo Arroyo, near the center of the quadrangle, and is the only dike mapped as minette (*m* on the geologic map). Several specimens from it are rich in glistening reddish-brown biotite leaves of rudely parallel arrangement, giving the rock an imperfect schistosity. The remainder of the rock is pinkish in color and evidently feldspathic to the naked eye, though no crystals are large enough to be recognized.

The microscope shows this rock to consist mainly of biotite, alkali feldspar, and apatite. Besides the larger crystals the mica occurs in minute leaves in intricate mixture with feldspar, which is developed mainly in groups of small prisms. Apatite needles penetrate the mica flakes in great numbers. Cloudy reddish-brown ferritic material occupies the wedge-shaped interstices between mica and feldspar, but no magnetite particles occur in the sections. The feldspar is presumably orthoclase. Augite appears to have been a prismatic constituent of the rock but much subordinate to the biotite. It is now almost wholly decomposed.

The other highly micaceous dike is at Mica Butte, west of Apishapa River and south of Tejano Arroyo, in the southern part of the quadrangle. It is a compound dike which, as represented by the single specimen in the collection, consists of augite minette penetrated in intricate fashion by a pale-green rock that must be referred to tinguaite. From the name given to the butte traversed by this dike it may be inferred that biotite is developed in much of the rock in larger crystals than in the specimen studied. This is made up of very fine grained brown material cut by tongues of greenish color. Both minerals exhibit a poikilitic texture by the glistening of cleavage faces of orthoclase, but the included particles are so small and numerous as greatly to obscure the intergrowth.

The minette part of the specimen has biotite, augite, orthoclase, apatite, and magnetite as its chief constituents, with a little interstitial brown glass. The green material injected all through the brown consists chiefly of alkali feldspar with ægirite, apatite, titanite, and magnetite. The several veinlets are of different grain and texture. Biotite and augite are mingled with the other minerals named in various proportions in different tongues of the tinguaitic material but in certain places are wholly lacking.

The meager information concerning this interesting occurrence scarcely warrants further discussion.

Olivine-bearing augite vogesite.—The most common type of the lamprophyre dikes of the Apishapa area consists principally of augite, olivine, magnetite, apatite, and a colorless base which in many specimens is clearly alkali feldspar but in some has consolidated as glass. Biotite is a common but variable constituent and brown hornblende is its associate in a few dikes. Analcite occurs in a few dikes in grains of megascopic size and not uncommonly in microscopic particles. Its frequent association with calcite and chlorite suggests a secondary origin in such rocks, but it seems possibly primary in others.

These vogesites are generally aphanitic, but analcite grains and olivine phenocrysts produce a subordinate porphyritic fabric. The analcite may be simply a filling of small pores. Under the microscope these rocks usually exhibit a microporphyritic texture through the development of olivine and augite. The greater part of the olivine occurs in relatively large crystals, and only a small part of the augite appears in corresponding size. Both grade in seriate manner into the groundmass, but only augite sinks to the minutest size. Biotite is found either in very small flakes or in sporadic megaphenocrysts.

The feldspathic base of these vogesites is in some specimens not individualized and appears as an isotropic substance, but more commonly there is a fibrous mass of alkali feldspar needles or rarely distinct grains. Plagioclase is rare or lacking.

The vogesites of above noted character are those given the symbol v on the geologic map.

Augite-hornblende vogesite.—A variety of vogesite in which brown hornblende is nearly or quite as important a constituent as augite is found in several dikes. Olivine is less abundant in these rocks than in the type above described, and plagioclase is apt to appear, though much less prominently than alkali feldspar, which is better developed than in the other vogesites. Analcite occurs in rather notable grains, in some specimens being, however, open to the suspicion that it is secondary.

The hornblende is of distinct brown color, never very dark, and its pleochroism is not so strong as in the usual camptonitic type. It occurs in short, stout prisms rather than in needles. Its crystals are euhedral and in some rocks they are as large as the largest augite, whereas in others they are restricted to the microgroundmass with minute biotite flakes.

The long dike on the south edge of Cordova Mesa, at the border of the quadrangle, is one of the coarsest of the hornblendic vogesites. Other dikes of this rock occur on the mesa escarpment southwest of Little Dome; on the north side of Smith Hollow, 2 miles south of Mica Butte, associated with the diabase dike; and on the mesa about 2 miles east of Apishapa River near the south edge of the quadrangle.

Diabase.—Two dikes of diabase have been indicated by the letter d on the geologic map, and a third, the one southwest of Haystack Butte, is also of this general type. These are more or less distinctly ophitic in fabric and they consist mainly of augite and plagioclase. In the east-west dike cutting across the finger ends of the mesa north of Smith Hollow, 2½ miles southwest of Mica Butte, the ophitic fabric is barely discernible with the naked eye. The plagioclase has been apparently determined as albite-oligoclase by its refractive index and extinction angles. In another dike the plagioclase appears to be oligoclase, and in the third it is highly sodic. These are therefore not typical highly calcic diabases, but they betray their genetic relation to the other lamprophyres by this alkalic plagioclase. Olivine is lacking and biotite rare in these rocks.

Olivine-plagioclase basalt.—Three dikes in the Apishapa quadrangle consist of aphanitic basalt and are represented on the geologic map by a distinct color. They are megascopically very similar to if not indistinguishable from the olivine-augite vogesites. In both rocks the felic constituents are subordinate in amount and hence a basaltic character can be indicated in the hand specimen only by a development of the plagioclase in larger crystals than is apparently common in this area.

These basalts differ from the corresponding vogesites mainly in the abundance of plagioclase, but they are also richer in olivine. Biotite is common in minute brown leaves, but hornblende has not been observed. Apatite and magnetite particles bear the same relations as in the vogesites. The augite is of the same pale-green color and of similar crystal development in the two rocks.

An intimate genetic relation between these basalts and the vogesites is further emphasized by the fact that the plagioclase of the basalts is not more calcic than andesine and in many crystals appears to be nearer oligoclase, though a variable amount of actual alkali feldspar, or glass base of that general composition, is present in some specimens.

Relations of the dikes of the Apishapa quadrangle.—The dikes of the Apishapa quadrangle belong to a series of several hundred such fissure fillings surrounding the adjacent centers of eruption at the Spanish Peaks and Silver Mountain. About 350 of these dikes are represented on the geologic maps of the Spanish Peaks, Walsenburg, and Elmoro folios and are there briefly described by R. C. Hills. Perhaps an equal number of dikes occur in the still unsurveyed area west of Spanish Peaks. Through the evidence of many intersections Hills was able to refer most of the 240 dikes of the Spanish Peaks quadrangle to five principal epochs of eruption, and the rocks of these epochs were distinguished on the map under the legend names "early monzonite porphyry," "early lamprophyre," "late monzonite porphyry," "late lamprophyre," and "basalt." Similar distinctions were made among the 94 dikes of the Walsenburg quadrangle.

In the folios mentioned the details of association and many variations in composition of the dike rocks are recorded by Hills. It will suffice to say here that the Apishapa dike rocks, with one or two exceptions, undoubtedly belong to types more or less common in the series. They can not, however, be assigned to Hills's groups in the absence of data of intersection.

A few rocks of the Apishapa area are properly called basalt and they no doubt belong to the youngest group of the Spanish Peaks center. The remaining types can only be characterized in a general way as lamprophyres without recognition of the earlier and later groups of Hills. It is doubtful whether any representative of his monzonite porphyry occurs in the Apishapa area.

GEOLOGIC HISTORY.

Pre-Paleozoic time.—The geologic history of this region is based on an interpretation of the records furnished by the rocks. As no rocks older than Jurassic, possibly none older than Cretaceous, occur at the surface of the Apishapa quadrangle, the earlier history must be drawn from the exposures along the Rocky Mountain front, 25 miles to the west. The oldest rocks found there are schists and granites of pre-Cambrian age. These rocks, or other similar ancient crystalline rocks, form the basement on which the known sedimentary rocks of the western Great Plains were deposited. They probably represent ancient sediments and igneous rocks that cooled and hardened below the surface of the earth and were later elevated and exposed at the surface by erosion.

Paleozoic erosion and sedimentation.—During part of Paleozoic time, when vast areas of the interior of North America were covered by a continental sea and received thick deposits of sediment, this area remained land and was worn down by long-continued erosion so that at times its surface became a relatively level plain. A few rock outcrops, however, on the western edge of the Plains preserve a record that the inland sea reached the foot of the Rocky Mountains in the Cambrian and Ordovician periods, and again in the Carboniferous period, and left thin deposits of sand and limy silt which have been hardened and preserved as sandstone and limestone. These Paleozoic formations probably also underlie the Apishapa quadrangle and are so shown in the structure section on the structural-geology map.

Early Mesozoic sedimentation.—It was not until late Carboniferous and Triassic time that thick sediments were accumulated over a large portion of this region. These sediments are highly colored, mostly bright red, and were probably derived from rock that had disintegrated on a relatively arid upland where the iron was highly oxidized. The detritus was carried to the lowlands by streams and deposited there in part as alluvial wash but also in shallow shifting bodies of water. These lakes gradually evaporated and the salts in solution were concentrated to such an extent that layers of gypsum (hydrous calcium sulphate) were precipitated and became interbedded with the sand and silt. Land shells and bones and teeth of large reptiles that lived at this time are now found fossilized in the consolidated rocks. Similar red sands and clays were deposited in Jurassic or earliest Cretaceous time and were consolidated into the Morrison formation, the oldest rocks exposed in the deep canyons of the Apishapa quadrangle. In other areas beds equivalent to this formation contain numerous remains of mammals, gigantic dinosaurs, and other animals now extinct that lived on the land during this period. In the Apishapa quadrangle a few shells were found indicating that the limestones containing them were sediments in a fresh-water lake.

Cretaceous sedimentation.—The change from the red impure sediments of the Morrison to the purer light-buff quartz sand of the Cretaceous marks a great change in the physical conditions in the area, for it represents the advent of marine waters. The sea occupied this part of the interior of the continent during most of Cretaceous time. At the beginning of the Purgatoire epoch pure white sand was carried into the sea by streams that had been accelerated by a rising land and had eroded their channels down into fresh rock. Later in the epoch erosive activity on the land subsided and fine carbonaceous muds and thin beds of peat predominated over the sands, while in southern Colorado and Texas, farther from the source of the land detritus, limy silts were accumulated. These beds contain a marine fauna, mostly mollusks, prolific and of great variety in the limy beds but less abundant in the sands and clay silts. Fish remains, however, are numerous in certain of the sandy layers. These fossils are all of Comanche (Lower Cretaceous) types.

The deposition of pure quartz sand was again revived in Upper Cretaceous time and produced the Dakota sandstone, one of the most widespread formations in the Great Plains region. The absence of marine shells and the occurrence throughout the formation of plentiful fragments of wood, leaves, and even large trunks of trees and locally of thin layers of coal and carbonaceous shale, have led to the general opinion that the Dakota sandstone was deposited in fresh water. It seems probable, however, that such a vast body of water must have been open to the sea and that most of the tree trunks and vegetable material inclosed in the sand were floated down to their resting place from the interior by streams, although favorable places became shallow enough during oscillations of the sea bottom for the luxuriant growth of plants and the formation of carbonaceous layers and soils or underclays. Be this as it may, it is certain that at the close of the Dakota epoch marine conditions prevailed and a great thickness of black clays or silts accumulated during the Graneros and Carlile epochs, interrupted first temporarily by the deposition of lime silt of the Greenhorn formation and later by the calcareous deposits of the Timpas and Apishapa formations. All these formations bear an abundant marine fauna, comprising oysters and numerous other mollusks, strange chambered ammonites, both coiled and straight, and fishes.

Late Cretaceous and Tertiary sedimentation.—Although the higher Cretaceous and Tertiary sediments that normally follow the limy beds of the Niobrara in adjacent areas are not now present in the Apishapa quadrangle, it is highly probable that they were originally deposited there, for they not only occur in the plains to the northeast but are preserved from erosion by the protection of injected igneous masses and dikes in the Spanish Peaks, to the southwest.

As shown by the records in these adjacent areas, marine conditions continued during the Pierre epoch, when fine black clays or silts were again swept from the land broadcast into the sea. Toward the close of the continuous sedimentation the sea became partly inclosed and the water brackish while the sands of the Fox Hills formation were accumulated. Marine conditions thereafter ceased in this region and the closing deposits of the Cretaceous and those of the early Tertiary are all terrestrial, laid down in part as lake sediments, in part as wash from the mountains and uplands out upon the plains. They inclosed many organic remains and, in favorable places, great peat bogs accumulated vast amounts of carbonaceous matter which has consolidated into thick beds of coal. Certain strata contain the bones of monstrous extinct mammals and other vertebrates that lived during the Eocene epoch, while these sediments were being deposited.

Tertiary uplift, igneous intrusion, and erosion.—Although minor elevation of the interior of the continent had been in progress, it was not until the Tertiary period, probably at the close of Eocene or in Oligocene time, that the interior of the continent was greatly uplifted, and the area to the west of the Apishapa quadrangle, now the Rocky Mountain region, was sharply raised above the plain and the strata along the margin were steeply upturned. The rocks of the Apishapa quadrangle were also affected by an offshoot from the Rocky Mountain uplift and were arched up into an anticline 2500 feet high. This fold collapsed on its margins and the blocks of strata settled, producing the displacement of strata now visible at the surface.

Uplift of the region was accompanied by the injection of great masses of molten rock, only the distant ends of which found their way through crevices and fissures in the rocks of the Apishapa quadrangle and solidified into dikes of igneous rock. Some of the molten material flowed out upon the surface as lava and is preserved on Raton Mesa and Mesa de Maya, south of this quadrangle.

Erosion was accelerated in the more elevated portion of the continent to the west, the softer rocks were rapidly removed and the older harder rocks were exposed. As uplift continued, these elevated regions eventually became mountains of the present proportions of the Rocky Mountains and the less elevated tracts to the east became lowland plains. A prolonged period of gradation followed, in which the higher parts of the folds in the plains region were eroded and the surface was reduced to gentle slopes. Then further uplift of the mountains to the west overcharged the streams with débris and a blanket of wash, called the Nussbaum formation, was spread widely over the plain. This peneplain passed over the tops of the Rattlesnake Buttes, and is probably entirely eroded in the quadrangle except where the remnants of the Nussbaum formation still rest upon it in the northeast corner. The present attitude of the peneplain floor preserved beneath the Nussbaum deposits in adjacent regions indicates that moderate folding continued into Quaternary time.

Quaternary sculpturing.—The details of the present topography—mesas, terraces, slopes, lowlands, and canyons—are the work of the most recent geologic processes, comprising the disintegration of the exposed rocks and the removal and transportation of the detritus to lower levels by rain, wind, and streams.

The resistant lavas of Raton Mesa were left as high hills and mountains above the Tertiary peneplain and probably helped to determine the northeastward slope of this part of the region toward Arkansas River and the consequent drainage in that direction. All the larger streams have superimposed channels, which originated upon the alluvium-covered late Tertiary peneplain, and now run in approximately parallel courses across the Cretaceous outcrops without regard to the dips of the strata or other structural features.

Apishapa River probably crossed the quadrangle in a shallow depression in the peneplain, approximately in the position that it now occupies but relatively several hundred feet higher. It continued to occupy this course, cutting its channel deeper and deeper into the soft rocks as the land rose until eventually it incised a canyon across the anticlinal area of Dakota sandstone upon which it was superimposed. This explains the apparently strange course of the Apishapa, as it leaves an open plain in soft rocks and passes through its canyon in the hard Dakota sandstone to emerge again on an open plain in the same soft rocks beyond. (See fig. 5, p. 2.)

High terrace gravels on the bluff east of Apishapa River a short distance northeast of the quadrangle, several hundred feet above the present stream, are composed of the same materials that are found generally in the Apishapa River gravels except that there is a noticeable absence of sandstone fragments. This deposit is therefore a record of the stream channel before it cut into the Dakota sandstone and fragments of that hard rock were ground into pebbles in its channel.

As previously mentioned, a rather narrow gap in the mesa northeast of the Juan Baca ranch, now draining only its immediate basin, was probably formed and once occupied by a larger stream which crossed the mesa at this point but which for some reason has since shifted its course. Gravels were not observed in this valley, but two small deposits along its lower course are in line with the larger gravel area at Snowden Lake. Probably either Timpas Creek or Apishapa River, when flowing about 300 feet higher than now, had its course through this gap.

Another high though much wider gap in the mesa front lies north of Haystack Butte. The stream now flowing through the gap heads on the Greenhorn limestone terrace in front of the mesa and could not possibly have excavated so wide a gap. Gravel was not found in this gap or channel, but the large deposits to the southwest suggest that the stream in Crossbars Canyon and associated streams once united and flowed through this gap and that the gravel deposits mark their course at that stage.

Doyle, Peterson, Mustang, and Saunders creeks, which flow northeastward down the surface of the central upland and through gaps in the mesa front, have all had similar histories. They were established with somewhat parallel courses on the inclined gravel-covered Tertiary peneplain which passed over the present crest of the mesa, as shown in figure 4. As the streams eroded their channels into the underlying rocks they were superimposed across the structure of the Cretaceous strata. They stripped the softer shales from the harder rocks and left the Dakota sandstone surface bare and the Timpas and Greenhorn limestones standing in relief as benches and mesas. Thus the streams passing out of the canyons in the Dakota sandstone to higher rocks go through gaps in the escarpments of these benches and mesas which they have slowly cut in the course of their descent, in the same manner as Apishapa River.

Shallow lake basins scattered over the quadrangle are periodically filled by rain water and emptied by evaporation. Most of these lakes are on the shales of the Benton group, but a few are located on the Dakota sandstone and one or two on the formations of the Niobrara group. On whatever formation they are their occurrence requires explanation.

Most of the lake basins can be best explained as the result of wind action. All those on the shales of the Benton group are probably of this origin. The shale soils in general are not fertile and support only a scant vegetation. Certain beds of black shale, particularly one just above the Greenhorn limestone, are especially unproductive and barren. The wind in eddying about some obstruction, such as a clump of trees or bushes, would tend to blow away loosened particles of the unprotected soil and start a depression, and, with the thin protection of vegetation removed, scouring to shallow depths would quickly follow. Rain water accumulating in these basins would attract buffalo, antelope, and cattle, which would further loosen the soil by wading and stamping. When the basins were dry these same animals, particularly the buffalo, would congregate here to stamp, roll, and throw dust over their bodies, thus aiding in loosening the soil and subjecting it to wind action. Such dry barren depressions were early known as "buffalo wallows."

Data gathered by Gilbert showed that the shape of many of the basins in the shales of the Benton group presents strong arguments in favor of wind scour, and some of the basins in the limy shales of the Niobrara group probably have a similar origin.

Certain ponded drainage channels of gentle grade in shale were regarded by Gilbert as having been dammed by windborne material, the amount of ponding varying with the relative activity of stream erosion and of filling by sand carried by winds which have a prevailing direction.

Some of the basins in the Dakota seem to be original irregularities or depressions in the sandstone surface formerly filled with shale which has been cleaned out by wind action. Others may have been structural basins in the Dakota surface or may have been formed by faulting, the inclosed shale having been likewise blown away by the wind. South Canyon Lake, which has a lower rim of Dakota sandstone ledges standing 25 to 30 feet above the water surface, seems to have been produced in some such way.

MINERAL RESOURCES.

The known mineral resources of the Apishapa quadrangle are few and of little commercial value, especially as there are so few residents in the area and as the railroad facilities are so poor. These resources comprise building stone, clay and shale (for brick), limestone (for lime, flux, and cement), fire clay, barite, water, and soil. Highly carbonaceous shale and thin seams of coal are locally present in the Purgatoire formation but have no economic value.

BUILDING STONE.

Many beds of the Dakota sandstone are suitable for local use in building but do not warrant quarrying for shipment nor are they favorably located for transportation. The same may be said of the sandstones at the top of the Carlile shale and the limestones at the base of the Timpas, which together form the cliffs at the edges of mesas, and of the beds of the Greenhorn limestone. The layers of these formations are largely of suitable thickness for use in building and are separated by shale which would make quarrying simple and inexpensive. However, there is at present no demand for the product and none has been quarried in the area.

LIMESTONE.

Lime has been burned for local use at only one place in the quadrangle, so far as known. In one of the reentrant valleys in the mesa front, west of Thatcher, a kiln was constructed in which limestone from the base of the Timpas formation was calcined. Although no analysis of the limestone in this quadrangle has been made, it is in general rather pure, as shown by the following analysis of a sample of the rock from the adjoining Pueblo quadrangle:

Analysis of Timpas limestone from Harp's quarry, Pueblo.

[By Pueblo Smelting Co.]

SiO_2	6.4
Al_2O_3	1.3
Fe_2O_3	2.1
$CaCO_3$	89.9
	99.7

The high percentage of iron is due to nodules of marcasite that are scattered through the rock. The limestone is extensively used for flux in the iron furnaces at Pueblo and, with proper selection and the removal of nodules, may be suitable for cement manufacture. With the increase in population due to the agricultural development by irrigation of the uplands in the northeastern part of the quadrangle, the use for wall plaster will increase, and possibly field lime will be demanded to restore the fertility of the soil. Limestone for these purposes can be had from almost any of the outcrops of Timpas limestone shown on the geologic map, and possibly also from the Greenhorn limestone.

BRICK CLAYS.

Shale and clay for brick can be obtained in all parts of the quadrangle except where the Dakota sandstone is exposed at the surface. The Graneros and Carlile formations and a large part of the Apishapa formation are composed almost entirely of argillaceous or clayey material which weathers at the surface to a soft clayey soil or adobe. This adobe is an excellent brick material and in the form of air-dried blocks is the chief building material in use in the portions of the plains not convenient to the railroads. The demand for burned brick from the same material will increase with the growth of the agricultural settlements.

FIRE CLAY.

Fire clays, containing high percentages of silica and alumina and small amounts of potash and other alkali salts, consequently refractory or fusing only at high temperatures, occur at the top of the Purgatoire formation throughout the quadrangle and are exposed in most of the deeper canyons in the area of the Dakota sandstone. The clay is both light and dark gray, compact, and usually hardened to an argillite. It occurs generally in thick beds beneath a roof of hard massive sandstone of the Dakota. The shale is not uniform in thickness, composition, or refractory character, and the degree of refractoriness must be determined by tests of each sample. Similar clays, usually in thinner layers, are interbedded in the Dakota sandstone, especially in the upper part.

In the vicinity of Thatcher the fire clay of the Purgatoire formation has been mined and large quantities were shipped to brick manufactories. The opening shown in Plate XI is on the west side of Timpas Creek, 2 miles northeast of Thatcher, to which station the clay was hauled for shipment. A section of the deposit here, measured by G. K. Gilbert, showed 40 feet of massive Dakota sandstone in the cliff underlain by 6 to 8 feet of dark-gray joint clay, weathering to cuboid blocks, divided by a sandstone layer ranging up to 3 feet in thickness.

A prospect for fire clay was also reported near Thatcher, 60 feet below the top of the Carlile shale, but the clay is a nonplastic clay weathered from normal clay shale and is probably unrefractory.

Nine samples of more or less refractory clays from the Dakota sandstone and possibly the Purgatoire formation of this quadrangle were analyzed as follows:

Analyses of refractory clays from the Dakota sandstone of the Apishapa quadrangle.

[By H. N. Stokes.]

	1	2	3	4	5	6	7	8	9
SiO_2	86.58	78.07	76.96	61.98	93.11	85.98	85.25	54.93	58.86
Al_2O_3	12.72	20.22	20.77	37.51	5.56	13.67	11.45	43.65	39.17
Fe_2O_3	.45	.89	1.11	.45	1.15	.41	2.24	.69	.55
CaO	.11	......	.71	.19	.32	.21	.26	.64	1.08
MgO	.11	.26	.32	.09	.10	......	.21	.05	.45
Total per cent of ignited substances	99.97	99.44	99.87	100.22	100.24	100.27	99.41	99.96	99.81
Loss on ignition	4.75	7.51	7.98	12.51	4.45	5.07	4.81	16.80	19.58

1. 12 feet below top, Jones Spring, near head of Hog Ranch Canyon.
2. 13 feet below top, Jones Spring, near head of Hog Ranch Canyon.
3. Transition beds at top, 3 miles southwest of Jones Spring, northeast slope of Turkey Ridge.
4. In canyon near Juan Baca ranch.
5. Transition beds at top, 3 miles southeast of mouth of Apishapa Canyon.
6. Just above sample 5, 3 miles southeast of mouth of Apishapa Canyon.
7. Transition beds at top, 5 miles west of mouth of Apishapa Canyon.
8, 9. About 40 feet below top, 2 miles west of Haystack Butte (possibly top of Purgatoire formation).

Three of these samples were given a practical fire test and all proved to be good fire clays. No. 4 stood a test to cones 35–34, No. 8 to cones 34–35, and No. 9 to cones 33–34.

A test of two samples of clay from the old workings in the Purgatoire formation 2 miles northeast of Thatcher showed them to be equal to cones 29 and 30–31. The physical appearance of the rock, the extent of the workings, and the reports of its successful use indicate that it is probably a fair grade of fire clay. The bed is thick, is well located for mining, and, being convenient to the railroad, offers the best opportunity for developing this industry in the quadrangle. Several other samples of clay taken from prospects in the Carlile shale and Dakota sandstone in the vicinity of Thatcher were tested and found not to be refractory but melted below cone 27.

BARITE.

Barite, sometimes called baryta or heavy spar, occurs as vein filling in large concretions in the Apishapa shale on the upland in the northeastern part of the quadrangle. In places the weathering of the calcareous shale has left the surface strewn with fragments of the translucent to transparent crystalline barite. The mineral when ground to powder is used commercially in the manufacture of paint and for other purposes, but it is doubtful whether a sufficient quantity of barite is present in the shale to afford the basis of such an industry here. The crystals of the barite, however, are sought by mineral collectors and the deposit is of some value for this purpose.

Barite is also found sparingly in similar concretions at the top of the Carlile shale, associated with calcite crystals, which are also attractive to the collector.

PRECIOUS AND USEFUL METALS.

The dikes in the quadrangle have been somewhat prospected for "mineral." Some that have decomposed to a yellow ocherous earth with ramifying ferruginous quartz seamlets look very attractive to the prospector, and holes have been dug in them to considerable depth. One shaft on the dike in the Dakota area near Bass Canyon went down 25 to 30 feet in the soft material without either striking hard rock or finding ore of value. Beyond any doubt no valuable deposits of this kind occur in the quadrangle.

WATER RESOURCES.

IRRIGATION.

Surface water is scarce throughout the quadrangle during the drier portion of the year. During the summer the grass dries up and the herds of cattle and sheep that are pastured on the plains find scant subsistence and barely sufficient water in the temporary lakes, water holes, and canyon bottoms. Most of the land is unfit for cultivation either because of its rocky nature, its barren soil, or because of its location. The sloping upland in the northeastern part of the quadrangle back of the mesa front is the most suited for cultivation, having good limestone soil and gentle slope, but it lacks water.

In the last few years this upland has been under development by irrigation projects. Dams have been built across the streams which issue from the Dakota sandstone canyons and flow through the gaps in the Timpas limestone mesas. The flood waters are ponded by this means and distributed by irrigation ditches over wide areas of the level plains. A growing settlement called White Rock is located between Twomile and Saunders arroyos, deriving its water for irrigation from the latter valley. Ranches and homesteads with their own small dams and irrigation ditches are scattered along the other streams crossing this upland plain, and this part of the quadrangle is no longer the desolate waste it used to be. This agricultural development has taken place since the Apishapa quadrangle was surveyed and consequently is not shown on the maps of this folio.

In no other portion of the quadrangle has irrigation been attempted. There are only two or three occupied ranches throughout the rest of the quadrangle, and almost no cultivated land. At the Reynolds ranch a patch of Mexican beans was being dry farmed in 1910. At the old adobe ranch house west of the Bonito Cordova ranch a windmill was formerly used to supply stock but is now in ruins. At Thatcher the Atchison, Topeka & Santa Fe Railway Co. has built a dam in the Timpas Canyon and confined a large body of water for use in its locomotives, also supplying the few residences in the village.

UNDERGROUND WATER.

Throughout most of the Great Plains underground water is obtainable by wells from the sandstones of the Dakota and Purgatoire formations and furnishes the water supply in many places. Several deep wells in the Arkansas Valley north of the Apishapa quadrangle get water from these beds.

The rain and surface water enters the sandy strata at their upturned ends on the flanks of the Rocky Mountains and in other high areas where the beds are exposed and, descending in the porous strata beneath the overlying impervious shales, is confined there under the pressure of the descending column of water. When the water-bearing bed is tapped by a well, the water rises until the pressure is exhausted, and in many places it reaches the surface or even flows. If the water in the well rises materially, even though it may not flow at the surface, it is called an artesian well.

The large area in the Apishapa quadrangle where the sandstones of the Dakota and Purgatoire are at the surface and are deeply cut into by canyons is one of the elevated tracts where water enters the porous strata and is a source of the underground water for areas in the plains to the east and northeast. Elsewhere in the quadrangle the water-bearing strata are under cover of overlying formations and can be reached by boring.

The bed that is most generally water-bearing is the open-textured sandstone of the Purgatoire directly beneath the impervious dark shale in the upper part of the formation and about 130 feet below the top of the Dakota sandstone. This water-bearing stratum may be struck by boring to depths ranging from 130 feet in the shale areas directly bordering the Dakota outcrops to about 700 feet on the mesas of Timpas limestone and to a maximum of 1000 feet in the plains in the extreme northeast corner of the quadrangle.

As the Dakota sandstone is exposed at the surface in so large a part of the quadrangle and much of the rest is not favorably located for irrigation even if artesian water could be had, an artesian-water map on the same scale as the other maps in this folio has not been constructed for this quadrangle. The approximate artesian head and the area in which flowing wells may possibly be had in the northeastern part of the quadrangle, however, are shown in the small-scale map, figure 21.

As previously stated, the artesian head, or elevation to which the water in the sandstones tends to rise, is controlled generally by the elevation of the sandstone in the foothills, where most of the water enters it. In the vicinity of the Apishapa anticline, however, the pervious layers are severed by the canyons, and if water were confined in these layers under pressure it would escape in springs. Such springs as do occur in the canyons are of short duration and appear to be only local seepages. Instead of this area being one of springs it is one of absorption of water, where the rainfall and streams sink into the sandstone, and it therefore controls the artesian head in the plains areas beyond. The determination of the artesian head in this area is based, therefore, on the elevation at which the top of the Purgatoire formation disappears under cover in the northeastward-dipping monocline in the Apishapa quadrangle and on the height of water in artesian wells at Delhi, Bloom, Timpas, Pueblo, Fowler, and La Junta. Because of insufficient data the head can not be accurately determined, but beyond much doubt areas in which flowing water can probably be had at moderate depth exist only in the Apishapa Valley in the extreme northeast corner of the quadrangle, as shown in figure 21.

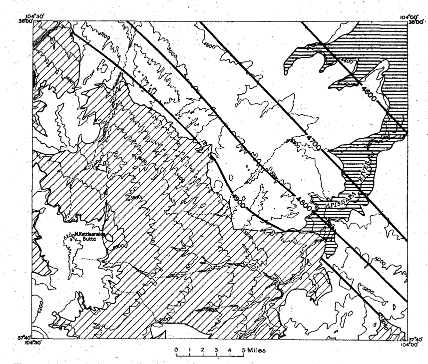


FIGURE 21.—Map of the northern portion of the Apishapa quadrangle showing artesian conditions.

The open ruling represents the area of outcrop of the Dakota and underlying sandstones; the denser ruling the area in which flowing wells may be expected at depths ranging from 100 feet in its southern part to 1000 feet in the northern. The heavy lines show the theoretic head of the underground water and the elevation to which water will probably rise in wells.

Should experimental irrigation prove successful in this northeastern part of the quadrangle, where agricultural communities are being established, good household water will be essential and the underground supply should be used. The most favorable places for artesian water will be near the bottoms of the valleys crossing the plain, where water may be expected at depths ranging from 700 to 1000 feet, although flowing wells may be expected only within the area indicated in figure 21.

The only deep borings in the quadrangle are those at Thatcher and Delhi, where artesian water was sought for use in the locomotives of the Atchison, Topeka & Santa Fe Railway. The well at Thatcher was sunk in 1884 to a depth of 920 feet and found water that rose within 620 feet of the surface. The boring passed through the purer sandstones of the Dakota and Purgatoire into the red strata of the Morrison and underlying "Red Beds." The well was abandoned and nothing is known of the quality or quantity of the water. The well at Delhi was sunk in 1901–2 to a depth of 322 feet and encountered water in several beds below 132 feet. Water rose within about 50 feet of the surface but is lowered by pumping. The boring began near the bottom of the Graneros shale and is mostly in the Dakota and Purgatoire formations. Its record is given in the section on the Dakota sandstone (p. 5).

March, 1912.

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

TOPOGRAPHY

COLORADO
APISHAPA QUADRANGLE

E. M. Douglas, Topographer in charge.
Triangulation by A. H. Thompson.
Topography by W. H. Herron
and Arthur Stiles.
Surveyed in 1896.

APPROXIMATE MEAN DECLINATION 1910.

Scale $\frac{1}{125000}$

Contour interval 25 feet.

Datum is mean sea level.

Note: *Dotted lines near northern edge of sheet show position of parallel and meridians corrected to join Nepesta sheet, which is projected from later data.*

Edition of Nov. 1897, reprinted Mar. 1912 with corrections.

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

AREAL GEOLOGY

COLORADO
APISHAPA QUADRANGLE

(Pueblo) (Nepesta) (Catlin)

LEGEND

SEDIMENTARY ROCKS

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

QUATERNARY — *Pleistocene*

- Qd — Dune sand *(derived from high terrace deposits by wind action)*
- Qht — High terrace gravel *(gravel and sand on terraces and valley slopes of present streams)*

TERTIARY — *Pliocene ?*

- Tn — Nussbaum formation *(gravel and sand of fluviatile origin on high divides)*

UNCONFORMITY

CRETACEOUS — *Upper Cretaceous*

Niobrara group

- Ka — Apishapa shale *(light-gray to yellowish shale)*
- Kt — Timpas limestone *(thin-bedded creamy-white limestone and calcareous shale)*

Benton group

- Kcr — Carlile shale *(dark-gray argillaceous shale containing large septarian concretions and friable brown sandstone near top)*
- Kg — Greenhorn limestone *(alternation of thin-bedded, blocky, light-blue limestone and calcareous blue shale)*
- Kgs — Graneros shale *(dark-gray to black shale with thin impure limestones near middle and at top)*

(Timpas)

CRETACEOUS — *Lower Cretaceous*

- Kd — Dakota sandstone *(light-gray to buff, compact, cross-bedded sandstone weathering rusty brown)*
- Kp — Purgatoire formation *(light-buff, open-textured, cavernous sandstone with few thin conglomeratic layers and dark-gray sandy shale with thin sandstone beds)*

JURASSIC OR CRETACEOUS

- Km — Morrison formation *(maroon, green, and drab argillite and shale, red, chocolate, and speckled-gray sandstone, and few thin fresh-water limestones)*

IGNEOUS ROCKS

TERTIARY — *Later than middle Eocene*

- Basalt dikes
- Lamprophyre dikes *(minette, m, vogesite, v, diabase, d, and other varieties)*

Faults

x *Fire clay prospect*
⊙ *Artesian well*

(Spanish Peaks) (Elmoro) (Mesa de Maya)

E. M. Douglas, Topographer in charge.
Triangulation by A. H. Thompson.
Topography by W. H. Herron and Arthur Stiles.
Surveyed in 1896.

TRUE NORTH — MAGNETIC NORTH 13¼°
APPROXIMATE MEAN DECLINATION 1910.

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 25 feet.

Datum is mean sea level.

Note: *Dotted lines near northern edge of sheet show position of parallel and meridians corrected to join Nepesta sheet, which is projected from later data.*

Edition of April 1912.

Geology by G. K. Gilbert, G. W. Stose, and F. P. Gulliver.
Surveyed in 1894 and 1910.

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

STRUCTURAL GEOLOGY

COLORADO
APISHAPA QUADRANGLE

LEGEND

SEDIMENTARY ROCKS

SHEET SYMBOL — SECTION SYMBOL

QUATERNARY — Pleistocene

Qd — Dune sand (derived from high terrace deposits by wind action)

Qht — High terrace gravel (gravel and sand on terraces and valley slopes of present streams)

TERTIARY — Pliocene ?

Tn — Nussbaum formation (gravel and sand of fluviatile origin on high divides)

UNCONFORMITY

CRETACEOUS — Upper Cretaceous

Niobrara group

Ka / Ka — Apishapa shale (light-gray to yellowish shale)

Kt / Kt — Timpas limestone (thin-bedded creamy-white limestone and calcareous shale)

Benton group

Kcr / Kcr — Carlile shale (dark-gray argillaceous shale containing large septarian concretions and friable brown sandstone near top)

Kg / Kg — Greenhorn limestone (alternation of thin-bedded, blocky, light-blue limestone and calcareous blue shale)

Kgs / Kgs — Graneros shale (dark-gray to black shale with thin impure limestones near middle and at top)

Kd / Kdp — Dakota sandstone (light-gray to buff, compact, cross-bedded sandstone weathering rusty brown)

Lower Cretaceous

Kp — Combined with Dakota sandstone on section — Purgatoire formation (light-buff, open-textured, cavernous sandstone with few thin conglomeratic layers and dark-gray sandy shale with thin sandstone beds)

JURASSIC OR CRETACEOUS

Km — Combined with pre-Cretaceous strata on section — Morrison formation (maroon, green, and drab argillite and shale, red, chocolate, and speckled-gray sandstone, and few thin fresh-water limestones)

PRE-CRETACEOUS

Do not outcrop in quadrangle — Pre-Cretaceous strata

PRE-CAMBRIAN

Do not outcrop in quadrangle — Pre-Cambrian schist and granite

IGNEOUS ROCKS

TERTIARY — Later than middle Eocene

Basalt dikes

Lamprophyre dikes (minette, m, vogesite, v, diabase, d, and other varieties)

Faults

Structure contours (the lines show elevation above sea and configuration of top of Dakota sandstone; contour interval 100 feet)

Note: Map has been cut in two and section inserted

E. M. Douglas, Topographer in charge.
Triangulation by A. H. Thompson.
Topography by W. H. Herron and Arthur Stiles.
Surveyed in 1896.

Scale 1/125000

Contour interval 25 feet.
Datum is mean sea level.

Note: *Dotted lines near northern edge of sheet show position of parallel and meridians corrected to join Nepesta sheet, which is projected from later data.*

APPROXIMATE MEAN DECLINATION 1910.

Edition of April 1912.

Geology by G. K. Gilbert, G. W. Stose, and F. P. Gulliver.
Surveyed in 1894 and 1910.

ILLUSTRATIONS

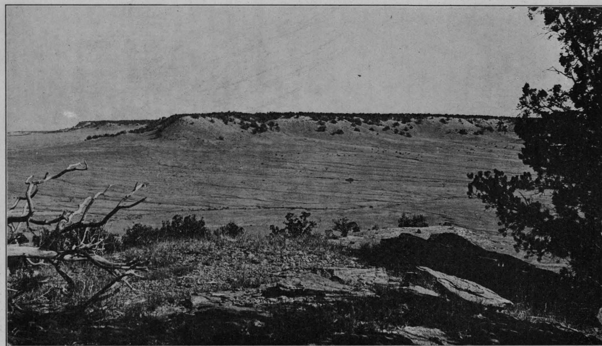


PLATE I.—TIMPAS LIMESTONE MESA WITH CHARACTERISTIC GROWTH OF TIMBER ON ITS SUMMIT, SOUTHEASTERN PART OF APISHAPA QUADRANGLE.
Sandstone at the top of the Carlile shale on mesa top in foreground.

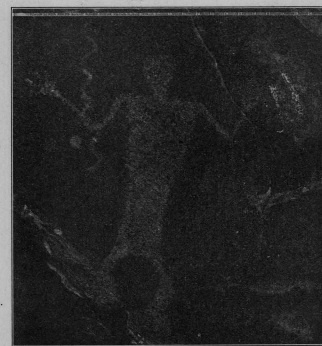


PLATE II.—INDIAN PICTOGRAPH ON DAKOTA SANDSTONE CLIFF IN APISHAPA CANYON BELOW MOUTH OF SOUTH CANYON.
Made by chipping the "desert varnish" from the weathered surface of the rock.

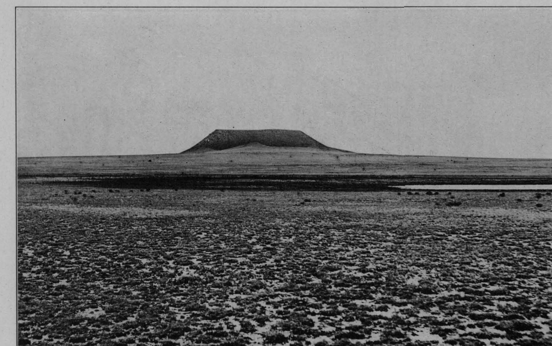


PLATE III.—HAYSTACK BUTTE, AN OUTLYING REMNANT OF THE TIMPAS LIMESTONE MESA.
Semiarid vegetation and shallow lake, characteristic of the Carlile shale areas, in the foreground.

PLATE IV.—VIEW LOOKING TOWARD THE MESA IN THE NORTHWESTERN PART OF THE QUADRANGLE.
Showing wooded mesa in the distance capped by Timpas limestone, wooded medial bench capped by Greenhorn limestone, and lowland underlain by Dakota sandstone.

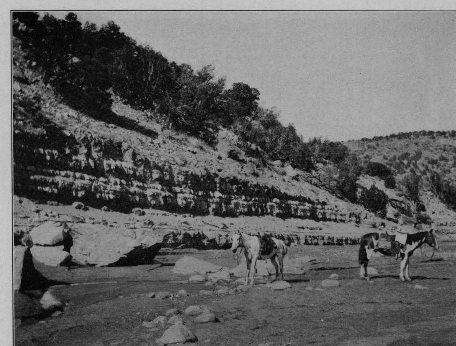


PLATE VI.—IMPURE GRAY LIMESTONE IN GREENISH-GRAY SHALE NEAR BASE OF MORRISON FORMATION, HUERFANO CANYON, NEAR WESTERN EDGE OF THE QUADRANGLE.

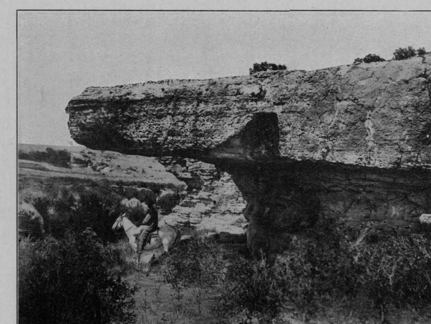


PLATE VII.—HARD AND SOFT SANDSTONE LAYERS OF THE DAKOTA SANDSTONE HOG RANCH CANYON.

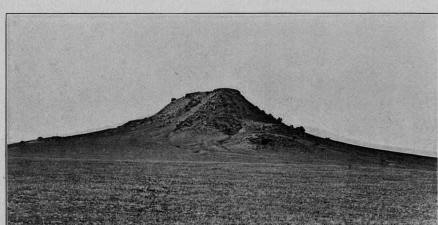


PLATE V.—RATTLESNAKE BUTTE, ONE OF THE HIGHEST POINTS IN THE QUADRANGLE, CAPPED BY FLAT-LYING TIMPAS LIMESTONE.

PLATE VIII.—APISHAPA CANYON, LOOKING NORTH TOWARD MOUTH OF JONES LAKE FORK.
Showing massive Dakota sandstone cliffs at brink of canyon and lighter-colored sandstone of Purgatoire formation on middle slopes.

PLATE IX.—UPPER BED OF DAKOTA SANDSTONE WEATHERED INTO DOMELIKE FORMS, NORTH OF JUAN BACA RANCH.

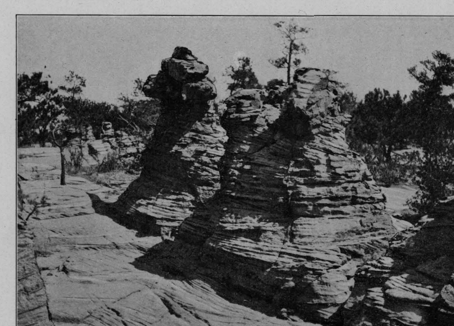


PLATE X.—UPPER CROSS-BEDDED SANDSTONE OF THE DAKOTA WEATHERED INTO TURRETED FORMS, EAST OF REYNOLDS RANCH.

PLATE XI.—OLD FIRE-CLAY WORKINGS IN DARK SHALE AT THE TOP OF THE PURGATOIRE FORMATION AND OVERLYING MASSIVE DAKOTA SANDSTONE, 2 MILES NORTHEAST OF THATCHER.

PLATE XII.—RHYTHMIC ALTERNATION OF THIN LIMESTONE AND SHALE BEDS IN GREENHORN LIMESTONE, NORTHWEST OF THATCHER.

PLATE XIII.—CLIFF OF DAKOTA SANDSTONE ON THE UPLIFTED SIDE OF THE TEJANO ARROYO FAULT LOOKING NORTHEAST.

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