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198

GEOLOGIC ATLAS

OF THE

UNITED STATES

CASTLE ROCK FOLIO

COLORADO

BY

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WASHINGTON, D. C.

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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.

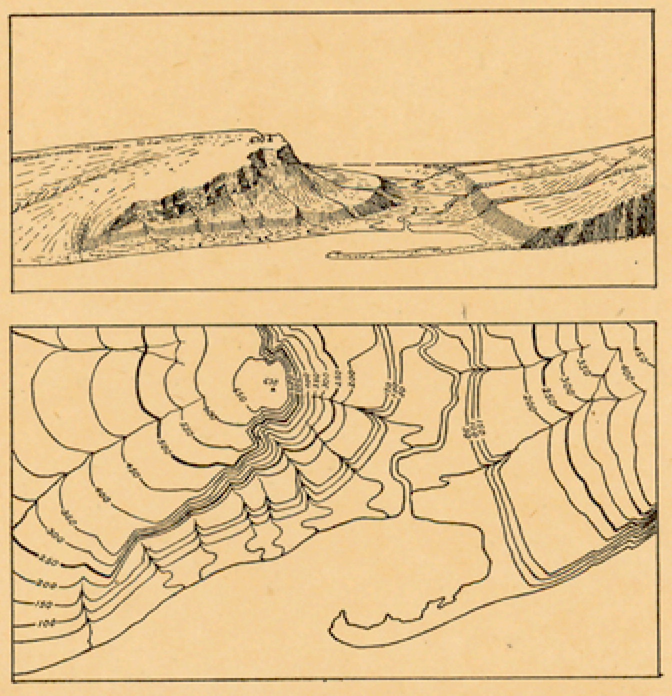

FIGURE 1.—Ideal view and corresponding contour map.

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*,

DESCRIPTION OF THE CASTLE ROCK QUADRANGLE.

By G. B. Richardson.

INTRODUCTION.

POSITION AND RELATIONS OF THE QUADRANGLE.

The Castle Rock quadrangle, which includes parts of Douglas, El Paso, and Elbert counties, Colo., is in the central part of the State, between Denver and Colorado Springs. It is bounded by meridians 104° 30′ and 105° and parallels 39°

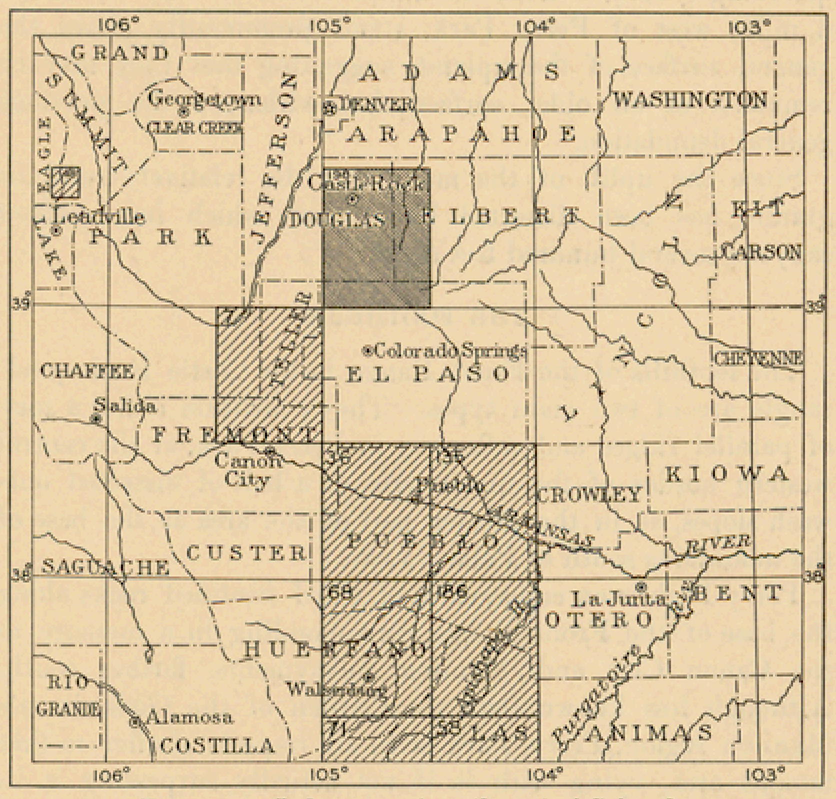

FIGURE 1.—Index map of south-central Colorado.

The location of the Castle Rock quadrangle is shown by the darker ruling (198). Published folios describing other areas, indicated by lighter ruling, are as follows: 7, Pikes Peak; 36, Pueblo; 48, Tenmile district; 58, Elmoro; 68, Walsenburg; 71, Spanish Peaks; 135, Nepesta; 186, Apishapa.

and 39° 30′, and covers 925 square miles. Most of the quadrangle lies within the Great Plains, but its southwest corner includes part of the Front Range of the Rocky Mountains. (See figs. 1 and 2.)

SETTLEMENT AND INDUSTRIES.

The lowland at the base of the Front Range is a natural route of travel and was much used by the early explorers. As the country became populated settlements grew up along this line of travel, especially in places where good supplies of water were available. Later the Denver & Rio Grande and the Atchison, Topeka & Santa Fe railroads, connecting Denver and Colorado Springs, were built along this highway in the valleys of Monument and Plum creeks. At Palmer Lake, on the divide between the Platte and Arkansas drainage, at the summit of the railroads, a summer resort has been established, and the towns of Castle Rock, Sedalia, and Monument are thriving settlements. Another railroad connecting Denver and Colorado Springs, the Colorado & Southern, has been built on the plains about 15 miles to the east, and along this line the towns of Elizabeth, Elbert, and Eastonville are situated.

The plains area was long used as a cattle range, and in the early days of settlement, because of the scarcity of water for irrigation, little attention was given to farming. In recent years, however, with the increasing popularity of dry farming, this region has been developed into a prosperous agricultural district, and dairying to supply the near-by cities of Denver and Colorado Springs is an additional source of wealth. A local industry, confined to the Castle Rock quadrangle, is the quarrying of a flow of rhyolite, which has furnished a building stone much used in near-by cities. The rugged mountains are ill adapted for settlement, and that portion of the Front Range which lies within the quadrangle is not permanently inhabited. A wagon road has been constructed across the mountains, connecting Palmer Lake with the Cripple Creek district and Trout Creek valley.

GEOGRAPHY OF THE REGION.

ROCKY MOUNTAIN PROVINCE.

The Rocky Mountain province comprises a large part of the easternmost division of the North American Cordillera. It lies between the Great Plains on the east and the Colorado Plateau, Great Basin, Columbia Plateau, and Northern Interior Plateaus on the west and contains a group of ranges that include many peaks which rise from 9,000 to more than 14,000 feet above sea level. In central Wyoming a belt of comparatively low country between the headwaters of the North Platte and Green rivers separates the Rocky Mountains into a northern division comprising the ranges in northwest Wyoming, Montana, Idaho, and Canada, and a southern division comprising the ranges of southern Wyoming, Colorado, and northern New Mexico. The southern division of the Rocky Mountains is composed of a group of ranges of general north to northwest trend, between certain of which lie wide valleys known as "parks."

In Colorado the main subdivisions of the Rocky Mountains comprise the features shown in figure 2. The Colorado or Front Range rises abruptly above the plains and extends from the northern boundary of the State to Arkansas River. South of Arkansas River the mountain front is formed by two ranges, Wet Mountain and that part of the Sangre de Cristo Range which is locally known as the Culebra Range. These three ranges are offset to the west in echelon and are separated by northwestward-trending valleys. West of the Front Range are North Park, Middle Park, and South Park, and west of Wet Mountain is Wet Valley, the southward continuation of the intermont belt of lowlands. The Park Range towers above North and Middle parks on the west, and its southward

FIGURE 2.—Relief map of central part of Colorado.

The Castle Rock quadrangle lies between Colorado Springs and Denver, covering the area shown by the darker ruling in figure 1.

Scale: 1 inch=40 miles, approximately.

continuation is divided by the headwaters ot Arkansas River west of South Park into the Sawatch Range and the Mosquito Range. The southward extension of this group is the Sangre de Cristo Range. Still farther west are San Luis Park, the mountains of the San Juan region, the Elk Mountains, and others on the western slope.

The Rocky Mountains form the Continental Divide in Colorado. Middle Park and the mountains of the western slope drain to the Pacific Ocean by the headwaters of Colorado River. The Rio Grande, flowing southward into the Gulf of Mexico, has its source in San Luis Park, and the rest of the mountains drain eastward to the Mississippi by Platte and Arkansas rivers.

The main ranges of the Rocky Mountains are composed of central cores of pre-Cambrian rocks along the flanks of which Paleozoic and Mesozoic beds crop out. Tertiary sediments overlap the older formations at many places and there are numerous occurrences of intrusive and extrusive igneous rocks. During Tertiary time, in particular, there was great igneous activity. In the Pleistocene epoch the higher peaks were centers of glaciation.

The general structure of the Rocky Mountain province is characterized by an anticlinal arrangement of the stratified rocks about the main ranges as axes, but this arrangement is modified by extensive faulting. The major system of faults is longitudinal, trending north and south, and most of the dislocations are normal.

The Colorado or Front Range, together with its northern continuation, the Laramie Mountains in Wyoming, forms the eastern Cordilleran front for about 250 miles, terminating on the south in the great mass of Pikes Peak. Viewed from the east, the Front Range presents an imposing spectacle, towering above the plains in an abrupt escarpment. (See Pl. I.) In central Colorado the base of the mountains stands about 6,000 feet above sea level, and within a few miles the range reaches altitudes of 9,000 to 14,000 feet, the culminating point being Pikes Peak, which attains an elevation of 14,109 feet. The range extends 25 to 45 miles westward and thence descends more gradually into North, Middle, and South parks. It is dissected by deep valleys which drain generally eastward to the plains or westward to the parks. South Platte River, rising in South Park, flows northeastward across the range in a canyon; North Platte River, rising in North Park, flows around the north end of the Laramie Mountains in Wyoming; and Arkansas River, rising in the Park Range and flowing between the Sawatch and Mosquito ranges, flows along the south end of the Front Range.

Viewed from elevations between 9,000 and 9,300 feet in the vicinity of the Castle Rock quadrangle, the range presents a series of flat to gently undulating areas which in imagination can be extended across intervening valleys so as to reproduce a former even surface. (See Pl. II.) These even-topped areas are interpreted as remnants of such a surface—a peneplain—above which the higher peaks now rise like monadnocks.

The greater part of the Front Range is composed of pre-Cambrian rocks consisting of an older group of dynamometamorphosed igneous and sedimentary rocks and a younger group of sediments and intrusive igneous masses which have not undergone such extensive metamorphism. In the Cripple Creek district, in the Pikes Peak quadrangle, which adjoins the Castle Rock quadrangle on the southwest, the prevailing rocks are described by Cross as granites, gneisses, and schists. Granite, which incloses blocks of Algonkian quartzite but is older than the only Cambrian sediments known in Colorado, constitutes the main mass of Pikes Peak and extends far to the north, where it forms the small portion of the Front Range included in the Castle Rock quadrangle. During Tertiary time volcanic eruptions broke through these ancient rocks at several points and piled tuffs, breccias, and lavas upon them. In Quaternary time Pikes Peak was occupied by glaciers of the alpine type. Two periods of advance of the ice have been recognized, but the glacial deposits are limited to elevations above 9,500 feet.

GREAT PLAINS PROVINCE.

Contrasted with the Rocky Mountains, the Great Plains are simple, although the study of the province has revealed many perplexing geologic problems.

The Great Plains province extends across the country in a broad north-south zone lying between the Rocky Mountains and the Prairie Plains of Mississippi Valley. (See fig. 2.) It is characterized by rolling plains, varied by buttes, tablelands bordered by escarpments, and areas of badlands. The province is drained chiefly by large rivers that flow in broad, shallow valleys, the largest of these streams rising in the Rocky Mountain region. The province as a whole slopes eastward at the rate of about 10 feet to the mile from an elevation of 6,000 feet at the base of the mountains to an elevation of 1,000 feet in the Mississippi Valley.

The surface of the Great Plains has been developed on a series of soft rocks, sands, clays, and loams, chiefly of Cenozoic age. The constituent materials of these rocks were derived mainly from the west and were deposited chiefly under continental conditions. The rocks over the larger part of the Great Plains, except in a few gentle flexures, have not been subjected to folding, but the region has been broadly uplifted and depressed a number of times.

In the foothill region, which constitutes a transition zone between the mountains and the plains, the outcropping edges of the older sedimentary beds, which are here upturned, are exposed in many places. The distribution and relations of these rocks show that the foothill zone has been subjected to great structural disturbance.

During portions of Paleozoic and Mesozoic time a part at least of the Front Range region was submerged and covered by a continuation of the strata that underlie the plains. In large measure these rocks have been removed by erosion, but remnants of Paleozoic beds in the valley of Trout Creek, a tributary of South Platte River, 5 miles west of the Castle Rock quadrangle, and of Mesozoic strata in the Breckenridge district, testify to a former greater development of these sedimentary rocks west of the plains.

By a series of uplifts that started near the beginning of the Tertiary period and continued at intervals throughout the Cenozoic era the Rocky Mountain region has been uplifted above the plains. The movement was apparently chiefly vertical but was in part lateral, and it resulted in tilting, folding, and faulting the strata in the foothill region. The largest of the folds is the syncline known as the Denver Basin, which extends from southern Wyoming to Arkansas River, a distance of more than 250 miles. South of the Denver Basin there is a group of parallel diagonal folds that produce offsets in the mountain front, the chief of which are the Canon City and Spanish Peaks synclines and intervening anticlines that strike diagonally across the trend of the mountains. Other folds which cause lesser offsets in the topography are developed northwest of Denver. Unsymmetrical synclines are defined by the steep dips of the foothills strata on their western limbs and by low westward dips on their eastern limbs.

Faults at the base of the Front Range in the vicinity of Boulder and Manitou have long been known, but not until the recent surveys has the more general presence of longitudinal dislocations been recognized.

PHYSIOGRAPHIC SUMMARY.

Davis has written the following terse outline of the physiography of this region:

> The Front Range of the Rocky Mountains in central Colorado, northwest of Denver, is a highland of disordered and generally resistant crystalline rocks, which shows signs of having been long ago worn down from its initially greater mass to a surface of faint relief, slowly depressed and more or less broadly buried under a heavy cover of sedimentary strata. Then, as the result of widespread uplift, a part of the compound mass west of a pronounced monoclinal displacement along a north-south line, came to stand above the rest, and thus the highland province of the mountains was marked off from that of the less uplifted plains on the east. The forms of the highland show that the whole region advanced far through the cycle of erosion introduced by the monoclinal uplift, so that the resistant underlying crystalline rocks of the mountain area were stripped of their cover and worn down to a gently rolling peneplain, diversified by irregularly scattered monadnocks, rising singly or in groups, with a relief of from 500 to 2,500 feet, while the valleys of the highland show that a renewed uplift gave the whole region a greater altitude than before, with a gentle up-arching along the north-south axis in the mountain area 15 or 20 miles west of the monocline, whereby the peneplain with its scattered monadnocks gained the highland altitude of the present Front Range. * * * The weaker strata of the plains are now again worn down to small relief, but the harder crystalline rocks of the mountainous highland are only submaturely dissected by normal submature or mature valleys, the higher parts of which have recently been strongly glaciated.[1]

PREVIOUS WORK.

The general geology of the Castle Rock region has long been known, but little has been written about the Castle Rock quadrangle. The Hayden Survey devoted some attention to the quadrangle, and Hayden described part of it in several papers, notably in his résumé of the geology along the eastern base of the Front Range, as did Peale also in the report of the South Park division. Parts of the quadrangle are considered in Darton's Geology and underground water resources of the Great Plains,[2] and in his Geology and underground waters of Arkansas Valley,[3] as well as in shorter papers by Cannon, Lee, and Darton.

The most comprehensive study of an adjacent area is that of Emmons, Cross, and Eldridge, published in the United States Geological Survey's monograph on the geology of the Denver Basin.[4] The Pikes Peak folio by Cross,[5] and the reports on the Cripple Creek district[6] by Lindgren and Ransome, on the Breckenridge district[7] by Ransome, and on the Georgetown district by Spurr, Garrey, and Ball,[8] throw light on the general geology of the region. The principal papers on this general region are listed below. They are arranged in order of publication.

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TOPOGRAPHY.

GENERAL FEATURES.

The greater part of the Castle Rock quadrangle lies in the Great Plains, but the southwest corner includes a small part of the Front Range, known as the Rampart Range, which rises 1,500 to 2,000 feet above its base, to an elevation of more than 9,000 feet above sea level, and is the dominant topographic feature of the area. The plains are so greatly dissected by streams that a large part of their surface is rolling upland, diversified here and there by conspicuous buttes. Along the base of the Front Range a belt of foothills forms a transition zone between the plains and the mountains. The quadrangle is thus divided into three topographic districts—the mountains, the foothills, and the plains—the main features of each district having been determined by the character and structure of the underlying rocks.

THE MOUNTAINS.

The small portion of the Front Range included in the quadrangle, only 70 square miles, is a deeply dissected mountain mass composed entirely of granite. At the eastern margin of the range the escarpment is more than 1,000 feet high, and some of the peaks rise 2,000 feet above the base of the mountains. The escarpment, continuing its trend from the Colorado Springs quadrangle, extends due north into the Castle Rock quadrangle for a distance of 13 miles; thence it turns northwestward and again northward around the Perry Park embayment. Outwash slopes composed of débris from the mountains extend along the base of the escarpment (see Pls. I and XIX), above which the range rises precipitously, the granite locally forming almost perpendicular cliffs. These are conspicuous at Mount Hermon, 2 miles south of Palmer Lake, where the escarpment is 1,400 feet high, its height increasing to 1,800 feet south of Deadmans Creek, at the southern end of the quadrangle. The summits and main divides rise to elevations between 9,000 and 9,400 feet above sea level, the highest point in the quadrangle, near its southwestern corner, having an elevation of 9,383 feet.

This upland apparently formed a rolling plain in the cycle of erosion preceding the uplift of the mountains. Stream erosion consequent to the uplift, however, has so greatly dissected the area that only the present divides testify to the former presence of the peneplain, which is strikingly apparent when viewed from the top of the mountains. (See Pl. II.) Viewed from the plains, the crest of the mountains shows an even sky line. (See Pl. I.) A few miles west of the quadrangle several isolated summits, like the Devils Head, 6 miles west of Perry Park, stand prominently above the general surface of the upland, suggesting that they may be remnants of an older surface that withstood the previous general denudation.

Since the uplift of the mountains the relatively resistant granite has been dissected by streams which have carved canyons several hundred feet deep.

THE FOOTHILLS.

The foothills of the Front Range in the Castle Rock quadrangle are of two main types. They constitute either a zone of parallel ridges and valleys as in Perry Park, at the central western border of the quadrangle, or a belt of dissected outwash slopes, as in the greater part of the area at the base of the mountains south of Palmer Lake.

Perry Park is an embayment of tilted stratified rocks along the base of the Front Range, corresponding in a measure to the Canon City and Manitou embayments, farther south. Although less known than the Garden of the Gods, in the Manitou region, Perry Park is in all respects similar to that famous area, vying with it if not actually surpassing it in natural beauty. The outcropping rocks are sandstones and shales eroded to fantastic forms marked by striking color effects. The park is composed of a group of ridges and intervening valleys which are the result of erosion acting differentially on hard and soft tilted strata. Streams from the mountains, flowing transversely across the foothills strata, have cut notches where they cross the harder beds, and tributary longitudinal streams have developed along the weaker rocks and formed the intervening valleys. The inner slopes of the ridges, toward the mountains, are relatively steep and are more or less strewn with the débris formed by the disintegration of the harder beds, and the outer, plainsward sides of the ridges are dip slopes developed on the inclined harder beds. The ridges, which vary with the thickness, hardness, and dip of the strata, are more or less conspicuous. The Dakota sandstone, here as elsewhere along the foothills of the Front Range, makes a conspicuous hogback, and other hard beds form other ridges. (See Pls. XII–XV.) A prominent ridge is formed by the Lyons sandstone which, west of Bear Creek, because of the fault that separates it from the softer Fountain formation, stands almost vertical. To the southeast, away from the influence of the uplift, the dip flattens out and the sandstone becomes less conspicuous. A striking example of the effect of stratigraphy and structure on the topography is shown at the eastern end of the park, where the hogback ridges formed by hard Cretaceous and older formations strike into the soft Pierre shale, from which they are separated by a fault. The ridges end abruptly at the fault line and give way to a lowland developed on the soft shale.

South of Perry Park hogbacks occur only occasionally, the most conspicuous being south of Deadmans Creek in sec. 8, T. 12 S., R. 67 W. In the greater part of the foothills area between Perry Park and the southern end of the quadrangle the hogback-forming strata are covered by younger rocks, which produce another type of topography. These younger rocks are outwash deposits of subaerial origin, which slope outward from the source of the material, in the mountains, toward the plains. There are two main types, one formed of the consolidated Dawson arkose and the other of unconsolidated Quaternary deposits.

The Dawson arkose along the base of the mountains south of Palmer Lake is tilted at various angles, in places as much as 90°, and forms dip slopes. Erosion has here and there caused the survival of conspicuous monument-like remnants of the arkose. One of these monuments is shown on the map just north of Deadmans Creek, on the section line between secs. 4 and 9, at an elevation of 7,200 feet. Another is 2 miles west of Monument, for which the town is named. (See Pls. VII and VIII.)

The slopes of Quaternary wash are the most striking feature of the topography at the base of the mountains in the southern part of the quadrangle, where they are finely developed south

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[1] Davis, W. M., Relation of geography to geology: Geol. Soc. America Bull., vol. 23, pp. 94-95, 1912.

[2] U. S. Geol. Survey Prof. Paper 32, 1905.

[3] U. S. Geol. Survey Prof. Paper 52, 1906.

[4] U. S. Geol. Survey Mon. 27, 1896.

[5] U. S. Geol. Survey Geol. Atlas, Pikes Peak folio (No. 7), 1894.

[6] U. S. Geol. Survey Prof. Paper 54, 1906.

[7] U. S. Geol. Survey Prof. Paper 75, 1911.

[8] U. S. Geol. Survey Prof. Paper 63, 1908.

of Beaver Creek. They include several sets of sloping terraces at different elevations and are much dissected by streams coming from the mountains, so that only at some places are remnants of the higher (older) terraces preserved, but the lower (younger) and more continuous slopes are well preserved. (See Pl. XIX.)

THE PLAINS.

The greater part of the quadrangle lies in the Great Plains province and the surface forms are sculptured in flat-lying deposits, generally the soft Dawson arkose and the more indurated Castle Rock conglomerate. Although erosion of the plains dates from the early part of the Tertiary period, the detailed sculpturing and the formation of the present features of the region was accomplished in late Tertiary and Quaternary time, in large part while the canyons were being cut in the Front Range. The vastly different results of the erosion of the mountains and the plains is due to the relative hardness of the rocks. While the steep narrrow gorges were being cut in the granite of the Front Range, widespread denudation was accomplished on the softer plains strata. An impressive idea of the amount of this erosion can be obtained by a view from some high point in the plains area, such as Dawson Butte, where the imagination can picture the immense volume of rocks which has been removed.

As a result of this erosion the present surface forms of the plains area are in adjustment to the character and structure of the rocks. The harder rocks form broad table-lands and buttes, bordered by escarpments, and the surrounding lowlands are carved in softer material. (See Pls. III, IV, and VI.) The highland belt extending from northwest to southeast across the central part of the quadrangle is upheld by the Castle Rock conglomerate, and a number of isolated hills including Dawson, Raspberry, and Larkspur buttes. Bald Mountain and other unnamed heights are capped by remnants of a flow of rhyolite occurring in the Dawson arkose.

The Plains are drained by a number of streams, some of which rise in the Front Range and others in the highland belt in the central part of the quadrangle. The principal streams are perennial, though none of them are very large, for the annual rainfall is only about 14 inches on the plains and the drainage area in the mountains is small. The short tributaries are intermittent and carry water only after storms. Most of the streams, including Plum, Cherry, Running, and Kiowa creeks, flow northward to South Platte River, though a few, the chief among which is Monument Creek, flow southward to Arkansas River. The Platte-Arkansas divide crosses the southern part of the quadrangle between Palmer Lake and Eastonville.

For the most part of their courses the streams occupy broad, open valleys carved in the soft Dawson arkose. Where they have cut through the more resistant Castle Rock conglomerate they flow in narrow valleys bordered by cliffs, as does Kiowa Creek in the vicinity of Elbert, and where they have not yet cut through the conglomerate the streams flow in small canyons, as does Cherry Creek just east of Castlewood Reservoir.

Terraces are more or less well developed along the major streams, but in places they are obscured by erosion or by later outwash deposits. The best-preserved terraces are in the valley of Plum Creek, where there are two sets 25 to 30 feet apart. These are well shown just above the town of Castle Rock. (See Pl. XX.)

GEOLOGY.

The rocks of the quadrangle are in part of igneous and in part of sedimentary origin and range in age from pre-Cambrian to Quaternary. The igneous rocks include pre-Cambrian granite and Tertiary rhyolite with which are associated beds of tuff. The sedimentary rocks, which occupy by far the greater part of the quadrangle, comprise indurated strata ranging in age from late Cambrian to Tertiary, inclusive, and unconsolidated deposits of Quaternary age. A generalized section of these rocks is shown on the columnar-section sheet. In the publications dealing with this region different names and ages have been given to some of the formations, as shown in the table on page 13.

PRE-CAMBRIAN IGNEOUS ROCKS.

PIKES PEAK GRANITE.

Definition.—That part of the Front Range which is included in the Castle Rock quadrangle consists entirely of granite, forming a part of the great batholithic mass of Pikes Peak, which was intruded into Algonkian quartzites. The Pikes Peak granite is thus defined by Cross:[1]

> The mass of Pikes Peak is principally made up of a single granite type, belonging to what is apparently one great body extending for many miles in all directions. * * * The main granite type is a very coarse grained biotite granite, or granitite, in most places of a prominent red color due to a pigment of hydrous iron oxide which conspicuously impregnates the feldspars.

[1] Cross, Whitman, U. S. Geol. Survey Geol. Atlas, Pikes Peak folio (No. 7), 1894.

Occurrence.—This granite occupies the entire mountainous southwest corner of the Castle Rock quadrangle, where it is a direct continuation of the type occurrence on Pikes Peak, 11 miles to the southwest. Prominent outcrops form steep cliffs along the eastern border of the range and are exposed in deep valleys by which it is cut. On the summit of the mountains there are good exposures of typically weathered granite.

Character.—The rock is a coarsely granular biotite granite composed dominantly of quartz and feldspar and subordinately of biotite. On the whole it is remarkably uniform but it presents local facies which differ with differences in the size and abundance of its component minerals. Thus there are coarse, medium, and fine-grained varieties with quartz, feldspar, and biotite in various sized grains and in different amounts. Feldspars are the predominant minerals and the largest crystals are about an inch long. They are commonly anhedral, though the larger ones have imperfect crystalline faces and most of them are stained reddish, giving the prevailing color to the rock. In places they are whitish. Microcline and orthoclase, which occur both individually and intergrown, are the most abundant feldspars. There are also small amounts of oligoclase and albite. The quartz is in irregular white anhedral grains. It contains fluid inclusions and some minute hairlike crystals that may be rutile. The biotite is in irregular aggregates that tend to weather out and leave the rock pitted. In some places it is absent or poorly developed; in others it occurs in conspicuous bunches and forms flakes, some as large as 4 inches long by an inch wide. The rock contains also minute amounts of apatite, zircon, and magnetite.

Joints traverse the granite in a number of directions and locally, as at Mount Hermon, are so prominently developed as to produce a gneissoid effect. On the plateau the outcrops of the granite are smooth, rounded surfaces showing pronounced spheroidal weathering. (See Pl. XVIII.) The rock disintegrates into a coarse sand, which litters the surface and at the base of the mountains forms conspicuous outwash slopes.

The granite is cut by small dikes of fine-grained biotite granite, few more than a foot thick having been seen, and also at some places by quartz veins. Fragments of a decomposed femic rock, presumably of a dike cutting the granite, were seen northwest of Palmer Lake, but the outcrop was not found.

Composition.—The chemical composition of the Pikes Peak granite is indicated by the following analyses of two samples collected about 40 miles apart, one southwest and the other northwest of the Castle Rock quadrangle.

Analyses of Pikes Peak granite.

	1	2
SiO_2	77.03	77.02
Al_2O_3	12.00	11.63
Fe_2O_3	.76	.32
FeO	.86	1.09
MgO	.04	.14
CaO	.80	1.24
Na_2O	3.21	2.85
K_2O	4.92	5.21
H_2O-	.14	------
H_2O+	.30	.35
TiO_2	.13	------
P_2O_5	Trace.	------
MnO	Trace.	------
BaO	Trace.	------
Li_2O	Trace.	------
F	.36	------
	100.55	------
Less O for F	15	------
	100.40	99.85

1. From Sentinel Point, Pikes Peak, Colo. Analysis by W. F. Hillebrand.
2. From Platte Canyon, Jefferson County, Colo. Analysis by H. N. Stokes.

These are analyses of typical granite, although the content of silica is somewhat high. The sum of the alkalies is also high, potash being notably excessive. The lime is rather low. In the quantitative classification the Pikes Peak granite belongs in the subrang alaskose (I.3.1.3).

Age.—In the Castle Rock and Colorado Springs quadrangles the Pikes Peak granite is unconformably overlain by the Sawatch sandstone, of probable Upper Cambrian age. In the Pikes Peak quadrangle it is intruded into Algonkian quartzite. Its age is presumably Algonkian.

SEDIMENTARY ROCKS.

CAMBRIAN SYSTEM.

The Cambrian system is represented in Colorado by a relatively thin deposit of sandstone or quartzite, of probable Upper Cambrian age. The Middle Cambrian is only sparingly represented and so far as known Lower Cambrian strata do not occur in the State. Apparently sands of Upper Cambrian age were deposited offshore in a sea advancing upon an old land. A number of sections of Cambrian rocks observed in widely separated areas are strikingly similar, showing at the base white quartz sandstone, in places conglomeratic, overlain by iron-stained and glauconitic sandstone. These Cambrian deposits probably underlie a considerable area east of the mountains, and their upturned edges outcrop at several localities along the Front Range, as in the Manitou embayment, west of Colorado Springs, and in the Castle Rock quadrangle.

SAWATCH SANDSTONE.

Name and definition.—In central Colorado, in the Crested Butte, Tenmile, Aspen, and other districts, the Upper Cambrian rocks are known as the Sawatch quartzite. The name was introduced by G. H. Eldridge in the Anthracite-Crested Butte folio in 1894, from the persistent occurrence of the formation on the flanks of the Sawatch Range. In the Crested Butte quadrangle two divisions were recognized by Eldridge. The lower division, which is from 50 to 200 feet thick, is a white quartzite with a persistent conglomerate of pure white quartz at the base. The upper division, which has a maximum thickness of 150 feet, is a red ferruginous and somewhat calcareous sandstone, consisting chiefly of quartz and feldspar but containing a small amount of mica. A green glauconitic mineral occurs in both divisions but more abundantly in the upper, which contains fossils of the Potsdam type.

Along the Front Range in Colorado the section of Cambrian rocks is similar to that in central Colorado and their probable equivalence is indicated by both lithology and stratigraphic position. Accordingly the name Sawatch sandstone is tentatively applied to the supposed Upper Cambrian rocks in the Front Range region. In central Colorado, however, the sandstones have been metamorphosed to quartzite, but in the Castle Rock quadrangle they are not much altered.

Distribution and character. — The Sawatch sandstone is exposed in three small areas along the base of the mountains in the western part of the quadrangle, in the central and southeastern parts of Perry Park, and south of Deadmans Creek. In all three areas the beds are tilted and the formation crops out in narrow bands on the inner side of hogbacks along the flanks of the mountains. (See Pls. XVI and XVII.)

Immediately south of Deadmans Creek, in the NE. ¼ sec. 8, T. 12 S., R. 67 W., and about 4 miles west of Husted, Cambrian beds occupy the saddle and inner slope of a small hogback of lower Paleozoic rocks and extend a short distance southeastward, the entire outcrop being only about one-fourth of a mile long and a little more than 100 feet wide. The dip of the beds is 35° E. at the north end of the hogback and becomes steeper farther south, being about 90° at the southern extremity of the outcrop, where they are apparently cut off by a fault. The following section was measured:

Section of Sawatch sandstone immediately south of Deadmans Gulch.

	Feet.
Manitou limestone, arenaceous, reddish gray, fossiliferous.	
Sawatch sandstone:	
Sandstone, fine grained, calcareous and glauconitic; thick and thin bedded; red to greenish	20±
Sandstone, fine grained, quartzose; calcareous near top; white to reddish	75
Sandstone, fine grained, quartzose; in places spotted with conspicuous rounded grains of quartz; brick-red	2
Sandstone, fine grained, quartzose; in places spotted with rounded grains of quartz, the largest one-eighth inch in diameter; white	15
Concealed	3
Pikes Peak granite.	
	115±

The relations of the sandstone and the granite are concealed by wash in the Deadmans Creek area, but at the west end of the exposure the sandstone appears to lie unconformably on the granite and at the south end the contact is probably faulted. The precise upper limit of the formation is also concealed, although it is marked by a change from sandstone to the overlying Manitou limestone that forms the crest and eastern slope of the hogback.

At the extreme southeast end of Perry Park, 12 miles north of the Deadmans Creek outcrop, there is another exposure of sandstone which on lithologic and stratigraphic grounds is tentatively regarded as Sawatch. This sandstone strikes northwestward and dips northeastward at angles ranging from 15° to 90°. It outcrops in secs. 1 and 2, T. 10 S., R. 68 W., and in sec. 35, T. 9 S., R. 68 W., occupying a narrow strip about 2 miles long between the granite at the base of the mountains and a hogback of Millsap limestone. The outcrop is cut off at its northwest and southeast ends by two great northward-trending faults.

The following section was measured in the SW. ¼ sec. 35, T. 9 S., R. 68 W., at the northwest end of this exposure:

Section of Sawatch sandstone in SW. ¼ sec. 35, T. 9 S., R. 68 W.

	Feet.
Limestone (Millsap)	60±
Concealed	5
Sawatch sandstone:	
Sandstone, fine grained calcareous, glauconitic, red and greenish	5
Shale, drab and purplish	12
Sandstone, fine grained, mottled red and white	30
Sandstone, massive saccharoidal, white	15±
Concealed.	
Pikes Peak granite.	

Just west of the mouth of Gove Canyon, in the NE. ¼ sec. 2, T. 10 S., R. 68 W., about 100 feet of fine-grained laminated sandstone is exposed. The lower part is a pure quartzose white sandstone with a few rounded pebbles of quartz, the largest, which are at the base, half an inch in diameter, the sandstone lying on a smooth, even surface of granite. (See Pl. XVII.) Higher up in the section the sandstone is mottled brown and white and in places stained red. The upper 10 to 25 feet consists chiefly of thin-bedded reddish calcareous sandstone containing a 4-foot bed of glauconitic sandstone, which lies 5 feet below a thin white limestone. Whether there is any Cambrian or Ordovician limestone in this section was not determined, but Mississippian fossils were found in cherty layers in the upper part of the limestone, which here is about 60 feet thick.

The remaining outcrop of sandstone, tentatively referred to the Cambrian, is 2 miles northwest of the locality just described, immediately southwest of the old hotel in sec. 22, T. 9 S., R. 68 W. This sandstone, which is 90 feet thick, lies on coarse red granite and is overlain by Mississippian limestone. (See Pl. XVI.) The outcrop occupies a narrow zone that is only a little more than a mile in length. At the base of the section is a little coarse arkose consisting of rounded pebbles of quartz, the largest a quarter of an inch in diameter, and grains of reddish feldspar, overlain by fine-grained saccharoidal quartzose sandstone, prevailingly white but in places stained red, which makes up nearly the whole section. No glauconitic sandstone was seen here.

The sections are very similar and present a striking resemblance to the Cambrian sections of central Colorado. In both regions the lower part of the section is composed of quartzose white sandstone, which in central Colorado is metamorphosed to quartzite, succeeded above by less pure calcareous and glauconitic sandstone.

Fossils. — Some fossils obtained from reddish calcareous sandstone about 60 feet above the base of the Sawatch sandstone, on the hogback south of Deadmans Creek, were identified by E. O. Ulrich as Obolus sp.? and Lingulella cf. *L. desiderata*.

ORDOVICIAN SYSTEM.

MANITOU LIMESTONE.

Distribution and character. — The Ordovician system is represented in several areas in Colorado by a magnesian limestone of Lower Ordovician age, called by Cross[1] the Manitou limestone, from its development near Manitou Springs and in Manitou Park. This limestone is not well exposed in the Castle Rock quadrangle, but sections in Williams Canyon near Colorado Springs show excellent exposures of the Sawatch sandstone and of the overlying Manitou limestone. In the Canon City embayment there are two younger Ordovician formations, the Harding sandstone and the Fremont limestone, but these formations are not known in the Castle Rock quadrangle.

The Manitou is a thin-bedded gray or reddish limestone, which is known to outcrop at only one place in the Castle Rock quadrangle—on the crest and eastern slope of the small hogback just south of Deadmans Creek, in the NE. ¼ sec. 8, T. 12 S., R. 67 W., where it dips about 30° E. The upper part of the section consists of thin-bedded gray magnesian limestone, which is underlain by about 25 feet of reddish and gray arenaceous limestone, beneath which lies the Sawatch sandstone. The formation is not exposed in its full thickness, for it is covered by wash and cut off on the east by a fault. It is barely possible that a few feet of Manitou limestone lies between the Sawatch sandstone and the Millsap limestone in the two areas in Perry Park where those formations are exposed, but no evidence of the presence of Ordovician strata in those areas was obtained.

Age and correlation.—The fossils listed below, collected at two horizons in the Manitou limestone on the hogback south of Deadmans Creek, have been identified by E. O. Ulrich:

Fossils from the basal red arenaceous limestone.

Billingsella plicatella.	Eccyliomphalus sp.
Eoorthis desmopleura.	Holopea or Hormotoma.
Owenella n. sp.	Fragments of trilobites.
Cameroceras sp.	

Fossils from the overlying thin-bedded gray magnesian limestone.

Hormotoma sp. cf. H. gracilis.	Ophileta n. sp.
Lophospira cf. gregaria (Billings).	Acrotreta sp.

Mr. Ulrich reports that the fossils from the gray magnesian limestone "seem to be Beekmantown, without doubt," and after comparing the collection from the red arenaceous limestone with a larger collection obtained by L. D. Burling from a lithologically similar limestone at apparently the same horizon near Manitou, Colo., he reports that they too should be classed with the Manitou limestone rather than with the underlying Sawatch sandstone.

Its fossils, together with its lithologic character and stratigraphic position, establish the equivalence of this isolated outcrop of limestone with part of the Manitou limestone at the type locality, 12 miles south. The Manitou limestone may be correlated in part with other formations in the Cordilleran region that contain a Beekmantown fauna, such as the Garden City limestone of northern Utah, the Longfellow limestone of central Arizona, and the El Paso limestone of west Texas.

[1] Cross, Whitman, U. S. Geol. Survey Geol. Atlas, Pikes Peak folio (No. 7), 1894.

CARBONIFEROUS SYSTEM.

Middle and Upper Ordovician, Silurian, and probably Devonian time is not represented by sediments in the Front Range region where, however, all three series of the Carboniferous system are believed to be developed. The Mississippian is represented by the Millsap limestone, the Pennsylvanian by the Fountain formation and Lyons sandstone, and the Permian probably by the Lykins formation. Other names have been used from time to time for these formations, as shown in the table on page 13, but those adopted here represent current usage.

MISSISSIPPIAN SERIES.

MILLSAP LIMESTONE.

Name.—The Millsap limestone was named by Cross in the Pikes Peak folio. In that quadrangle the formation is represented by about 30 feet of thin-bedded, variegated dolomitic limestone containing a few thin layers of sandstone. Chert nodules in the upper part of the limestone carry casts of characteristic Mississippian fossils.

Distribution and character.—In the Castle Rock quadrangle the Millsap limestone outcrops at the base of the mountains at two localities in Perry Park, one at the southeastern extremity of the park and the other west of Bear Creek. These areas, which are about 2 miles apart, are separated by a fault.

At the southeast end of Perry Park, in secs. 1 and 2, T. 10 S., R. 68 W., and in the SW. ¼ sec. 35, T. 9 S., R. 68 W., the Millsap limestone forms the crest and outer slope of a line of hogbacks at the base of the mountains.

The formation is less than 100 feet thick and the outcrop forms a narrow band extending northwestward about 2 miles. For a considerable part of its extent the limestone is covered by vegetation and talus, but fairly good exposures are made by a few creeks which cross the formation. West of the mouth of Gove Canyon, in the NE. ¼ sec. 2, T. 10 S., R. 68 W., the following section was measured:

Section of Millsap limestone at mouth of Gove Canyon.

	Feet.
Fountain formation:	
Arkose.	
Millsap formation:	
Shale, sandy, and clay, red	25±
Limestone, thin bedded; gray to purplish chert nodules in upper part containing Mississippian fossils	60
Sawatch sandstone.	

West of Bear Creek the formation occupies an area less than half of a square mile in extent at the western margin of the quadrangle. The following measurement was made in the SW. ¼ sec. 22, T. 9 S., R. 68 W.:

Section of Millsap limestone west of Bear Creek.

	Feet.
Fountain formation:	
Arkose.	
Millsap limestone:	
Shale, sandy, and clay, red	25±
Limestone, purplish to gray, fossiliferous chert nodules in upper part	40
Sandstone, fine grained, quartzose, reddish	½–1½
Sawatch sandstone.	

Plate XVI shows the general relations of the Millsap to adjacent formations at this place. A thin bed of indurated reddish sandstone rests on an uneven surface of white sandstone, which is tentatively referred to the Sawatch. At the top of the section the relations of the red shale to the overlying coarse white arkose of the Fountain formation are obscure. As no fossils have been found in the red shale its stratigraphic place is in doubt, but it is tentatively referred to the Millsap.

Age and correlation.—The fossils listed below, found in chert nodules in the upper part of the limestone below the red shale, were determined by G. H. Girty:

Fossils from the Millsap limestone in SW. ¼ sec. 22, T. 9 S., R. 68 W.

Fistulipora? sp.	Composita subquadrata?
Fenestella sp.	Myalina arkansana?
Lioclema? sp.	Conocardium sp.
Schuchertella sp.	Streblopteria media.
Cranaena subelliptica var. hardingensis.	Small gastropods.
Spirifer centronatus.	Beyrichia sp.
Spiriferina solidirostris.	Paraparchites sp.

Fossils from SW. ¼ sec. 35, T. 9 S., R. 68 W., west of Gove Creek.

Cranaena subelliptica var. hardingensis.	Conocardium sp.
Spirifer? sp.	Orthoceras sp.
Composita subquadrata?	Paraparchites? sp.

Fossils from NE. ¼ sec. 2, T. 10 S., R. 68 W., west of mouth of Gove Canyon.

Stenopora? sp.	Myalina arkansana?
Cranaena subelliptica var. hardingensis.	Conocardium sp.
Spirifer centronatus.	Paraparchites sp.
Spirifer sp.	Primitia sp.
Eumetria marcyi.	Beyrichia sp.

Mr. Girty states that this is the well-known fauna of the Millsap limestone, which is of Mississippian age. All the fossils came from the upper part of the limestone, so that the lower part may possibly be Devonian. This possibility must be borne in mind, because in southwest Colorado the Ouray limestone, which contains a Mississippian fauna in its upper part, contains in its lower part a Devonian fauna. But Devonian fossils have not been found in any of the Front Range sections of Paleozoic rocks, and in the absence of evidence to the contrary it may be assumed that the strata between the Pennsylvanian and Cambrian rocks, in Perry Park, comprising less than 100 feet, are Mississippian.

Marine waters were apparently widespread in the Cordilleran region during Mississippian time, and it seems probable that the Millsap is equivalent to the upper parts of the Leadville limestone of central Colorado, the Ouray limestone of southwest Colorado, and the Madison limestone of Montana, Wyoming, and Utah; also to the Escabrosa limestone and the lower part of the Redwall limestone of Arizona.

PENNSYLVANIAN SERIES.

FOUNTAIN FORMATION.

Name.—The name Fountain formation was given by Cross in the Pikes Peak folio to a series of red sandstones, grits, and conglomerates, a part of the so-called "Red Beds," found in typical development on Fountain Creek below Manitou Springs. In the Castle Rock quadrangle the Fountain formation is about 2,000 feet thick and is of the same general character as at the type locality, which is only 10 miles to the south.

Distribution.—In the Castle Rock quadrangle the Fountain formation occupies an area of about 5 square miles in Perry Park. On the east it is brought into contact with the Pierre shale by a great fault and on the west it is divided into two parts by another fault that almost completely separates the area of outcrop of the formation into two parts, which are joined by a strip only a quarter of a mile wide in the SE. ¼ sec. 22, T. 9 S., R. 68 W. The southeastern area is the larger of the two and is characterized by low strike ridges and intervening valleys formed by relatively hard and soft beds. The strata strike almost east-west and dip from 12° to 15° northward, except at the south end of the outcrop, where the dip steepens to 45°. Only a small part of the northwestern area of the Fountain formation lies in the quadrangle. In this area the beds outcrop in irregularly dissected masses, which dip northeastward at an angle of about 15°. Against the granite, however, at the base of the mountains the dip increases to 75° and 80°.

In the southern part of the quadrangle, in the foothills, a few small areas of steeply eastward-dipping beds of the Fountain formation have been exposed by erosion of the cover of outwash deposits.

Character.—The Fountain formation is a complex mass of arkosic sandstone and conglomerate and subordinate shale, and is of various color, composition, and texture. In the Castle Rock quadrangle the bulk of the formation consists of medium to coarse grained sandstone. Beds of conglomerate are not common and where pebbles are present they are generally interspersed in the sandstone in irregular layers. Interbedded with the prevailing coarse sandstone are thinner bedded fine-grained sandstones and a few thin beds of shale. The rocks weather into irregular forms, as shown in Plates X and XI.

Red in various shades is the predominating color of the formation, dark brick-red being the most common tint, but in places the lower 200 to 300 feet of the formation is light colored or even white. The prevailing red color is due to ferric oxide that occurs in two forms—as an inclusion in the feldspars and as an interstitial filmlike coating on the minerals composing the rock.

The dominant mineral constituents are quartz and feldspar of various degrees of coarseness, embedded in a matrix of finer grains of the same minerals. Mica is very subordinate, but muscovite, presumably in large part a decomposition product of orthoclase, is rather common in the finer grained sandstone. The conglomeratic layers are composed of subangular and rounded pebbles, the largest 3 inches in diameter, chiefly of quartz but also of granite, red sandstone, chert, and limestone, probably chiefly Millsap limestone, though no fossiliferous pebbles were found. Cross-bedding is common throughout the formation.

Relations.—In the Castle Rock quadrangle the Fountain formation lies unconformably on the Millsap limestone and is overlain in apparent conformity by the Lyons sandstone. In parts of the foothills it overlaps older rocks or occupies faulted relations with several formations.

Age and correlation.—In the absence of fossils the Fountain formation was formerly assigned to the "Jura-Trias" system by some geologists and to the Carboniferous by others, but fossils collected in it at different localities in recent years show that it is of Pennsylvanian age. Along the foothills in the northern part of the State and elsewhere thin beds of limestone in the formation have yielded species of undoubted Pennsylvanian fossils. Neither limestone nor fossil shells have been found in the formation in the Castle Rock quadrangle, but a lycopodiaceous root was discovered in white arkose above the Millsap limestone in the SW. ¼ sec. 22, T. 9 S., R. 68 W. This root is identified as *Stigmaria verrucosa* (Martin) S. A. Miller by David White, who states that "this type of root, familiarly known as *Stigmaria ficoides*, probably belonged to several sigillarioid or lepidodendroid species, the differentiation being too little for corresponding specific correlation. The *verrucosa* type is essentially characteristic of the Pennsylvanian." No other fossils were found in the formation in the quadrangle, but inasmuch as the lower part of the overlying Lyons sandstone has yielded a Pennsylvanian fauna in northern Colorado the Fountain may be considered to be entirely of Pennsylvanian age.

The formation has been traced, except in areas occupied by younger overlapping deposits, from northern Colorado to the vicinity of Pueblo, and throughout that distance it is appropriate to designate it by one name. The Fountain is equivalent to the lower part of the "Lower Wyoming" of the Denver region, and probably also should be correlated with the Maroon conglomerate of the Anthracite-Crested Butte region and with the Hermosa formation of the San Juan region.

LYONS SANDSTONE.

Name.—In the Front Range foothill region at several localities between the Colorado–Wyoming boundary and Arkansas River the coarse-textured arkosic sandstones of the Fountain formation are succeeded by several hundred feet of fine-grained red and white quartzose sandstone, which has been recognized as a distinct formation and named by Fenneman the Lyons sandstone, from the town of Lyons, in Boulder County. Eldridge[1] included these beds in the upper part of the "Lower Wyoming."

The formation can not be traced from its type locality to the Castle Rock quadrangle because of the cover of Quaternary deposits in intervening areas, and in the absence of direct tracing or of distinctive fossils the absolute equivalence of these beds to the Lyons formation can not be established, but it seems appropriate to apply the name Lyons to the beds in the Castle Rock quadrangle because of their similarity in general lithologic character and in stratigraphic position to the Lyons formation farther north. In the area under consideration the sandstone is less indurated, is not so flaggy, and is not notably cross-bedded, as in the type locality. It is about 600 feet thick.

Distribution and character.—Nearly everywhere throughout its extent the Lyons sandstone forms prominent topographic features. In Perry Park it crops out in a narrow curved ridge conforming to the general structural trend. At the southeast end of the park, in secs. 36 and 25, T. 9 S., R. 68 W., it occupies a narrow zone between the Fountain formation and the Pierre shale. In secs. 25 and 26 it occupies a broader belt, a little more than a mile in length, northwest of which the outcrop is again narrow. Northwest of the lake in Perry Park the sandstone forms a striking feature of the topography, standing out in a narrow dissected ridge of brick-red sandstone 200 or 300 feet high, rivaling in effect some of the celebrated scenery of the Garden of the Gods. (See Pls. XII–XV.)

The Lyons sandstone lies in apparent conformity between the Fountain and Lykins formations. Just east of the road in sec. 25, T. 9 S., R. 68 W., fine-grained quartzose red sandstone lies directly on a coarse-grained arkosic reddish sandstone. The surface of separation is somewhat uneven and a few pebbles of quartz, one-eighth to one-fourth inch in diameter, occur at the base of the generally fine-grained sandstone. A mile southeast of the lake in Perry Park there is an apparent transition from the Fountain to the Lyons, marked by lenses of fine-grained red sandstone at the top of the arkose and by streaks of coarse arkose at the base of the Lyons.

The formation is an evenly fine grained sandstone composed of rounded grains of quartz. Local variations are caused by irregular streaks of coarse sandstone, composed in some places of larger grains of quartz and in others of quartz and feldspar. Small bits of feldspar and mica are distributed in minor quantity through the sandstone. A notable feature of the sandstone in Perry Park is that the lower part is generally pinkish red (a color due to the coating of the quartz grains by a thin film of iron oxide) and the upper part of the formation is generally white. A mile southeast of the lake in Perry Park, in sec. 23, T. 9 S., R. 68 W., the twofold color is well shown, but from that place westward to the lake the upper part of the sandstone is varicolored. This is well shown in the bluff immediately southeast of the lake, where the colors are buff, gray, and various shades of red, all merging one into the other. West of the lake the sandstone is practically all red. The white sandstone is in places seamed with minute veinlike streaks of silica, which, being harder than the surrounding material, stands out conspicuously on weathered surfaces. A conglomeratic phase of the sandstone, which occurs in the Colorado Springs quadrangle, was not found in the Castle Rock area.

Age and correlation.—Fossils have not been found in the Lyons sandstone in central Colorado, but at Owl Canyon, 16 miles south of the Wyoming boundary, Henderson, of the Colorado Geological Survey, reports the presence of Pennsylvanian shells in a limestone at or near the base of the Lyons sandstone. Six miles farther south the limestone is reported practically to disappear and to pass into the Lyons. The Lyons is therefore, at least in part, of Pennsylvanian age. The overlying Lykins formation is tentatively referred to the Permian by Girty, but where to draw the line between the Pennsylvanian and Permian here as in other regions is not yet known. In the absence of evidence to the contrary the whole formation is here tentatively referred to the Pennsylvanian.

The Lyons formation is probably in part represented in the Denver region by the "Creamy sandstone" of Eldridge, which Darton has shown is probably equivalent to the Pennsylvanian Tensleep sandstone of Wyoming.

[1] U. S. Geol. Survey Mon. 27, p. 19, 1896.

PERMIAN (?) SERIES.

LYKINS FORMATION.

Name.—The Lykins formation is the name given by Fenneman to a group of strata comprising several hundred feet of soft red sandstone, and sandy shale, including some limestone and beds of gypsum in its upper part. In the Castle Rock quadrangle it is about 225 feet thick. The name is taken from Lykins Gulch, north of Boulder, Colo. The Lykins formation outcrops in detached areas in the foothill region between the Colorado–Wyoming boundary and Arkansas River, where it is easily recognized by its characteristic lithology and its stratigraphic position between the Lyons sandstone and the Morrison formation. Eldridge[1] named the same beds "Upper Wyoming."

Distribution and character.—In the Castle Rock quadrangle the Lykins formation outcrops in a narrow, curved belt about 4 miles long, varying in width from less than 100 feet to about 600 feet, and extending northwest and southeast of the lake in Perry Park. Near the boundary between T. 9 S., R. 68 W., and T. 9 S., R. 67 W., the formation strikes into the Pierre shale, from which it is separated by a great fault, and it extends westward beyond the limits of the quadrangle.

As it is composed in general of soft, easily eroded beds the formation occupies a valley between the more resistant Lyons sandstone and a less conspicuous ridge of limestone near the base of the overlying Morrison formation. (See Pls. XII–XIV.)

In sec. 23, T. 9 S., R. 68 W., the lower part of the formation is made prominent by two small hogbacks formed by thin beds of limestone, but such a development is uncommon. The full section of the formation is nowhere exposed in the quadrangle because the soft rocks are generally covered by débris.

The formation is composed chiefly of sandy and clay shale, brilliantly colored in various shades of red, with thin beds of gray sandy limestone, a bed of crinkly laminated white sandstone in the lower part, and considerable gypsum at the top. The most complete section was measured about a quarter of a mile northwest of Bear Creek as follows:

Partial section of Lykins formation in sec. 15, T. 9 S., R. 68 W.

	Feet.
Morrison formation.	
Lykins formation:	
Gypsum, white	50±
Concealed; probably sandy and clay shale and thin sandstones, red	100±
Sandstone, quartzose, thin bedded, brown	3
Sandstone, quartzose, white	1
Shale, red	7
Sandstone, calcareous, quartzose, thin bedded and massive; brecciated	4
Sandstone, quartzose, thin bedded, reddish and white	4
Shale, sandy, red	9
Sandstone, quartzose, crinkly, white	3
Shale, sandy, and clay, red (partly covered)	30
Limestone, sandy, brecciated, pitted	4
Shale, red.	
	215±

Two thin beds of limestone, ranging in thickness from a few inches to 4 feet, are well exposed in places in the quadrangle and in sec. 23, a mile southeast of the lake, they form two low ridges. There the gypsum at the top of the Lykins is the most conspicuous member of the formation. It is about 40 feet thick and is well exposed in a line of low hills. (See Pl. XIV.) The following section of gypsum was measured in the face of the hill just west of the road in sec. 24:

Gypsum at top of Lykins formation in sec. 24, T. 9 S., R. 68 W.

	Feet.
Morrison formation.	
Lykins formation:	
Gypsum, massive and thin bedded; banded with thin streaks of gray shale and sandstone	35
Gypsum, massive, white and pinkish	10
Concealed	35
Shales, red.	

The gypsum is a massive-bedded granular variety of various degrees of purity, the variation being due to admixture of sand and clay. Bands of satin spar 3 to 4 inches thick with striæ perpendicular to the bedding occur in some places.

[1] U. S. Geol. Survey Mon. 27, p. 20, 1896.

Age and correlation.—The fossils listed below, identified by G. H. Girty, were found by the writer in 1911 in a thin bed of white limestone a few feet above the base of the Lykins formation three-fourths of a mile southeast of the lake in Perry Park.

Fossils from Lykins formation in NW. ¼ sec. 23, T. 9 S., R. 68 W.

Allerisma sp.	Aviculipecten sp.
Edmondia sp.	Alula squamulifera.
Myalina perattenuata?	Loxonema sp.

Mr. Girty tentatively regards these fossils as Permian and is inclined to correlate the Lykins with the Rico formation of the San Juan district. On stratigraphic evidence Darton[1] has correlated the Lykins with the Chugwater formation. It is possible that the upper part of the Lykins is of Triassic age, but of this there is no evidence.

JURASSIC OR CRETACEOUS SYSTEM.

MORRISON FORMATION.

In this region the absence of rocks belonging to the Triassic system and to part, at least, of the Jurassic indicates a considerable hiatus after the deposition of the Lykins formation, for the Morrison formation, which directly overlies the Lykins, is of doubtful Upper Jurassic or Lower Cretaceous age.

Name.—The Morrison formation, named by Eldridge[2] from its development near the town of Morrison, in Jefferson County, Colo., consists at the type locality of about 200 feet of varicolored shale, a few bands of sandstone and fresh-water limestone, and a conspicuous bed of sandstone 60 feet below the top. The clays of the lower part of the formation have been called the "Atlantosaurus beds," from the predominant form of a remarkable series of reptilian remains which have been found in them.

Distribution and character.—The formation outcrops in Perry Park in a narrow curved zone extending about 4 miles in a general northwest-southeast direction and lying between the Dakota hogback and the low gypsum ridge that marks the top of the Lykins formation in T. 9 S., R. 68 W. Like the underlying Lykins the Morrison formation is composed of soft, easily eroded strata, and the two together occupy a strike valley between ridges formed of more resistant rocks. (See Pls. XII and XIII.) This valley is longitudinally bisected by the low ridge formed by the limestone near the base of the Morrison. The greater part of the Morrison occupies the inner slopes of the Dakota hogback. (See Pl. XIV.)

The soft rocks of which the formation is composed are rarely exposed in the quadrangle, as they occupy either a grass-covered lowland or a slope littered with talus of the overlying beds. Their estimated thickness is 200 feet. The best exposure of the formation was found in sec. 15, T. 9 S., R. 68 W., where the following partial section was measured:

Partial section of Morrison formation in sec. 15, T. 9 S., R. 68 W.

	Feet.
Sandstone of Purgatoire formation.	
Morrison formation:	
Interval, in part red shale	150
Sandstone, quartzose, white	3
Interval	10
Limestone, fine grained, gray	2±
Interval, in part drab clay shale	35
Lykins formation; gypsum.	
	200±

In the SW. ¼ sec. 24 the following section of the lower part of the formation is exposed:

Section of lower part of Morrison formation in sec. 24, T. 9 S., R. 68 W.

	Feet.
Limestone, fine grained, gray; showing on weathered surface cross sections of fresh-water gastropods	2
Shale, drab to green	15
Sandstone, quartzose, fine grained, gray	5
Shale, drab, green, and red	15
Gypsum; top of Lykins formation.	

Along the western border of the lake in Perry Park small patches of fine-grained quartz sandstone, thin gray limestone, and gray and reddish shale of the Morrison formation are exposed, but in general the Morrison outcrop is covered by débris which conceals the character of the formation.

On account of the poor exposures the character of the upper and lower contacts of the Morrison formation in the Castle Rock region is not evident, but in other places the formation lies unconformably on the underlying rocks. In the Pikes Peak quadrangle it directly overlies the Fountain formation.

Age and correlation. — These rocks are assigned to the Morrison formation because of their lithologic character and stratigraphic position. Their occurrence in Perry Park is only 25 miles south of the type locality at Morrison, and although the formation can not be traced continuously between the localities on account of overlap by younger deposits, there can be no doubt of their equivalence.

The only fossils obtained by the writer from these rocks in the Castle Rock quadrangle are remains of fresh-water gastropods, cross sections of which were found on weathered surfaces

[1] Darton, N. H., U. S. Geol. Survey Prof. Paper 32, pp. 83-88, 1905; Geol. Soc. America Bull., vol. 15, pp. 421-423, 1904.
[2] U. S. Geol. Survey Mon. 27, p. 60, 1896.

of a bed of limestone near the base of the formation. An unidentified dinosaur bone, preserved in the collection of the East Denver High School, is reported also to have been obtained from these beds in Perry Park.

At several localities in the foothills of the Front Range, notably at Morrison and at Garden Park, near Canon City, a variety of well-preserved vertebrate remains, including dinosaurs, crocodiles, and turtles, have been found in the Morrison formation. Notwithstanding these collections, the age of the Morrison is in doubt. At first it was considered Jurassic, but during recent years the drift of opinion seems to be toward assigning the formation to the Lower Cretaceous.

CRETACEOUS SYSTEM.

LOWER CRETACEOUS SERIES.

Though this region was a land area in the early part of the Mesozoic era it was submerged during Lower Cretaceous time, when the marine Purgatoire formation was deposited. Until recently this formation was thought to be part of the Dakota sandstone, but the discovery in it of Comanche fossils proves that the early Cretaceous sea invaded this area, although the deposits are very thin compared with those of the Comanche in Texas.

PURGATOIRE FORMATION.

Distribution and character.—The Purgatoire formation, a name given by Stose in the Apishapa folio to the Lower Cretaceous strata of part of southeastern Colorado and derived from the name of Purgatoire River, comprises about 200 feet of sandstone and shale. Although a thin formation, the Purgatoire has been recognized in a number of areas east of the Front Range. In the Colorado Springs quadrangle Finlay has divided the Purgatoire into two parts, an upper shale member and a lower sandstone member, to which he gives the name Glencairn shale member and Lytle sandstone member, respectively. Characteristic Lower Cretaceous fossils have not been found in the Castle Rock quadrangle, but shale and sandstone that occupy the stratigraphic position and possess the lithologic character of the Purgatoire are present and are tentatively correlated with that formation. The exposures are so poor, however, that the two thin members are not separately mapped.

The strata assigned to the Purgatoire formation outcrop in Perry Park on the inner flanks of the Dakota hogback, a prominent strike ridge that curves northwestward across the central part of T. 9 S., R. 68 W. (See Pls. XII, XIII, and XIV.) The beds dip northeastward at angles ranging from 20° to 80°. The formation is cut off on the southeast by a fault and on the northwest is exposed for only a few miles beyond the quadrangle and is again cut off by a fault. In general the beds are concealed, the belt of outcrop being littered with débris of the Dakota sandstone. The lower sandstone member of the Purgatoire formation, however, is well exposed at some places, as immediately west of Bear Creek. (See Pls. XII and XIII.) In sec. 15, T. 9 S., R. 68 W., the strata are almost vertical, and in places the weathering of the upper shale member of the Purgatoire causes a narrow depression just below the crest of the hogback.

The formation is composed of a lower sandstone member, about 80 feet thick, and an upper shale member, about 160 feet thick, corresponding respectively to the Lytle sandstone member and the Glencairn shale member of the Purgatoire formation as mapped by Finlay.[1] The sandstone member is best exposed at the north end of the lake in Perry Park, in the SE. ¼ sec. 15, T. 9 S., R. 68 W., where 80 feet was measured above the covered base. The sandstone is fine grained and is composed chiefly of quartz, but it is also locally feldspathic, especially in its lower part, which contains grains of kaolinized feldspar. It includes also conglomeratic lenses consisting of rounded pebbles of chert and quartz, the largest a quarter of an inch in diameter, as well as iron-stained concretions. The upper beds of sandstone are ripple marked. Although the upper part of this formation is not well exposed, the outcrops in places show beds of drab and carbonaceous clay shale.

Age and correlation.—The only fossils obtained from these beds were found near the base of the shale immediately above the lower sandstones in the SE. ¼ sec. 15, T. 9 S., R. 68 W. These were identified by Stanton as Lingula sp. and worm burrows. He reports that though it is probable that this collection is from beds referred to the Lower Cretaceous series near Canon City, the specimens of Lingula do not in themselves furnish sufficient evidence to demonstrate that fact. There are species of Lingula in the Upper Cretaceous as well as in the Comanche, and they do not show enough differences to make them safe stratigraphic guides.

The sandstone and shale of the Purgatoire formation, by their lithology and stratigraphic position, suggest comparison with the Lakota sandstone and Fuson shale of the Black Hills region, but the Purgatoire is marine, whereas those formations are presumably fresh-water deposits.

[1] Finlay, G. I., U. S. Geol. Survey Geol. Atlas, Colorado Springs folio (in preparation).

UPPER CRETACEOUS SERIES.

Upper Cretaceous time in this region was characterized by continued subsidence and by the presence during most of that epoch of a great interior sea in which many thousand feet of strata were deposited. These strata are subdivided into the Dakota sandstone, the Colorado and Montana groups, and the Laramie formation.

DAKOTA SANDSTONE.

The Dakota sandstone, the oldest of the Upper Cretaceous deposits, is exposed only in Perry Park, where it forms the crest and dip slope of the ridge, which here, as elsewhere in the foothill region, is the most conspicuous of the Cretaceous hogbacks. The Dakota hogback curves from northwest to southeast across the central part of T. 9 S., R. 68 W. (See Pls. XII and XIII.) The sandstone caps the ridge and forms the dip slope, as shown in Plates XIV and XV. Good exposures of the sandstone are shown where West Plum and Bear creeks have cut across the ridge.

The Dakota is a fine-grained white to gray quartzose sandstone indurated by siliceous cement. About 60 feet of it is exposed at localities favorable for measurement, but the contacts with the underlying and overlying shales are concealed by débris.

Fossil leaves, identified by F. H. Knowlton as *Salix protecæfolia* Lesquereux and *Sapindus morrisoni* Lesquereux, were collected from the Dakota sandstone in the SE. ¼ sec. 15, T. 9 S., R. 68 W., a quarter of a mile northwest of Bear Creek. Mr. Knowlton reports that these are both well-known Dakota species, found in the beds of that age at Morrison, Colo.

COLORADO GROUP.

BENTON AND NIOBRARA FORMATIONS.

The Colorado group, which overlies the Dakota sandstone, is ordinarily divided into the Benton shale and the Niobrara limestone, but in the Castle Rock quadrangle the rocks are so covered by Quaternary deposits that it is not practicable to divide the group.

Character and distribution.—The Benton consists of about 600 feet of dark shale with interbedded fossiliferous gray limestone and in places a sandstone, which is locally developed in the upper part of the formation. In the area south of the Castle Rock quadrangle the Benton is divided into three formations—the Graneros shale at the base, the Greenhorn limestone and the Carlile shale above. The Niobrara consists of about 400 feet of limestone and calcareous shale, generally with a well-developed limestone at the base.

The Colorado group outcrops in two areas in the southwestern part of the quadrangle, one north of Deadmans Creek, and the other in the hogback area northeast of Perry Park. A complete section is not exposed because of faulting in the area north of Deadmans Creek and of Quaternary cover northeast of Perry Park.

In the hogback region, in T. 9 S., R. 68 W., most of the Colorado group occupies a lowland belt lying parallel to and at the base of the Dakota hogback. In this belt it consists of soft shale and thin limestone, but a harder zone of sandy limestone forms a ridge which in places is more prominent than the Dakota hogback.

In the area north of Deadmans Creek, in the NE. ¼ sec. 5, T. 12 S., R. 67 W., a narrow belt of the Colorado group is exposed for a distance of about half a mile. The strata are steeply tilted and locally overturned in a fault zone. In this area there is a threefold division of the Benton, apparently corresponding to the Graneros shale, Greenhorn limestone, and Carlile shale, but because of the poor exposures and the scale used it is not practicable to map the group in this area.

The following section was measured in the NW. ¼ sec. 5, T. 12 S., R. 67 W.:

Partial section of Colorado group in NE. ¼ sec. 5, T. 12 S., R. 67 W.

	Ft.	in.
Limestone, whitish	50+	
Shale, drab, clay	1	3
Sandstone, calcareous gray, fossiliferous	10	
Shale, fissile, blue-black, clay	25	
Limestone, thin bedded, fine grained, gray	75	
Shale, drab to bluish	50	

Scattered exposures in gullies northeast of Perry Park show dark fissile clay shale streaked with thin bands of fossiliferous gray limestone in the lower part of the section. These soft strata are 500 feet thick and are succeeded above by a ridge-making zone of gray sandy limestone which is about 50 feet thick.

Fossils.—The following fossils, referred to the Benton by T. W. Stanton, were collected from the Colorado group in the Castle Rock quadrangle:

Fossils from limestone lenses in shale in NW. ¼ sec. 15, T. 9 S., R. 68 W.

Ostrea sp.	Inoceramus sp.

Fossils from limestone in SE. ¼ sec. 15, T. 9 S., R. 68 W.

Inoceramus fragilis Hall and Meek.	Scaphites warreni Meek and Hayden.

Fossils from calcareous sandstone in NE. ¼ sec. 5, T. 12 S., R. 67 W.

Ostrea sp.	Prionocyclus wyomingensis Meek.
Inoceramus fragilis Hall and Meek.	Fish vertebra.
Scaphites warreni Meek and Hayden.	

MONTANA GROUP.

PIERRE SHALE AND FOX HILLS SANDSTONE.

The Montana group, which overlies the Colorado group, comprises the Pierre shale and Fox Hills sandstone, marine deposits that aggregate several thousand feet in thickness. In normal sections in this region the Pierre shale conformably overlies the shale of the Niobrara group and grades upward into the overlying shale and sandstone of the Fox Hills formation, which represent the final marine deposits of the great interior Upper Cretaceous sea.

Both the Pierre shale and the Fox Hills sandstone are exposed in the area about Denver and Colorado Springs and doubtless underlie the Castle Rock quadrangle, but their character and thickness in that quadrangle are not known, for the rocks are faulted and in large part are covered by Quaternary deposits. It is impossible to separate the Pierre and Fox Hills formations in this area, and they are therefore mapped together.

The Montana group occupies an area of a little more than 5 square miles in the northeastern part of T. 9 S., R. 68 W., an undulating lowland area mantled with Quaternary débris and traversed by West Plum Creek. A small continuation of the outcrop extends in a narrow belt into the southwestern end of T. 9 S., R. 67 W., where the Pierre shale is brought into contact with all the underlying formations down to the Fountain formation by a great normal fault. In the southwestern part of the quadrangle, where the Montana would normally outcrop, it is covered by younger deposits.

The Pierre in adjacent areas is a great mass of dark-colored clay shale reported to be 2,500 feet thick in the Colorado Springs quadrangle and 7,700 feet thick in the Denver area, although the enormous thickness last given has been questioned. The uniformity of this great mass of shale is relieved by scattered thin lenses of limestone, which in places, as a result of weathering, cap low hills that form characteristic features of the Pierre outcrop and have been named "tepee buttes." One of these buttes is poorly developed in the Castle Rock quadrangle, near the center of sec. 10, T. 9 S., R. 68 W.

The Fox Hills sandstone in adjacent areas consists of several hundred feet of sandy shale capped by a bed of persistent sandstone. It is reported to be 500 to 1,000 feet thick in the Denver area and about 600 feet thick in the vicinity of Colorado Springs.

Fossils.—The fossils named below were identified by T. W. Stanton.

Pierre fossils from limestone near center of sec. 10, T. 9 S., R. 68 W.

Inoceramus barabini Morton.	Scaphites nodosus Owen.
Lucina occidentalis (Morton).	Baculites compressus Say.

Fossils from limestone lens 200 feet below the base of the Laramie formation in NE. ¼ sec. 3, T. 9 S., R. 68 W.

Avicula nebrascana Evans and Shumard.	Scaphites sp.
Limopsis (?) sp.	Fragment of a large specimen apparently belonging to S. conradi (Morton).
Anchura americana (Evans and Shumard).	

Stanton states that the fossils last named are either Fox Hills or upper Pierre.

LARAMIE FORMATION.

Name and identification.—The status and the nomenclature of the Laramie formation have been the subject of controversy for many years, and it is still a question whether certain strata in the Rocky Mountain region shall be called Laramie. It is generally agreed, however, that the beds in the Denver region referred to the Laramie by Eldridge[1] are correctly assigned, and the foothill region of the Front Range in the Denver Basin has come to be recognized as the type area for the Laramie. The name Laramie is applied to brackish and fresh water beds that conformably succeed the uppermost marine Montana. It is the youngest Cretaceous formation in the Colorado Front Range region.

In the vicinity of Denver the Laramie formation, which there conformably overlies the Fox Hills and is unconformably overlain by the Arapahoe, is reported[1] to be between 600 and 1,200 feet thick and divisible into two parts, a lower sandstone member about 200 feet thick and an upper clay member. Both divisions carry workable seams of coal.

In the foothill region of central Colorado the Laramie formation outcrops in detached areas separated by overlapping deposits in a narrow belt of steeply tilted eastward-dipping strata that extend from a point a few miles north of Denver to the vicinity of Colorado Springs. The dip becomes less toward the east and in the central part of the Denver Basin, where the rocks lie almost flat, the formation is deeply covered by the Dawson arkose or by the Arapahoe and Denver formations.

[1] Emmons, S. F., Cross, Whitman, and Eldridge, G. H., Geology of the Denver Basin in Colorado: U. S. Geol. Survey Mon. 27, 1896.

On the eastern limb of the basin, where the dips are low to the west, coal-bearing rocks, which are thought to be the eastward continuation of the Laramie formation but from which satisfactory collections of fossils have not yet been obtained, are revealed by the erosion of the prevailing cover of younger deposits. These rocks are underlain by the Fox Hills sandstone, fossiliferous beds of which crop out in the breaks of Beaver Creek, 5 miles east of Agate, a station on the Union Pacific Railroad.

No complete section of the Laramie is exposed in this region on account of a widespread cover of Tertiary and Quaternary deposits, and the original thickness of the formation is not known because of the erosion that followed the post-Laramie uplift of the Rocky Mountain region. In the vicinity of Colorado Springs only the lower 250 or 300 feet of the Laramie formation is preserved.

Distribution and character.—In the Castle Rock quadrangle, which is on the western limb of the Denver Basin, an isolated outcrop of strata referred to the Laramie lies about midway between the area covered by that formation in the Denver Basin and the area covered by it in the Colorado Springs quadrangle. The Laramie formation has been traced southeastward from the Denver area to a point within 8 miles of its outcrop in the Castle Rock area. Farther south there is an interval of 18 miles between the Laramie in the Castle Rock quadrangle and the nearest exposed Laramie in the Colorado Springs quadrangle, the formation being covered by younger deposits in both the intervening areas. The Laramie in the Castle Rock quadrangle crops out in a narrow curved belt about 9 miles long and less than half a mile wide in the southeast quarter of T. 8 S., R. 68 W., in the northeast quarter of T. 9 S., R. 68 W., and in the southwest quarter of T. 9 S., R. 67 W. In the northern part of the area the strike is northwest-southeast and the dip is N. 45° to 50° E.; in the southern part the strike is north and the dip is steeper. East of the outcrop nothing is known of the Laramie formation within the quadrangle except that it is deeply buried under the Dawson arkose. Even along the zone of outcrop the beds are generally covered, being exposed only here and there. The best exposures are west of West Plum Creek, where the formation occupies a width of 1,630 feet, and as the dip is 50° a thickness of about 1,200 feet is there indicated. No complete section of the formation is exposed in the quadrangle, but local outcrops, as in sec. 34, T. 8 S., R. 68 W., show that it is a massive fine-grained white quartzose sandstone near the base, with associated thin-bedded buff and brownish sandstone, though apparently most of it consists of sandy and clay shale, carbonaceous, buff or drab in color, intercalated with thin-bedded fine-grained sandstone composed chiefly of quartz but containing subordinate feldspar and muscovite. Small nodules of clay ironstone occur throughout the formation. Coal is not exposed in the quadrangle, but it is probable that here, as in the areas to the north and south, the Laramie is coal bearing. It is possible that the lower part of the formation, including the coal zone, may be concealed by the northward extension of the fault which borders Perry Park on the east.

Fossils.—Good collections of fossil plants, including about 100 species, have been obtained from the lower few hundred feet of the Laramie formation in the vicinity of Denver and Colorado Springs, and a few brackish and fresh-water shells have been found in the formation in the Denver area.

In the Castle Rock quadrangle the plants listed below, which were identified by F. H. Knowlton, were collected from the whitish sandstone in sec. 34, T. 8 S., R. 68 W. Concerning these Mr. Knowlton reports that the plants are not very well preserved and that the species were therefore not positively determined, but there can be no doubt that they are properly referable to the Laramie.

Fossil plants from sandstone of the Laramie formation.

From SE. ¼ sec. 34, T. 8 S., R. 68 W.:
- Palm, rays only.
- Populus mutabilis ovalis? Heer.
- Viburnum platanoides? Lesq.
- Juglans? sp.
- Ficus sp.

From NW. ¼ sec. 34, T. 8 S., R. 68 W.:
- Palm, rays only.
- Ficus not unlike F. spectabilis but secondaries fewer.
- Cinnamomum affine Lesq.? or Ficus of the type F. planicostata, broken at the base.

TERTIARY SYSTEM.

Continental uplift and erosion marked the end of Cretaceous and the beginning of Tertiary time in the Front Range region. A considerable thickness of Mesozoic and older rocks was removed and a complex mass of continental deposits accumulated on an eroded surface of the Laramie and older formations. In the Castle Rock area and on the Platte-Arkansas divide the post-Laramie deposits have long been known as the "Monument Creek group." The name was introduced in 1869 by Hayden, who described the rocks as a "series of variegated beds of sands and arenaceous clays * * * of various colors * * * and of various degrees of texture." During the recent survey of the Castle Rock quadrangle it was found desirable to separate the "Monument Creek group" into two formations, separated by a well-marked unconformity, which was first pointed out by Emmons and Eldridge.[1] This unconformity is well marked on Castle Rock, north of the town of that name, and can be readily traced throughout the field. The upper formation, named the Castle Rock conglomerate, is of Oligocene age and the lower, named the Dawson arkose, is referred to the Eocene.

EOCENE SERIES.

DAWSON ARKOSE.

Name.—The Dawson arkose was named from Dawson Butte, which stands 4 miles northeast of Perry Park. The formation includes that part of the Monument Creek group of Hayden which lies between the unconformity exposed on Castle Rock and the Laramie formation.

Distribution and character.—The Dawson arkose outcrops on the Platte-Arkansas divide between Denver and Colorado Springs and extends an undetermined distance eastward from the base of the mountains, at least as far as the valleys of Kiowa and Bijou creeks, a distance of 40 or 50 miles. (See fig. 3.) This formation occupies by far the greater part of the surface of the Castle Rock quadrangle. Originally the Dawson arkose was more widely distributed, extending to the base of the Front Range and farther out on the plains to the east,

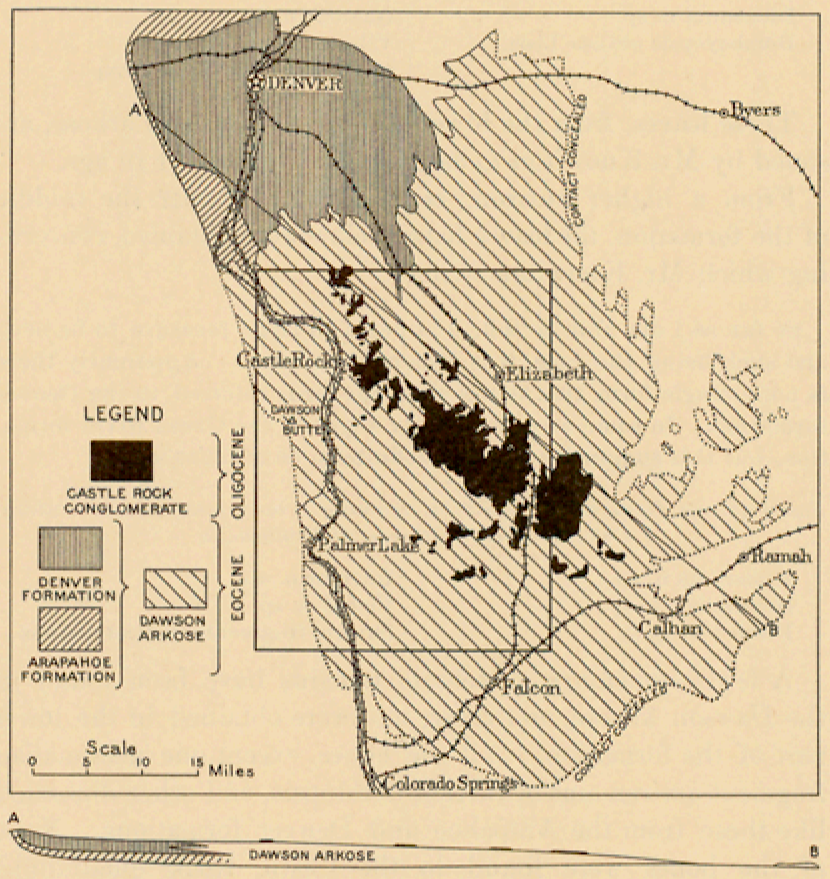


Figure 3.—Sketch map and section of Castle Rock quadrangle and vicinity, showing the distribution of the Tertiary formations. The Eocene-Cretaceous boundary on the east has not been determined. The section below the map shows the profile and relation of the rocks underground along the line A–B on the map.

but it has been extensively eroded. Throughout the greater part of the quadrangle it lies almost flat, but locally, in the foothills, the beds are tilted at angles which are in places as high as 90°. Where the arkose adjoins the Pikes Peak granite in the vicinity of Palmer Lake the contact is faulted. Along the base of the mountains the Dawson in large part is concealed by wash of Quaternary age. (See Pl. XIX.)

In places the Dawson arkose weathers into peculiar erosional forms (see Pl. IX), such as fantastically shaped columns capped by local protecting harder layers. These forms are notably developed in Monument Park, a few miles south of the Castle Rock quadrangle, but similar forms are not so well preserved in the area under consideration. In the southwestern part of the quadrangle there are, however, isolated erosion remnants or "monuments" of the Dawson arkose, from one of which the town of Monument is named. (See Pls. VII and VIII.)

The Dawson arkose has a maximum thickness of about 2,000 feet. It is thicker on the west, toward the source of the deposits in the mountains, and thins out eastward. Its original thickness was greater, but how much greater is not known because of pre-Oligocene erosion.

This formation is composed of a complex mass of varicolored and varitextured arkosic conglomerate, sandstone, shale, subordinate carbonaceous deposits, and clay derived chiefly from the rocks of the Front Range and deposited under various continental conditions. Sandstones comprise the greater part of the Dawson arkose. They are medium to coarse textured arkosic grits, composed chiefly of angular and semirounded bits of quartz and weathered feldspar derived from the Pikes Peak granite and associated rocks. The finer textured sandstones contain mica, both biotite and muscovite, in addition to the prevailing quartz and feldspar. Beds and lenses of conglomerate occur throughout the formation but are more common in its lower part and in areas near the mountains, where a well-developed basal bed consists of pebbles of granite, quartz, quartzite, chert, and scattered fragments of limestone and sandstone derived from the strata in the foothills and embedded in an arkose matrix. It includes also local bodies of clay. The formation is notably finer textured in its eastern part, away from the source of the material, than it is near the mountains.

The prevailing tone of the formation is whitish, a shade due to quartz and feldspar, but where the feldspars are iron stained various shades of red and yellow appear, so that rusty tones are common. At some places the clays are brilliantly varicolored.

The Dawson arkose shows various degrees of induration. Although the greater part of the formation, where exposed at the surface, is somewhat loosely consolidated, local ledges are formed by hard layers. The hills east of Palmer Lake, for example, are formed of local hard beds, whose induration, however, extends for only a few miles, for farther southeast, along the strike, the hard beds give way to loosely cemented material, which is topographically inconspicuous. The plateau east of the railroads and north of Larkspur is a plain underlain by uncommonly hard beds. In general the arkose does not form cliffs but commonly weathers to form a gently undulating surface and is prominently exposed, principally on the flanks of buttes that are capped by the rhyolite which occurs in the upper part of the formation. (See p. 9.)

No complete section of the Dawson arkose is exposed in the quadrangle, so that a detailed measurement can not be made of the entire formation without drilling, and even such a measurement would have little value, for no two sections would be alike. Pronounced irregularity in the arrangement and sequence of the deposits is a characteristic feature of the Dawson arkose. Abrupt changes in composition and texture of the rocks are common and, as is usual in continental deposits, there are a number of local unconformities.

An unconformity in the Dawson arkose of more than usual prominence is exposed near the top of a number of the buttes that are capped by rhyolite in the vicinity of Larkspur and Greenland. The following section, measured on Larkspur Butte, is typical:

Section of upper part of Larkspur Butte.

	Feet.
Rhyolitic rocks, capping hill	30±
Arkose, reddish, conglomeratic; containing fragments of white arkose like the underlying beds and pebbles of granite, quartz, and quartzite	25±
Unconformity; uneven eroded surface.	
Arkose, whitish, fine textured	25+

This unconformity evidently records changed conditions, but whether it represents any considerable hiatus is not known, because no fossils have been obtained from the immediately overlying or underlying rocks.

Another unconformity is shown by the uneven surface below the rhyolite on the west side of Dawson Butte. Although the surface on which the rhyolitic rocks lie is generally concealed, this exposure on Dawson Butte suggests that the igneous rocks were deposited on an eroded surface of the Dawson arkose, but there is no evidence of the length of time represented by this erosion.

In the greater part of the area erosion has carried away the deposits that formerly overlay the rhyolite, but about 4 miles southeast of Castle Rock 20 to 30 feet of fine-textured arkose lies between the rhyolite and the base of the Castle Rock conglomerate.

The lower contact of the Dawson arkose is characterized by an erosional unconformity that separates it from the underlying Laramie. In the Castle Rock quadrangle the base of the arkose outcrops for only a few miles west and south of Dawson Butte, and there the actual line of separation between the Laramie deposits and the arkose is concealed. The zone, however, is characterized by conglomeratic débris, and the change from the fine-textured sandstones and shale of the Laramie formation to the conglomeratic Dawson arkose is pronounced. The best exposures are west of Dawson Butte, on both sides of West Plum Creek, where the typical fine-grained Laramie and the characteristic basal conglomerate of the Dawson are in close proximity, both formations dipping northeastward at an angle of about 45°. The contact, showing an uneven, eroded surface, is well exposed near Pulpit Rock in the Colorado Springs quadrangle.

Andesitic member.—In the valley of Cherry Creek, at the north end of the quadrangle, there is an exposure of sandstone and shale composed of andesitic material. The rocks consist of about 50 feet of drab to grayish-green sandy and clay shale and thin-bedded sandstone composed of fragments of andesite, plagioclase feldspars, micas, and subordinate ferromagnesian minerals. Quartz is conspicuously absent and the material contrasts sharply with the arkose. The beds lie practically flat. Their base is not exposed and they are overlain by arkose typical of the Dawson. The upper contact is undulating, and there is an abrupt change from the fine-textured andesitic material to the overlying coarse arkose. Presumably this andesitic material is a lens in the Dawson arkose, the undulating contact at its top marking one of the many local unconformities in the Dawson arkose. This outcrop of andesitic material on Cherry Creek is the direct southern continuation of the Denver formation as mapped in the monograph on the geology of the Denver Basin.

[1] U. S. Geol. Survey Mon. 27, pp 38, 252, 1896.

Relation of Dawson arkose to Denver and Arapahoe formations.—Before considering the age of the Dawson arkose it is necessary to refer to the post-Laramie Arapahoe and Denver formations, which are well exposed immediately north and northwest of the Castle Rock quadrangle and have been described by Eldridge and Cross.[1] The Arapahoe formation, which is separated from the underlying Laramie by a well-marked erosional unconformity, is reported by Eldridge[2] to consist of "two well-marked series of beds—a lower of sandstones and conglomerates," composed of pebbles of the older formation, "50 to 200 feet thick, and an upper of clay, 400 to 600 feet thick." The Denver formation, which overlies the Arapahoe, is composed of sandstone and conglomerates about 1,400 feet thick, the lower part consisting chiefly of the débris of eruptive rocks (andesites) and the upper part of material derived from granite or gneiss mixed with andesitic débris.

Both the Arapahoe and Denver formations have yielded many plant remains and a number of vertebrate fossils, including turtles, crocodiles, and dinosaurs, among which the genus Triceratops is notable. Because of the Mesozoic affinities of these fossil vertebrates, the Arapahoe and Denver formations were reluctantly assigned to the Cretaceous system by Emmons, Eldridge, and Cross,[3] who pointed out that the unconformity by which they are separated from the Laramie would otherwise be sufficient reason for the assignment of these post-Laramie continental deposits, so unlike the underlying Cretaceous beds, to the Eocene.

The "Monument Creek formation," as described by Eldridge,[4] consists chiefly of sandstone and grit of Archean or sedimentary débris lying unconformably on older beds, in places on the Denver, in others on the Arapahoe, and in still others on the Laramie, and was provisionally assigned to the Miocene in conformity with the practice of the Hayden Survey.

Recent studies in the Castle Rock quadrangle have led to the recognition of previously unsuspected relations between the Arapahoe and Denver formations and the Monument Creek group of Hayden. The upper part of the "Monument Creek group" is now known to be Oligocene and a portion of its lower part, the Dawson arkose, is known to be equivalent to the Arapahoe and Denver formations. These relations are shown by both stratigraphic and paleontologic data.

The Dawson arkose strikes into and merges into both the Arapahoe and Denver formations, as shown in figure 3. Anyone following the Dawson arkose northward along the strike from the vicinity of Dawson Butte to the area mapped as Arapahoe in the Denver monograph will find it impossible to separate these formations, even at the type locality of the Arapahoe along the bluffs of Willow Creek, 3 or 4 miles southeast of the entrance to the Platte Canyon, which is only 3 miles west of the Castle Rock quadrangle. Eldridge recognized this difficulty, but on the assumption of the Miocene age of the "Monument Creek," an arbitrary boundary between it and the Arapahoe was drawn east of Willow Creek.

Likewise, the Dawson arkose and Denver formation merge into each other. Changes from andesitic to arkosic material occurring as interfingering lenses are common near the south end of the Denver formation, a few miles north of the Castle Rock quadrangle. In a gulch 8 miles north of Sedalia, for instance, layers of arkose typical of the Dawson are intercalated with andesitic Denver material. The marked difference in lithology between the andesitic Denver and the arkosic Dawson may be accounted for by the geographic distribution of the rocks that supplied the sediments, the arkose being derived mainly from the Pikes Peak granite and associated rocks, whereas the Denver formation was derived, apparently simultaneously, from a local source of andesite.

This stratigraphic evidence of the equivalence of the lower part of the Dawson arkose and the Arapahoe and Denver formations is corroborated by paleontologic evidence, for both fossil plants and vertebrates found in the Dawson arkose are correlated with more complete collections from the Arapahoe and Denver formations, as mentioned below.

Fossils.—Several collections of leaves and a few fossil bones, listed below, have been obtained from the Dawson arkose.

Fossil leaves from the Dawson arkose.

[Identified by F. H. Knowlton.]

Sec. 11, T. 12 S., R. 62 W., 1 mile southwest of Calhan, Colo., about 300 feet above top of Laramie formation:

Cornus studeri? Heer of Lesq.	Vitis olriki? Heer of Lesq.
Palmocarpon commune? Lesq.	Artocarpus? sp.
Palm, Sabalites? sp.	Ficus latifolia? Lesq. fragment.
Populus nebrascensis? Newberry.	Ficus sp.
Ficus, type of F. planicostata Lesq.	Sapindus? sp.

Sec. 3, T. 14 S., R. 65 W., 9 miles east of Colorado Springs, about 400 feet above top of Laramie formation:

Ficus sp., type of F. trinervis Knowlton, but not the same.	Flabellaria eocenica Lesq.
Cyperacites? sp.	Gigantic leaf, genus? No margin.
Fungus (genus? parasitic on Cyperacites? sp.).	Ficus tiliæfolia Al. Braun of Lesq.
Geonomites tenuirachis Lesq.	Ficus sp., type of F. planicostata Lesq.
	Pteris erosa Lesq.

[1] U. S. Geol. Survey Mon. 27, pp. 151–252, 1896.
[2] Idem, p. 152.
[3] Idem, p. 250.
[4] Idem, pp. 252–253.

Sec. 3, T. 14 S., R. 65 W., 9 miles east of Colorado Springs, about 500 feet above top of Laramie formation:

Platanus rhomboidea Lesq.	Ficus n. sp., five-ribbed, large.
Cinnamomum affine Lesq.	Berchemia multinervis (Al. Braun) Heer.
Ficus denveriana? Cockerell.	Palmocarpon commune? Lesq.
Rhamnus goldianus? Lesq.	

NW. ¼ sec. 34, T. 6 S., R. 68 W., 4 miles northwest of Sedalia, on hillside east of road:

Carpites sp.	Laurus brossiana? Lesq.
Ficus sp., narrow leaf of the general type of F. planicostata Lesq.	Quercus or Ficus sp., probably new.
	Dombeyopsis obtusa? Lesq.

From several localities, at about the same horizon, between 2 and 4 miles southeast of Monument and 2 miles east of the railroads:

Carpites sp.	Ficus denveriana Cockerell.
Platanus raynoldsi? Newberry.	Undescribed species of ferns.

NW. ¼ sec. 2, T. 7 S., R. 66 W., from andesitic member of Dawson arkose 6 miles north of Franktown:

Ficus denveriana Cockerell.	Ficus sp.

Fossil plants collected by Arthur Lakes from Dawson arkose NE. ¼ sec. 20, T. 7 S., R. 68 W., 3 miles west of Sedalia, 700 to 900 feet above the base of the Laramie formation:

Acer trilobatum productum? (Al. Braun) Heer.	Dryopteris lakesii (Lesq.) Knowlton.
Acorus brachystachis Heer.	Dryopteris lesquereuxii Knowlton.
Pteris erosa Lesq.	Ficus planicostata Lesq.
Berchemia multinervis (Al. Braun) Heer.	Hicoria sp. Knowlton.
Cissus lævigata Lesq.	Laurus primigenia Unger.
Cissus lobato-crenata Lesq.	Nelumbo lakesii (Lesq.) Knowlton.
Dicksonia n. sp.	Phyllites n. sp.
Dombeyopsis obtusa Lesq.	Quercus n. sp.
	Viburnum n. sp.
	Woodwardia latifolia Lesq.

These leaves, from the lower half of the Dawson arkose, are stated by Mr. Knowlton to be undoubtedly Denver in age.

From a higher horizon, estimated to be near the middle of the formation, the leaves listed below were obtained, concerning which Mr. Knowlton writes:

So far as I am able to tell, it appears in large measure to be new, and such being the case, it is difficult to place it. Apparently there is not a single form that is found in the beds referred to the Denver formation. In some ways it slightly suggests the Green River formation, but this suggestion is too indefinite to be of much use.

Fossil plants from cut at railroad crossing 1 mile southwest of Falcon, Colo., 10 miles southwest of Eastonville.

Asplenium n. sp.	Quercus n. sp.
Hemitelia? n. sp.	Ficus? n. sp.?
Pteris? n. sp.?	Several fragmentary dicotyledons.

A few fragmentary vertebrate remains have been found in the Dawson arkose, and these, too, were obtained in the lower part of the formation. All the bones, except one mammalian fragment are remains of turtles, Ceratopsia, and other dinosaurs like those from the Arapahoe and Denver formations. None of the bones were found in the Castle Rock quadrangle, although they all came from the Dawson arkose in areas near the quadrangle.

Many years ago Prof. O. C. Marsh found fragments of vertebrate remains, evidently of this same characteristic fauna (fauna of the "Ceratops beds") in the well-known rock columns (composed of Dawson arkose) of Monument Park.[1] This discovery by Marsh has recently been corroborated by Gilmore and Lee.[2] In 1912 Lee found pieces of turtle and ceratopsian bones in the Dawson arkose a few miles east of Colorado Springs, and in 1913 Gilmore visited the same locality and obtained similar fragmentary material.

In 1910 the writer found a small mammalian bone in the SW. ¼ sec. 2, T. 14 S., R. 65 W., 9 miles east of Colorado Springs, in the Dawson arkose, at a horizon estimated to be 600 feet above the base of the formation. This is about the place at which Gilmore and Lee later obtained reptilian fossils, whose association with mammalian remains is very interesting. Although the mammalian bone was found loose on a hillside, it was presumably in the immediate vicinity of the rocks in which it was entombed.

Concerning this mammalian bone J. W. Gidley, of the United States National Museum, reports:

It is the distal end of a tibia, which, while not generically determinable, is characteristically creodont, and indicates a rather highly advanced species of this group. The fore and aft concavity of its articular face, together with the considerable development of a median ridge, denotes a specialized type of hind foot leading toward the true carnivores.

Age.—The Dawson arkose is assigned to the Tertiary by all who have described it. Hayden, in 1869, before any fossils had been found in the rocks, regarded the "Monument Creek group" as "modern Tertiary," because of "the modern appearance of the group of coarse sandstones and conglomerates above the true Cretaceous beds." Later the group was assigned to the Miocene because of the discovery in it of vertebrate fossils characteristic of the White River group, which was formerly classified as Miocene, though it is now referred to the Oligocene. In 1896 Emmons,[3] referring to the fact that the horizon or source of the bones by which the Miocene age of the

[1] U. S. Geol. Survey Mon. 27, p. 479, 1896.
[2] Lee, W. T., Recent discovery of dinosaurs in the Tertiary: Am. Jour. Sci., 4th ser., vol. 35, pp. 531–534, 1913.
[3] U. S. Geol. Survey Mon. 27, p. 38, 1896.

beds was determined had not been precisely fixed, suggested that they probably came from the lower division of the "Monument Creek beds" and that the upper division might be Pliocene. Recent work has shown, however, that the Oligocene bones must have come from the upper part of the group, that is from the Castle Rock conglomerate, and the lower part of the group, the Dawson arkose, is assigned to the Eocene.

Although the Dawson arkose has always been considered Tertiary, the fact that it is in part equivalent to the Arapahoe and Denver formations was not recognized until recently. Notwithstanding the reasons given by Cross[1] for regarding them as Tertiary, the Arapahoe and Denver formations were classed as Cretaceous because of the Mesozoic affinities of the vertebrate remains found in them. The correlation of part of the Dawson arkose with the Arapahoe and Denver formations has reopened an old discussion involving the classification of the "Ceratops beds" of Wyoming and adjacent States, now known as the Lance formation. Because of the presence in the Arapahoe and Denver formations of Triceratops and two or three other genera of dinosaurs which also occur in the Lance these formations have been thought to be equivalent, although their equivalence has not been established. The subject will not be discussed at length here; only some of the main points involved will be mentioned.

The evidence for the Cretaceous age of the Lance formation may be summarized as follows: (1) The Mesozoic affinities of the vertebrate fossils, which, besides Ceratopsia, includes a considerable reptilian fauna; (2) the closer relationship, according to Stanton, of the brackish and fresh water invertebrates to known Cretaceous faunas than to known Eocene faunas; (3) the Cretaceous character of the invertebrate fauna of the Cannonball[2] marine member of the Lance formation in North and South Dakota, a fauna which, according to Stanton, is closely related to and directly derived from the Fox Hills fauna; (4) the apparently continuous sedimentation from the acknowledged Cretaceous to the Lance.

On the other hand the evidence indicating the Eocene age of the Lance formation may be thus outlined: The flora of the Lance, compared with that of the underlying Cretaceous formations, according to Knowlton, includes a considerable proportion of new genera and is in large part identical with and generally indistinguishable from the flora of the overlying Fort Union formation, of recognized Eocene age. These two formations, the Lance and Fort Union, over large areas constitute a stratigraphic unit which can not be satisfactorily divided; and the Lance formation contains mammals which, according to Gidley, more closely resemble the mammals of the Fort Union and other lower Eocene formations than those of any known Cretaceous types. Moreover, in places there is evidence of erosion at the base of the Lance formation, which, together with the fact that the Laramie has not been recognized in areas occupied by the Lance, suggests a time interval between the deposition of that formation and that of the underlying Cretaceous (Fox Hills or Pierre), corresponding, it is thought, to the widespread post-Laramie unconformity of Colorado, southern Wyoming, and northern New Mexico.

But whatever may be the age of the Lance formation the Dawson arkose may be assigned to the Eocene on both stratigraphic and paleontologic grounds.

The erosional unconformity separating the brackish and fresh water Laramie beds from overlying continental deposits in the Denver Basin is pronounced. It is shown by the marked change in the character of the deposits from the fine-grained, prevailingly dull-colored, evenly stratified Laramie formation to the overlying coarse-grained, varicolored, irregularly assorted Dawson arkose, the basal conglomerate of which contains pebbles of many of the underlying formations and rests on an uneven surface of the Laramie. The extent of the hiatus involved by the post-Laramie and pre-Dawson erosion need not be discussed here, but it may be pointed out that in the vicinity of Colorado Springs the Laramie is less than 300 feet thick, whereas northeast of Perry Park, in the Castle Rock quadrangle, less than 25 miles north of the Colorado Springs area, it is at least 1,200 feet thick. The widespread extent of an unconformity, presumably at this horizon, in the Front Range region is indicated by the stratigraphic break between the "Upper Laramie" and "Lower Laramie" in southern Wyoming, described by Veatch, and by the unconformity in the Raton Mesa region of New Mexico, which separates the Eocene Raton formation from underlying beds of Montana age, described by Lee. Cross in several papers has emphasized the importance of the unconformity in the Denver Basin and has regarded it as a sufficient reason for assigning the post-Laramie deposits to the Eocene.

In addition to these physical grounds for drawing the boundary between Mesozoic and Cenozoic deposits of the Front Range region at the top of the Laramie, recent paleontologic work affords evidence of the Eocene age of the post-Laramie

[1] U. S. Geol. Survey Mon. 27, pp. 206–208, 1896.
[2] Lloyd, E. R., and Hares, C. J., The Cannonball marine member of the Lance formation of North and South Dakota and its bearing on the Laramie-Lance problem: Jour. Geology, vol. 23, pp. 523–547, 1915.

deposits of the Denver Basin. The creodont bone found in the Dawson arkose, associated with fragmentary ceratopsian remains, indicates, according to Gidley, a rather highly developed species of the group, of a type not hitherto found in beds older than Wasatch; and Knowlton and Berry, as a result of their recent study of the fossil floras, correlate the Dawson arkose, and the Arapahoe and Denver formations with the Eocene Wilcox formation of the Gulf coast. Assuming that this correlation is correct, a link has thus been established between continental Rocky Mountain deposits and a well-known marine section. In this connection it is noteworthy that in the Atlantic and Gulf coastal plains the line of separation of Cretaceous and Eocene deposits is marked by evidence of erosion, which is believed to have been contemporaneous with the post-Laramie diastrophism in the Front Range region.

It therefore appears that the major part of the evidence now available indicates that the Dawson arkose is of Eocene age and it is therefore assigned to the Eocene in this folio. But considering the difference of opinion as to where the boundary shall be drawn between Cretaceous and Eocene rocks in the Rocky Mountain region, as shown by the diverse views expressed at the recent symposium on that subject conducted under the auspices of the Geological Society of America,[1] it is evident that the final word on the subject still remains to be said.

OLIGOCENE SERIES.

Widespread erosion preceded the deposition of the Oligocene deposits in most if not all of the areas in which they now outcrop in the Great Plains and Rocky Mountain regions. This erosion is indicated by differences in the age of the rocks that immediately underlie the Oligocene, which range from Eocene to Pierre and older. Later Tertiary and Quaternary erosion has in turn carried away these middle Tertiary deposits from large areas and the Oligocene rocks in the Castle Rock quadrangle are outlying erosion remnants of a former greater extent of rocks of the age of the White River group, which is typically developed in southwestern South Dakota and western Nebraska.

CASTLE ROCK CONGLOMERATE.

Name.—Castle Rock conglomerate is the name now assigned to the uppermost part of Hayden's Monument Creek group—that part of it lying above the unconformity which is finely exposed on Castle Rock, a prominent hill immediately north of the town of that name.

Distribution and character.—The Castle Rock conglomerate outcrops in detached areas on the divides between the tributaries of South Platte River from the vicinity of Elbert to the vicinity of Sedalia, a distance of about 40 miles. (See fig. 3.) The conglomerate was undoubtedly chiefly derived from the rocks of the Front Range, the material apparently being laid down as wash and fluviatile deposits after a period of uplift of the mountains to the west, during which period the underlying Dawson arkose was eroded. The conglomerate occurs in the south-central part of the Denver Basin, where the strata lie nearly flat but have a distinct though slight northward dip, conforming with the pitch of the syncline. Throughout its extent the formation is generally well exposed, for, being composed of hard material overlying the softer Dawson arkose, it usually forms cliffs. (See Pl. VI.)

The greater part of the Castle Rock conglomerate lies in the Castle Rock quadrangle, where it caps the dissected upland that extends northwestward across the quadrangle. Kiowa and Cherry creeks have cut through the formation, separating it into its two largest areas, but a number of smaller isolated outliers occur as mapped.

The Castle Rock conglomerate has a maximum present thickness of 300 feet, its original thickness not being known because of erosion. Over a large part of its extent this formation is now less than 50 feet thick, and in places it is represented only by residual pebbles, which caused difficulty in mapping, for differences of opinion may naturally exist as to whether certain areas that carry a thin sprinkling of pebbles should be mapped as Castle Rock conglomerate or not. For example, in an area east of Eastonville, at the border of the quadrangle, a few scattered pebbles form the last residue of the conglomerate, but they are so few that the area is mapped as Dawson arkose, whereas the top of the plateau west of Elizabeth, although certain areas are doubtful, is mapped as Castle Rock conglomerate because it bears an extensive sheet of residual pebbles of that formation. Some ledges show that these pebbles are practically in place. Difficulty was also encountered in determining the line of separation between this formation and the underlying arkose in the northern part of the quadrangle, northeast of Sedalia—difficulty due to the presence of beds of conglomerate throughout an unusually great stratigraphic interval. In the absence of Titanotherium bones or of fragments of rhyolite in the conglomerate the delimitation of the formation is in places extremely difficult.

[1] Geol. Soc. America Bull., vol. 25, pp. 321–402, 1914.

A complete section of the Castle Rock conglomerate is not exposed. Its composition is so variable, however, that even if such a section were found its detailed measurement would not apply to a wide area. The formation is composed essentially of indurated conglomeratic arkose. It includes a cliff-making basal conglomerate, usually well developed, above which lies coarse arkosic sandstone streaked with lenses of conglomerate, these making up the remainder of the formation. Cross-bedding and lenticular structure are common. The pebbles were derived from various rocks in the Front Range and foothills and also from the rhyolite in the upper part of the Dawson arkose. The most abundant pebbles include red and gray coarse and fine textured granite, coarse and finely laminated gneiss, white and gray quartzite, white vein quartz, bits of black and gray chert, scattered fragments of porphyry and rhyolite, in rounded and in angular blocks. These pebbles are embedded in a medium to fine grained matrix composed of angular to subrounded fragments of quartz and feldspar, indurated by siliceous cement. The pebbles differ considerably in size, ranging from a fraction of an inch up to a foot or more in diameter. Most of them are between 2 and 4 inches in diameter. The large size of some of the pebbles found at a distance of 30 to 40 miles from their source is difficult to account for. They may have been transported by torrential streams, but the action of floating ice is also suggested, although no proof of the presence or action of ice in this area has been obtained.

The Castle Rock conglomerate lies on an uneven eroded surface of the Dawson arkose, which is well exposed at many places, notably on Castle Rock and in the vicinity of Castlewood reservoir. (See Pls. III–VI.) Castle Rock is capped by 90 feet of indurated conglomeratic arkose, which at the base is a coarse conglomerate that marks an abrupt change from the underlying fine-textured Dawson arkose. The contact is uneven. In the vicinity of Castlewood Reservoir the conglomerate forms a line of cliffs, and the undulating line of separation between the conglomerate and the Dawson arkose is well exposed.

Age and correlation.—A number of vertebrate fossils have been found in the Castle Rock conglomerate. The collections from the "Monument Creek group" obtained by Cope in 1873 doubtless came from the Castle Rock conglomerate, although the places at which they were found are not recorded. Likewise the collections by Darton and Fisher from localities northwest of Calhan and southwest of Elizabeth were made from the same formation.[1] The writer obtained at the places indicated below a number of Titanotherium bones, which were determined by J. W. Gidley, of the United States National Museum, as follows:

About 4 miles northwest of Elbert, in the NE. ¼ sec. 30, T. 9 S., R. 64 W., embedded in the Castle Rock conglomerate about 100 feet above its base, a nearly complete femur and the distal end of a humerus of a Titanotherium.

About 5½ miles northwest of Eastonville, in the SE. ¼ sec. 2, T. 11 S., R. 65 W., in an outlier of the Castle Rock conglomerate, the distal portion of a humerus of Titanotherium sp. and portion of calcaneum of Cænopus sp.

About 2 miles east of the border of the sheet, in the SW. ¼ sec. 29, T. 10 S., R. 63 W., from the Castle Rock conglomerate 120 feet above its base, fragments of an upper jaw containing one premolar of Titanotherium sp.

From about 5 miles east of Elbert a jaw bone and teeth of *Titanotherium trigonias?* or possibly *T. coloradense.*

The best specimen examined was found in 1906 by J. A. Boston, of Elbert, 1½ miles east of Elbert near the middle of sec. 36, T. 9 S., R. 64 W. This was the left jaw with teeth of *Titanotherium trigonoceras?*.

These bones prove that the Castle Rock conglomerate is of lower Oligocene age and it is correlated with the Chadron formation or "Titanotherium beds," the lowest formation of the White River group, as typically developed in southwest South Dakota. The representative of the White River group that lies nearest to the Castle Rock conglomerate is in the bluffs west of Akron, Colo.

Late Tertiary deposits have not been recognized in the Castle Rock quadrangle, although such deposits are found in areas to the east and southeast. At least a part of the quadrangle was probably once mantled with late Tertiary deposits that have been removed by erosion. Erosion has been predominant in this region since Oligocene time and has carried away a considerable thickness of rock, the products having been transported, deposited, and re-sorted many times.

QUATERNARY SYSTEM.

In addition to the general veneer of little-transported débris, composed of the disintegrated underlying rock and soil which cover the entire area except where the bare hard rock is exposed, the Quaternary deposits of the quadrangle consist of wash débris and stream alluvium.

Wash.—The highlands are flanked by wash consisting of disintegrated material that has been transported, chiefly by torrential floods, from higher to lower elevations, where it usually forms graded débris slopes. The best developed deposits of this kind lie at the base of the Front Range between Palmer Lake and the southern end of the quadrangle, where conspicuous wash-covered slopes extend from the mountains almost to Monument Creek. (See Pls. I and XIX.) Streams that head in the mountains have cut through these deposits so that they are not continuous but consist of disconnected areas of sand and gravel, which form a veneer ranging in thickness from less than a foot to about 20 feet. In places several different sets of wash deposits rise in tiers one above another, but parts of the older or upper ones have been removed by erosion, so that the best preserved is the lowest or youngest set, which is illustrated in Plate XIV. The slope of the surface of the wash is generally about 2° or 3°.

[1] Darton, N. H., Age of the Monument Creek formation: Am. Jour. Sci., 4th ser., vol. 20, pp. 179–180, 1905.

Stream alluvium.—The valleys of all the streams are floored with alluvium, but only the principal deposits are shown on the map, and it was not found practicable to distinguish those of Recent from those of Pleistocene age. Along Plum Creek, for instance, there are two sets of terraces. (See Pl. XX.) On East Plum Creek, between Sedalia and Castle Rock, the stream has cut down 20 feet in an old flood plain composed of well-stratified sand and clay. Above this old flood plain are remnants of another, 25 to 30 feet higher, which is obscured by outwash slopes from the adjacent uplands. Similar terraces occur on West Plum Creek. There is also a wide exposure of alluvium in the valley of Cherry Creek below the gorge leading from Castlewood Reservoir, where the flood-plain deposits merge laterally into the outwash slopes.

Immediately southwest of the quadrangle, on the peneplained surface of the Front Range, at an altitude of about 9,300 feet, there is a veneer of unconsolidated deposits of unknown extent. Similar material probably once occupied an adjacent part of the Castle Rock quadrangle but has been removed by erosion. It consists of rudely assorted bowlders, gravel, and sand, composed of granite débris and fragments of different kinds of volcanic rocks like those of the Cripple Creek district. In these deposits several prospect pits, dug in a search for placer gold, have been sunk, one to a reported depth of 50 feet without striking bedrock. The distribution and composition of this material suggest that it is of fluvial origin and Pleistocene age, or possibly older.

Fossils.—Bones of Pleistocene elephants have been found in the outwash and terrace deposits at several places, namely:

In the outwash deposits along the base of the mountains a few miles south of the quadrangle, a tooth of *Elephas columbi.*

In the banks of a branch of Running Creek 4 miles southwest of Elbert, parts of three vertebræ of Elephas sp. ?.

At a place half a mile west of Cherry Creek, in the SW. ¼ sec. 34, T. 7 S., R. 66 W., the posterior portion of a molar of *Elephas columbi?*.

In the valley of Cherry Creek, 8 miles north of the Castle Rock quadrangle, in sec. 19, T. 5 S., R. 66 W., the inner half of the lower end of the left humerus and the upper end of the left tibia of *Elephas columbi?* or *E. imperator?*.

In the valley of West Plum Creek, 2 miles northwest of Dawson Butte, in sec. 26, T. 8 S., R. 68 W., on the place of Mr. Upton Smith, the tusks and teeth of an extinct elephant.

All the bones but the first and last mentioned were examined and identified by J. W. Gidley, of the National Museum.

TERTIARY IGNEOUS ROCKS.

RHYOLITE LAVA AND ASSOCIATED TUFF.

Toward the close of the time during which the Dawson arkose was being deposited, volcanic activity in the vicinity of the Platte-Arkansas divide resulted in the eruption of a small amount of tuff followed by a flow of rhyolite. The location of the vent and the original extent of these rocks are not known.

Distribution and occurrence.—These rocks occur only in the Castle Rock quadrangle, where they cap a number of isolated hills and small mesas between and near Palmer Lake and Sedalia. Rhyolite forms the conspicuous cap rock of prominent buttes like Raspberry, Larkspur, Dawson, and others not named on the map. (See Pl. X.)

These separated masses presumably are the remnants of a formerly continuous sheet of lava which has been elsewhere removed by erosion. Each of the remnants lies practically flat, but, considered as a whole, the bed of rhyolite dips northeastward about 75 feet in a mile, in conformity with the dip of the overlying and underlying deposits. Thus the altitude of the outcrops decreases from nearly 7,900 feet east of Palmer Lake to 6,700 feet north of Castle Rock.

These volcanic rocks are interstratified with the extreme upper part of the Dawson arkose. The tuff apparently did not extend over so large an area as the rhyolite, but its distribution is not clear. It is well exposed in the group of small buttes 3 to 5 miles northeast of Palmer Lake, where 20 feet of tuff was measured, although the ordinary thickness is considerably less.

The overlying sheet of rhyolite is about 15 feet thick. Exposures of the contacts are rare but where observed show an abrupt change from loosely consolidated tuff or arkose to compact hard lava. Where the contact is exposed, as at the western end of Dawson Butte, the rhyolite lies on an undulating eroded surface. On Larkspur Butte fragments of arkose are included in the rhyolite, which at the contact is glassy. Inclusions of indurated (baked) arkose also occur in the lava 5 miles northeast of Palmer Lake. At most places the beds that immediately overlay the lava have been removed and the rhyolite caps the hills, but at a few places the lava is overlain by arkose without evidence of intervening erosion. About 2½ miles southeast of Castle Rock, for example, about 30 feet of Dawson arkose lies between the rhyolite and the Castle Rock conglomerate.

Character and composition.—The rhyolite in general is a relatively hard, though rather porous fine-textured gray to reddish porphyritic rock, composed of small crystals of feldspar and less abundant biotite, which are irregularly distributed through an aphanitic groundmass that comprises the great body of the rock. Local variations are caused by differences in hardness and porosity, in color, and in the abundance and size of the phenocrysts. Gas cavities of irregular shape and jagged internal outline are common. At some places, as for instance in Hathaway's quarry, 2½ miles southeast of Castle Rock, well-shaped crystals of barite, the largest found 3 inches in length, occur in the cavities. Radiating crystals of barite also occur in films along joint planes. The barite was probably formed soon after the magma solidified.

Under the microscope the feldspar phenocrysts are seen to be chiefly idiomorphic crystals of sanidine, less commonly of oligoclase, and rarely of microcline. The crystal faces are generally of perfect outline, but some show evidence of resorption. Next to feldspar in abundance is biotite, which occurs here and there as perfect hexagonal plates. Grains of quartz occur sparingly as phenocrysts. The groundmass ranges from cryptocrystalline to partly glassy. Its distinguishable components are minute crystals of quartz and feldspar, which occur locally in spherulitic aggregates. In some of the slides the groundmass shows flow structure.

Two sets of perpendicular joints traverse the rhyolite. Quarry faces usually show vertical joints, which are generally curved, and the rock breaks characteristically with conchoidal fracture. In the San Francisco quarry, west of Castle Rock, weathering along intersecting joints has broken the rock into polygonal blocks, the results simulating columnar structure. The rock breaks up along horizontal fracture planes, so that the tops of most of the hills on which it crops out are littered with slabs ranging in thickness from a fraction of an inch to a few inches. In places where the cap is thin the entire mass is thus broken up. These fracture planes are presumably caused by flow structure, and this is also apparently the cause of the horizontal banding of the rhyolite which, though not common, is locally clearly developed.

A partial analysis of a sample of the rhyolite from the western knob of Raspberry Butte, by J. S. Fairchild, gave the percentages SiO_2, 73.75; K_2O, 5.83; Na_2O, 3.72; indicating a normal rhyolite. Its composition is closely like that of the Pikes Peak granite.

This rhyolite has been erroneously called tuff in publications that followed the earlier usage of Eldridge.[1]

Age.—As the rhyolite occurs in the extreme upper part of the Dawson arkose, its age must be Eocene, but in what stage of that epoch it was poured out is not yet known.

STRUCTURE.

GENERAL CONDITIONS.

The metamorphic complex which constitutes so large a part of the Front Range bears witness to the diastrophism which the region suffered in pre-Cambrian time. Although the greater part of the deformation of this mass antedates the intrusion of the Pikes Peak granite, the many fractures by which the granite is traversed testify that it too was subjected to considerable stresses. The succeeding period, in which the several thousand feet of Paleozoic and Mesozoic rocks accumulated, was a time of comparatively little structural disturbance. There were beyond doubt a number of broad earth movements and oscillations of land and sea, resulting in unconformities and overlaps, yet the structurally conformable sequence of beds from the Cambrian through the Cretaceous indicates relative freedom from deformation. But beginning with the final withdrawal of the sea and the emergence of the continent, dating from the close of Laramie time, the rocks were subjected to uplifting and compressive forces which, continuing at intervals during the Cenozoic era, resulted in the present attitude of the strata. The dominant structural feature of the quadrangle is the steeply tilted and faulted foothill zone, which marks the uplift of the Front Range. East of this zone the strata of the plains are gently folded into the broad syncline known as the Denver Basin.

STRUCTURE OF THE FOOTHILLS.

The structure of the foothills is characterized by steeply upturned and dislocated strata, which lie at the base of the Front Range. The prevailing dip of these beds is eastward, away from the mountains, but in the northern part of Perry Park the beds in one place are overturned and dip steeply westward. The monoclinal structure is complicated by curved strikes, by varied dips, and by pronounced faulting parallel to the general trend of the mountains.

The mountain front trends almost due north from the southern border of the quadrangle northward for 13 or 14 miles. Thence it trends northwestward for 6 miles to the west border of the quadrangle, beyond which it again trends northward. (See fig. 5.)

In Perry Park the strike of the beds, which are well exposed in ridges, is distinctly curved. From the southeast to the northwest end of the park the strike passes from directly north through N. 40° W., N. 75° W., to N. 35° W. at the west margin of the quadrangle, beyond which the strike is north for a few miles. West of Sedalia, just beyond the border of the quadrangle, the strike turns again to the northwest. These strikes are found only in the rocks below the Montana group, for the outcrop of the Laramie formation in the quadrangle forms a broad curved belt which is only approximately parallel to the outcrop of the older strata. Apparently some of the stresses that deformed the more resistant beds nearer the mountains were taken up by the Pierre shale, so that the outlying Laramie and younger rocks were not so much disturbed.

Profound faulting has occurred in the foothill zone parallel to the trend of the mountains. In the southwestern part of the quadrangle the faulting is in large part concealed, but in places it is plainly apparent, and there can be no doubt that a fault zone lies parallel to the mountains along their base.

Two northward-trending faults are exposed in the southwestern part of the quadrangle, in T. 12 S., R. 67 W. They are well shown in secs. 5 and 8 and are represented in structure sections forming figure 4. The dip of these faults is

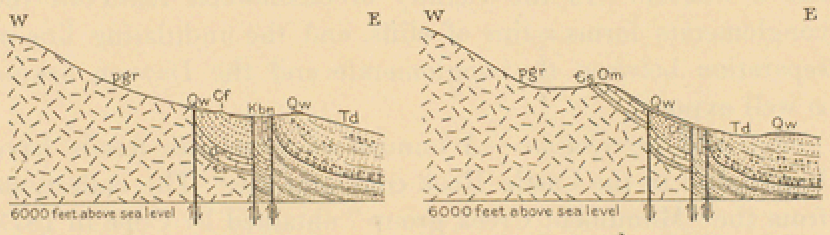


FIGURE 4.—Structure sections at the foot of the Front Range in vicinity of Deadmans Gulch.

a, Section north of the gulch across northern part of sec. 5, T. 12 S., R. 67 W.; b, Section south of the gulch across northern part of sec. 8, T. 12 S., R. 67 W.

Qw, Wash; Td, Dawson arkose; Kbn, Benton and Niobrara formations; Cf, Fountain formation; Om, Manitou limestone; Єs, Sawatch sandstone; pgr, Pikes Peak granite.

Scale: 1½ inches=1 mile.

apparently about 90°. The displacements can not be measured closely, but in the exposure in the NE. ¼ sec. 5 they are sufficient to bring rocks of the Colorado group into contact with the Fountain formation on the west and into contact with the Dawson arkose on the east. The Fountain in turn is probably faulted against the granite on the west. (See section a, fig. 4.)

Half a mile farther south, in the SE. ¼ sec. 5, along the strike of the Colorado beds just mentioned, a different section is exposed, the interpretation of which appears to demand the presence of a branched fault. If the white quartzose sandstone exposed here is the upper member of the Lyons and the overlying limestone is a part of the Lykins formation such a branched fault must be inferred, but as no fossils were obtained here the identifications suggested are doubtful, and these rocks are therefore mapped as the southern continuation of the narrow band of Colorado mentioned above. This narrow block, only a few hundred feet wide, in which the strata stand almost vertical, is separated by faults from steeply dipping beds of the Fountain formation on the west and from beds of the Dawson arkose on the east, as in section a, figure 4.

South of Deadmans Creek the relations are concealed by Quaternary outwash, but it is evident that the outcrop of the Sawatch sandstone and Manitou limestone forming the hogback in sec. 8, T. 12 S., R. 67 W., is cut off from the younger rocks to the east by a fault, because there is not sufficient space between them to accommodate the normal thickness of the strata. (See section b, fig. 4.)

The northward continuation of this zone of faulting along the base of the mountain is defined in the vicinity of Palmer Lake by outliers of Dawson arkose abutting against Pikes Peak granite, which rises abruptly several hundred feet above the arkose.

The most pronounced exposures of dislocations in the quadrangle are about Perry Park, most of the park area lying in the quadrangle being a fault block between nearly parallel fault planes. (See section B–B, structure-section sheet.) These faults are represented on the geologic map and their extensions beyond the limits of the quadrangle are indicated in the sketch map forming figure 5 and in the sections in figure 6.

The fault on the east side of the block causes the formations from the Fountain to the Colorado inclusive to strike into and abut against the Pierre shale. Near the contact the Pierre strikes north and stands almost vertical, but on the opposite side of the fault the strike is northwest and the dip is 10° to 45° NE. This fault trends for about 3½ miles slightly east of north from the south end of Perry Park to a point where, conforming with the general structure of the region, it apparently turns northwestward and continues to and beyond the west border of the quadrangle. After turning northwestward, however, its position is concealed, but it probably forms the boundary between the Montana group and the Laramie formation, cutting off the lower part of the Laramie, as is indicated by the fact that the lower coal zone, prominently developed in the vicinity of Denver and Colorado Springs, is not exposed in the Castle Rock quadrangle. (See section F–F, fig. 6.) A small branched fault occurs between the upper part of the Lyons sandstone and the Fountain formation in sec. 36, T. 9 S., R. 68 W.

The fault along the west side of the Perry Park block is in a general way parallel to that which borders the block on the east and is also well exposed. This displacement causes the Fountain formation, dipping 10° to 15° N. and striking about N. 80° W., to abut abruptly against the Pikes Peak granite in secs. 34, 27, and 22, T. 9 S., R. 68 W. (See section B–B, structure-section sheet.) South of Perry Park Lake this fault, in cutting across the Fountain formation, here about 2,000 feet thick, reduces the outcrop to a width of less than 1,000 feet. Thence to the west border of the quadrangle the fault lies between the Fountain formation and the Lyons sandstone,

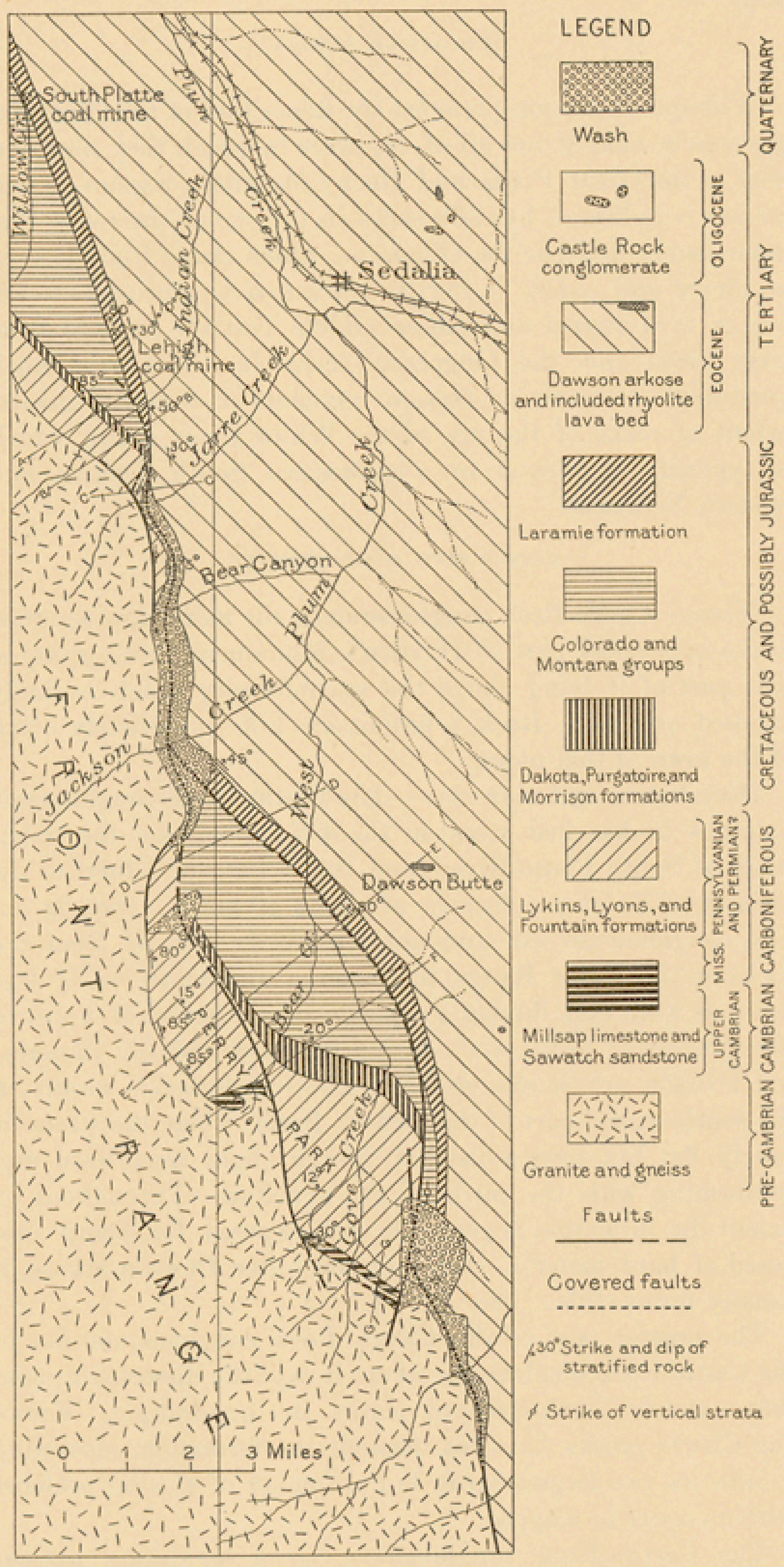


FIGURE 5.—Geologic sketch map of the foothill region from Perry Park northward to South Platte coal mine west of Sedalia.

the Fountain dipping about 15° NE. and the Lyons standing almost vertical. (See section A–A, structure-section sheet.) Subsidiary strike faults are developed in the belt of nearly vertical rocks northwest of Perry Park Lake, as is shown by slickensided surfaces and by local thinning of the formations.

The continuation of this zone of faulting beyond the quadrangle is shown in figure 5. Half a mile west of the border of the quadrangle, in the NW. ¼ sec. 4, T. 9 S., R. 68 W., slightly overturned limestone beds of the Colorado group strike north and dip steeply westward, in contact with the Lykins formation. (See section E–E, fig. 6.) A little farther north the strata on the west side of this displacement strike abruptly into the Pikes Peak granite, indicating another fault along that contact.

Near the mouth of the canyon of Jackson Creek, 4 miles northwest of Dawson Butte, these Perry Park faults appear to come together, and thence the zone of displacement continues northward along the base of the mountains. The relations of the rocks in this part of the disturbed zone, however, are completely concealed by wash as far north as Jarre Creek, a distance of 6 miles, where the steeply tilted strata are again

[1] Emmons, S. F., Cross, Whitman, and Eldridge, G. H., Geology of the Denver Basin in Colorado: U. S. Geol. Survey Mon. 27, p. 399, 1896.

exposed in fault relations shown in sections A–A, B–B, and C–C of figure 6.

The contact between the Pikes Peak granite and the sedimentary rocks is generally concealed. At some places, as on Bear Creek southwest of Perry Park Lake, the sediments lie on the granite in apparently undisturbed relations, but at other places, as for instance 1½ to 2 miles south of Jackson Creek and also north of the mouth of Jarre Canyon, the sedimentary rocks strike toward the granite, indicating faulting.

Two and a half miles southwest of Raspberry Butte a longitudinal fault along the base of the mountains has caused the repetition of a block of Sawatch sandstone and Millsap limestone, which are separated from the main outcrop of those formations by a narrow belt of Pikes Peak granite. This fault is similar to the one between the South Boulder Peaks, northwest of Denver, which has been explained as a thrust fault whose plane originally dipped eastward but has been rotated to its present position by later movement. Such an explanation of the fault southwest of Raspberry Butte seems unnecessary. Apparently it is a normal fault with downthrow on the southwest, as shown in section G–G, figure 6.

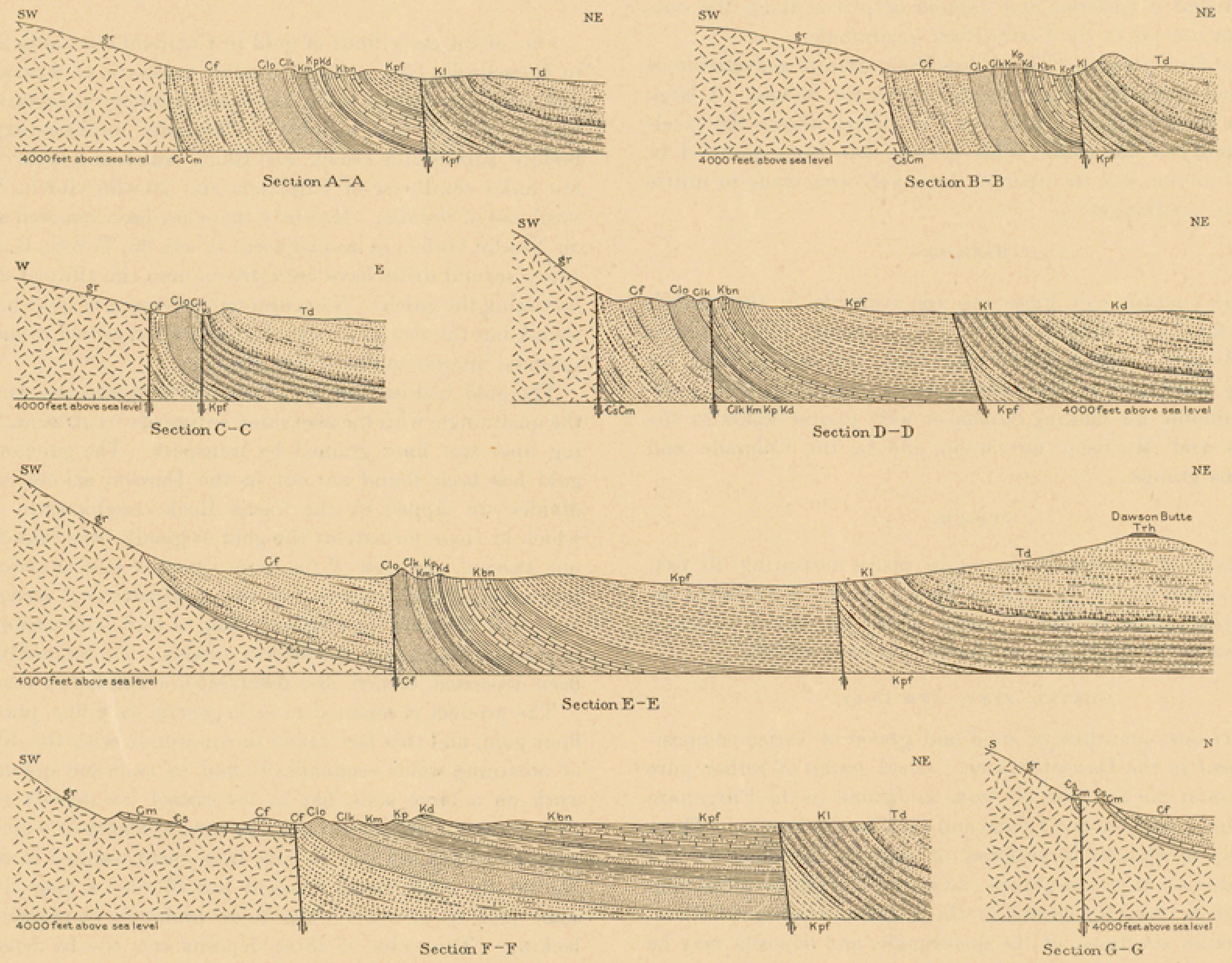


FIGURE 6.—Structure sections across foothills region from Perry Park northward to Lehigh coal mine along lines shown on the map in figure 5. Scale: 2 inches=1 mile.

Trh, Rhyolite lava and tuff; Td, Dawson arkose; Kl, Laramie formation; Kpf, Pierre shale and Fox Hills sandstone; Kbn, Benton and Niobrara formations; Kd, Dakota sandstone; Kp, Purgatoire formation; Km, Morrison formation; Clk, Lykins formation; Clo, Lyons sandstone; Cf, Fountain formation; Cm, Millsap limestone; Ꞓs, Sawatch sandstone; gr, granite and gneiss.

What appears to be a small thrust is exposed at the base of the mountains on the east side of the mouth of Gove Canyon, shown in Plate XVII. There the Pikes Peak granite seems to have been thrust over the Sawatch sandstone and Millsap limestone for a few hundred feet, but the relations are obscure. The slightly overturned beds in Perry Park, immediately west of the quadrangle, also suggest a possible westward inclination of the fault plane, so that this dislocation also may be of the reverse type.

The discovery of faults along the base of the Front Range in this region leads to a modification of the former interpretation of the structure. Instead of producing a simple monocline, as has been heretofore supposed, the uplift produced also a series of longitudinal faults, some lying between the sedimentary rocks and the pre-Cambrian complex, and others lying farther out in the foothills. The occurrence of these faults also necessitates the discarding of a former explanation of the relations of the beds in Perry Park involving marked unconformities and overlaps in the hypothetical "Castle Arch" and "Perry Park syncline."[1]

STRUCTURE OF THE PLAINS.

East of the disturbed foothill belt the dip of the strata decreases rapidly, so that within a few miles of the mountains the beds lie at low angles and over wide areas are practically horizontal. (See structure-section sheet.) They slope toward the axis of the Denver Basin, which lies 15 or 20 miles east of the Front Range, beyond which the strata gently rise to form the eastern limb of the syncline.

The detailed structure of this part of the plains in the Castle Rock quadrangle is not known because of the variability of the subaerially accumulated deposits that form the Dawson arkose, which occupies so large a portion of the area, and because of the absence of deep-well records to reveal the position of the underlying strata. The rhyolite in the upper part of the Dawson arkose and the base of the massive and persistent Castle Rock conglomerate, despite the fact that both the rhyolite and conglomerate were laid down on an uneven surface, are the best available guides to the structure of the plains region in the quadrangle. A general northward dip is illustrated by the difference in altitude of the rhyolite on Bald Mountain east of Palmer Lake (7,900 feet) and its altitude on the hills south of Douglass (6,900 feet), a difference of 1,000 feet in 11 miles. The northward dip along the east side of the quadrangle is shown by the base of the Castle Rock conglomerate, the altitude of which decreases 700 feet, from 7,500 to 6,800 feet within 8 miles.

The axis of the Denver Basin apparently crosses the northeast corner of the quadrangle in a curved line trending in general northwestward. Its northwestward pitch is indicated by the decrease in altitude of the base of the Castle Rock conglomerate from about 6,800 feet in the vicinity of Elbert to about 6,400 feet in the northwestern part of the quadrangle.

GEOLOGIC HISTORY.

PRE-CAMBRIAN TIME.

A long and varied record of sedimentation, metamorphism, igneous intrusion, diastrophism, and erosion is revealed by the pre-Cambrian complex of the Front Range. Presumably the Castle Rock region shared in this history, although there the greater part of the record is blank, for only the youngest pre-Cambrian formation—the Pikes Peak granite—crops out within the quadrangle. This granite, which is part of a great batholith, was in late Algonkian time intruded at some distance beneath the surface into pre-Cambrian rocks. It has not undergone dynamometamorphism, but the many joints by which it is traversed testify to the strains to which it has been subjected. After the intrusion the region was uplifted and eroded to such an extent that the deep-seated granite was laid bare.

PALEOZOIC ERA.

During Paleozoic time in general the Rocky Mountain region was submerged beneath the sea and was an area of deposition. The beds then laid down comprise several thousand feet of marine sediments, but the sedimentary record of the Paleozoic era in the region is not complete in any one area and a number of unconformities testify to uplifts and considerable breaks in the record.

Early Cambrian time is not represented by sediments in the Castle Rock region. The area was then doubtless a land mass composed of the uplifted pre-Cambrian rocks, which were reduced by long erosion to a peneplain, as indicated by the remarkably even floor on which the overlying sands were deposited. This peneplained surface was submerged probably in Upper Cambrian time, which witnessed the transgression of the sea and the deposition of the Sawatch sandstone. At first only pure white quartz sand, cleansed of impurities by attrition, accumulated, but subsequently sands not so well sorted, of various composition, were laid down, probably farther offshore.

The deposition of the Sawatch sandstone was followed, apparently conformably, by that of calcareous material relatively free from terrigenous débris, forming the Manitou limestone, of Lower Ordovician age In the Canon City region the Manitou limestone is succeeded by two other Ordovician formations, the Harding sandstone and the Fremont limestone, but their original extent is not known. Whether the absence of later Ordovician and of Silurian and Devonian strata in this area means nondeposition or their removal by erosion is undetermined. Here, as elsewhere in the Rocky Mountain region, a considerable thickness of early Paleozoic limestone may have been deposited, only a relatively small amount of which remains. A period of emergence and erosion preceded the deposition of the lowermost Carboniferous rocks, for in Perry Park the Sawatch sandstone is immediately overlain by the Mississippian Millsap limestone.

The accumulation of the Mississippian limestone, was followed by continental uplift and widespread erosion, shown by the overlap in the Front Range district of deposits of Pennsylvanian age on eroded surfaces of the older formations. These Pennsylvanian deposits are the red beds which outcrop so conspicuously in the foothills of the Front Range. They were laid down under various conditions, but their general composition and prevailingly red color give them unity. In large part they are composed of the waste of crystalline rocks of the Front Range. These rocks, presumably were reduced to a residual red soil, although some of the red color no doubt is due to dehydration of disseminated ferric hydrate, a change that occurred after the deposition and burial of the sediments. The coarse grits of the Fountain formation apparently accumulated in large part under subaerial conditions, although fossils from calcareous beds in the Colorado Springs quadrangle indicate local incursions of the sea. The overlying fine-grained, more homogeneous Lyons sandstone, composed chiefly of pure quartzose sand, indicates a better sorting of the sediments. The general absence of the red coloring material in the upper part of the Lyons may be accounted for by offshore attrition of the particles of sand, which removed the pigment and washed it away. Later Carboniferous time is recorded by the Lykins formation, which accumulated under conditions permitting the alternate deposition of sandstone, shale, and thin beds of marine limestone. Finally the waters became landlocked and the climate more arid, and the close of the Paleozoic era is marked by the deposition of gypsum.

MESOZOIC ERA.

During the early part of the Mesozoic era there was apparently a considerable land area in the Colorado Front Range region. In the Castle Rock quadrangle, so far as known, Triassic and Jurassic time was not recorded by sediments, unless the Morrison formation belongs to the Jurassic period. Fossils of supposed Triassic age have been reported in southeastern Colorado, and marine Jurassic beds are of widespread occurrence in Wyoming and extend southward into Colorado, but whether beds that were formed in either of those periods were deposited in the quadrangle and subsequently removed is not known.

The variegated beds constituting the Morrison formation are of subaerial and lacustrine origin. Although this formation is thin, generally less than 300 feet thick, it is of widespread distribution, indicating a prevalence of similar conditions of deposition over a large area. Immense reptiles thrived in this region during the deposition of the Morrison formation, which is notable for the remarkable saurian forms entombed in it. The land in which these animals lived was then submerged by the northward advance of the Lower Cretaceous sea, in which the Purgatoire formation was laid down. This advance of the sea is marked by the change from the variegated Morrison deposits to the overlying white quartzose sand and drab clay shale of the Purgatoire formation, in which marine shells occur.

Upper Cretaceous time was characterized by the presence during most of that epoch of a great interior sea, extending between the present Great Basin and Mississippi Valley and connecting the Gulf of Mexico with the Arctic Ocean, in which many thousand feet of conformable strata were deposited. The Dakota sandstone, the basal Upper Cretaceous formation, is succeeded by a thick series of marine sediments of widespread uniformity, constituting the Colorado and Montana groups. These groups include several thousand feet of fine-grained deposits, which maintain their individuality over many thousand square miles and emphasize the similarity of the conditions that prevailed in a great area during the Upper Cretaceous submergence. The withdrawal of the later Cretaceous sea began with the accumulation of the Fox Hills sandstone toward the close of Montana time and finally the coal-bearing Laramie formation was deposited in brackish and fresh water.

[1] Lee, W. T., Geology of the Castle Rock region: Am. Geologist, vol 29, pp. 96–109, 1902.

CENOZOIC ERA.

TERTIARY PERIOD.

Eocene epoch. — Uplift of the Front Range region and accompanying erosion, after the deposition of the Laramie beds, marked the close of the Mesozoic and the beginning of the Cenozoic era. A great thickness of Cretaceous and older rocks was eroded from the Front Range region and a mass of continental deposits accumulated on an uneven surface of the Laramie and older formations east of the mountains. The Dawson arkose, derived from the Pikes Peak granite and associated rocks, was laid down under various continental conditions, chiefly as wash and fluviatile deposits accompanied by local ponding. During the accumulation of the arkose this region may be conceived of as a piedmont area having a moist and temperate climate, an area in which the vegetation was characterized by the presence of many fig trees, palms, magnolias, poplars, willows, oaks, maples, etc., and which was occupied by Triceratops (huge three-horned dinosaurs), crocodiles, turtles, and other reptiles and by primitive mammals. An outburst of volcanic activity toward the close of the period of accumulation of the Dawson arkose is shown by the local deposits of tuff and rhyolitic lava.

Oligocene and later Tertiary epochs.—After the Dawson arkose was laid down there was further uplift and renewed erosion, resulting, finally, in the deposition of the Castle Rock conglomerate, of Oligocene age. This formation, which is composed of débris of the Pikes Peak granite and associated rocks of the Front Range, including reworked Dawson arkose with angular fragments of rhyolite in the basal conglomerate, is apparently composed of wash and fluviatile material. It represents the coarse-grained Piedmont phase of the usually fine-grained Oligocene deposits laid down farther east on the plains. The region was occupied by huge rhinoceros-like herbivorous mammals (Titanotheridæ), remains of which are found in the conglomerate.

Later Tertiary events are not recorded by sediments within the quadrangle, but there is abundant evidence of prolonged erosion of the Front Range region, which was reduced to a rolling plain. This period of relative freedom from diastrophism was succeeded by uplift, which culminated in the mountain zone rising above the plains. The uplifted peneplain is recognizable in the general even surface of the mountain top as shown in Plate II. Subsequent to the uplift erosion proceeded with renewed energy, and a great quantity of sedimentary rocks from the eastern slopes and the plains was removed while canyons were being cut in the more resistant granite. Differential uplift and erosion resulted in the mountains standing out in bold relief against the plains.

QUATERNARY PERIOD.

During the Pleistocene epoch glaciers of the alpine type occupied the higher portions of the Front Range. In the Pikes Peak district, for instance, a few miles southwest of the Castle Rock quadrangle there are cirques, moraines, and other evidences of the former presence of glaciers. But such phenomena do not occur below an altitude of about 9,500 feet, and no indication has been found that glaciers occupied the Castle Rock quadrangle. In this area during Pleistocene time wash deposits were laid down along the base of the Front Range and alluvium accumulated in the river valleys. In Recent times these Pleistocene deposits have been dissected into a series of disconnected terraces, and the sculpturing of the hills and valleys has been continued and has finally produced the present aspect of the country. As the result of long-continued erosion the surface forms are adjusted to the character and structure of the underlying rocks, as has been stated in the description of topography (p. 2).

ECONOMIC GEOLOGY.

RESOURCES AVAILABLE.

The mineral resources of the quadrangle include building stone, limestone, gypsum, sand, clay, gravel, probably coal, some gold, and underground water. These substances are of so widespread occurrence along the foothills of the Front Range, except of course the gold, that proximity to market rather than the existence of the material is the controlling factor in production. Most of the mineral resources in the vicinity of Denver, Colorado Springs, and Pueblo are available for use in the Castle Rock quadrangle, but the present demand is not sufficient to warrant their exploitation. The rhyolite, which is quarried for use as building stone in the vicinity of Castle Rock, however, is limited in occurrence to this area.

BUILDING STONE.

The formations that are particularly suitable for use as building stones are the rhyolite in the upper part of the Dawson arkose, the Lyons sandstone, and the Pikes Peak granite. Other though less important building stones are available in selected sandstones from the Sawatch, Fountain, Lykins, Purgatoire, Dakota, and Laramie formations.

Rhyolite.—The rhyolite is said to have been first quarried about 1876 and since then it is reported that some 30,000 carloads have been marketed. The stone has been extensively used for building in Denver, Colorado Springs, and Pueblo, where it has given general satisfaction. The quarries, to which railroad spurs have been constructed, are near the town of Castle Rock. Prospecting, however, has been extended to most of the outcrops, the occurrence of which is shown on the geologic map.

The stone is readily accessible, is easily worked, is of pleasing gray to pinkish color, stands the weather well, and is sufficiently strong for ordinary purposes, although the more porous varieties are not adapted for use where great strength is desired. In recent years the production of this stone has fallen off because of the competition of other building materials.

Lyons sandstone.—The Lyons sandstone is much used as building stone in the cities along the eastern base of the Rocky Mountains. Its popularity is due to its pleasing colors, ranging from various shades of red, brown, and cream to whitish, and to its uniform and fine-grained texture. It is easily worked and is quarried at a number of places along the outcrop but not yet in the Castle Rock quadrangle.

Pikes Peak granite.—The Pikes Peak granite is available in enormous quantity when demand arises for its use. A large slab in front of the old hotel in Perry Park shows the excellent quality of the rock. This granite has been quarried in Platte Canyon, but no attempts have yet been made to utilize it in the quadrangle.

LIMESTONE.

Large quantities of limestone are available in the foothill region for the manufacture of lime and cement. The Manitou and Millsap limestones are magnesian and are suitable for making fertilizer and some wall plaster; nonmagnesian limestone suitable for making cement or wall plaster occurs in the Lykins and Morrison formations and in the Colorado and Montana groups.

GYPSUM.

Gypsum of variable thickness, in places measuring 40 feet, occurs at the top of the Lykins formation and is available for use as plaster and fertilizer. Much of the gypsum is pure and white and of high grade. It has not yet been utilized.

GRAVEL, SAND, AND CLAY.

Enormous quantities of sand and gravel of varied composition occur in the Dawson arkose. Good grades of rather pure quartz sand can be obtained from sandstone in the Purgatoire formation and from the Lyons and Dakota sandstones. There are also inexhaustible supplies of clay in the shale of the Colorado and Montana groups and in the Purgatoire formation. High-grade fire clay occurs in the Dawson arkose at Calhan, a few miles southeast of the quadrangle, and deposits may be found in the area here considered.

COAL.

Coal has not yet been found in the quadrangle, although it probably occurs there, because the Laramie formation carries the coal beds that have long been mined near Denver and Colorado Springs.

Wherever the Laramie formation has been systematically exploited in the Denver Basin coal has been found, but the beds are irregular and are not everywhere of workable thickness. Two general coal zones are reported in the Laramie of this region, one in the lower 200 feet of the formation, which is prevailingly sandy, and the other near the top of the formation, some 1,200 or more feet above its base, where shale predominates. The lower zone carries the coal beds that are mined in the vicinity of Denver and Colorado Springs. The beds at Scranton, 20 miles east of Denver, are in the upper zone, according to Eldridge, and the coal which crops out in the valley of West Bijou Creek, east of the Castle Rock quadrangle, appears to be approximately at the same horizon, although the age and correlation of these beds has not yet been determined.

The Denver and Colorado Springs coal fields have been described in detail by Eldridge, Martin, and Goldman in reports of the United States Geological Survey. (See bibliography on p. 2.) Only the lower zone occurs in those areas, where, in general, there are from one to three lenticular beds of coal showing a maximum thickness of 14 feet, but averaging, where they have been developed, perhaps 4 or 5 feet. As they conform with the general structure of the region the coal beds are highly inclined near the base of the mountains, but their dip decreases eastward, and under a large part of the basin they are either gently inclined or practically level. The coal is a fairly good subbituminous variety, formerly called black lignite, which successfully competes with better grades because of the proximity of good markets.

The upper coal zone is not so widely distributed. The coals of the upper beds contain more ash and moisture than those of the lower beds and are distinctly of lower grade.

In the Castle Rock quadrangle the Laramie crops out about midway between the exposures of the formation in the Denver and Colorado Springs areas, the connection being concealed by a cover of younger deposits. The outcrop occupies a narrow curved belt about 9 miles long in the central western part of the area, and the entire quadrangle, except the southwest corner, where older rocks occur, is underlain by the Laramie formation. If coal is not found after systematic prospecting along the outcrop of the formation its absence at the surface may be due to the fault which extends along the east side of Perry Park (see p. 10), in which event the lower coal zone should be encountered in drilling. In the greater part of the quadrangle, however, that zone lies at a considerable depth beneath the surface, and in the central highland belt, where the Castle Rock conglomerate and the upper part of the Dawson arkose are present, the lower coal zone lies below the workable limit for subbituminous coals, which is now considered to be 2,000 feet. In places, particularly in the northeastern part of the quadrangle, the upper coal zone may be present beneath the cover of younger rocks but if so can be determined only by drilling.

GOLD.

One of the early finds of gold in Colorado was made in 1858 in Russellville Gulch, about 5 miles southeast of Franktown[1] and ever since then there has been desultory prospecting for placer gold in that vicinity. The chief localities explored, besides Russellville Gulch, are Ronk Gulch and Gold Run, a few miles southwest of Elizabeth, and Newlin Gulch, 7 miles northeast of Sedalia. Recently there has been renewed activity on Newlin Gulch, in and adjacent to sec. 36, T. 6 S., R. 67 W., where several drifts have been driven into the alluvial deposits bordering the gulch. No considerable amount of gold has been found, but the fact of its actual presence has served to maintain sporadic interest in the occurrence.

The gold had its source in the mountains and was carried to the quadrangle with the associated sediments by streams, becoming finer and finer grained by transport. The gulches where gold has been found are cut in the Dawson arkose, but the divides are capped by the Castle Rock conglomerate. With which of these formations the gold originally was laid down is not known. In view of the more vigorous stream action that accompanied the deposition of the conglomerate it seems probable that the gold was derived from it and later accumulated in alluvial deposits in the present valleys. Undoubtedly it has been deposited, eroded, and redeposited a number of times.

The product is reported to be in general very fine, practically flour gold, and this fact, taken in connection with the difficulty of obtaining water economically and in sufficient quantity for work on a large scale, has so far caused the deposit to have little commercial importance. Several attempts in which large sums of money are said to have been spent resulted in failures. But on the other hand the gold has afforded a poor living to some persons at times when more profitable employment was lacking. The value of these deposits can not be determined until the area is systematically prospected.

WATER.

The Castle Rock quadrangle is in the semiarid region. The mean annual rainfall at Colorado Springs is 14.3 inches and at Denver 13.7 inches. On the Platte-Arkansas divide, in the southern part of the quadrangle, and in the mountains, the precipitation is somewhat greater, but statistics are not available.

Surface water supply.—There are no large streams in the quadrangle and most of the drainageways are dry during the greater part of the year, although the principal creeks carry a small perennial flow. At a few favorable places storm waters are impounded in reservoirs. Thus near the head of Monument Creek in the mountains west of Palmer Lake water is stored in two reservoirs, and others are located at Palmer Lake and at Monument. The lake in Perry Park collects the water of Bear Creek, which is used for stock. The largest reservoir in the quadrangle is formed by Castlewood dam, at the head of the gorge 3½ miles south of Franktown, where the water of Cherry Creek, is impounded. (See Pl. VI.) This water might be used for irrigating the broad lowland in the vicinity of Franktown, but instead it is transported in the Arapahoe canal about 25 miles northward to irrigate land in a suburb of Denver.

In the greater part of the quadrangle the supply of surface water is so meager that only small tracts can be successfully irrigated. Ground water lies near the surface in the bottom lands along the drainageways, however, and most of these are consequently very fertile. The rainfall usually is sufficient for dry farming on the uplands and is so well distributed through the growing season that good crops are common.

A conspicuous group of springs occurs in Cherry Creek valley north of Franktown, at the north end of the quadrangle. They are situated at the contact of coarse-grained sandstone and of underlying more compact clayey material of the andesitic member of the Dawson arkose and extend for a distance of about 3 miles. A spring in the flood plain of Cherry Creek

[1] Hall, Frank, History of Colorado, vol. 3, p. 333, 1891.

in the SE. ¼ sec. 3, T. 7 S., R. 66 W., is reported to flow 125 gallons a minute.

Underground water supply.—The underground water supply of the quadrangle is obtained from consolidated rocks and from unconsolidated deposits chiefly in the flood plains of creeks.

In a large part of the quadrangle the older formations lie at a great depth beneath the surface and the consolidated rocks available for water supply are chiefly certain beds in the Dawson arkose. The eastward dip of the strata causes the water to be under pressure, but the altitudes in practically all the region are so great as to preclude surface flow. Only in a small area in the valley of Plum Creek below Sedalia are flowing wells obtained.

At the Du Pont Powder Works at Louviers, 3 miles below Sedalia, just beyond the boundary of the quadrangle, there is a flowing well 680 feet deep. In this well a number of water-bearing beds were encountered at depths between 85 and 652 feet beneath the surface, the well yielding in August, 1911, a total flow of 178 gallons a minute through a 6-inch pipe. This is the southernmost flowing well of the Denver artesian area.

At Sedalia and Castle Rock several deep wells have been sunk without obtaining flows, although the water is reported to have risen within 60 or 70 feet of the surface.

On the central highland belt between Castle Rock and Elizabeth a few wells have been sunk to a depth of 150 feet, only to obtain a small yield, and a number of dry holes have been dug at various localities.

The main water supply of the quadrangle is obtained from shallow wells sunk in the unconsolidated flood-plain deposits of the creeks. From this source most of the towns and outlying farms get their supplies. The town of Castle Rock, for instance, obtains its water by pumping from underground galleries and from shallow wells sunk in the flood plain of Plum Creek.

December, 1913.

Correlation and diversity in classification and nomenclature of the rocks of the Colorado Front Range region as given in various publications.

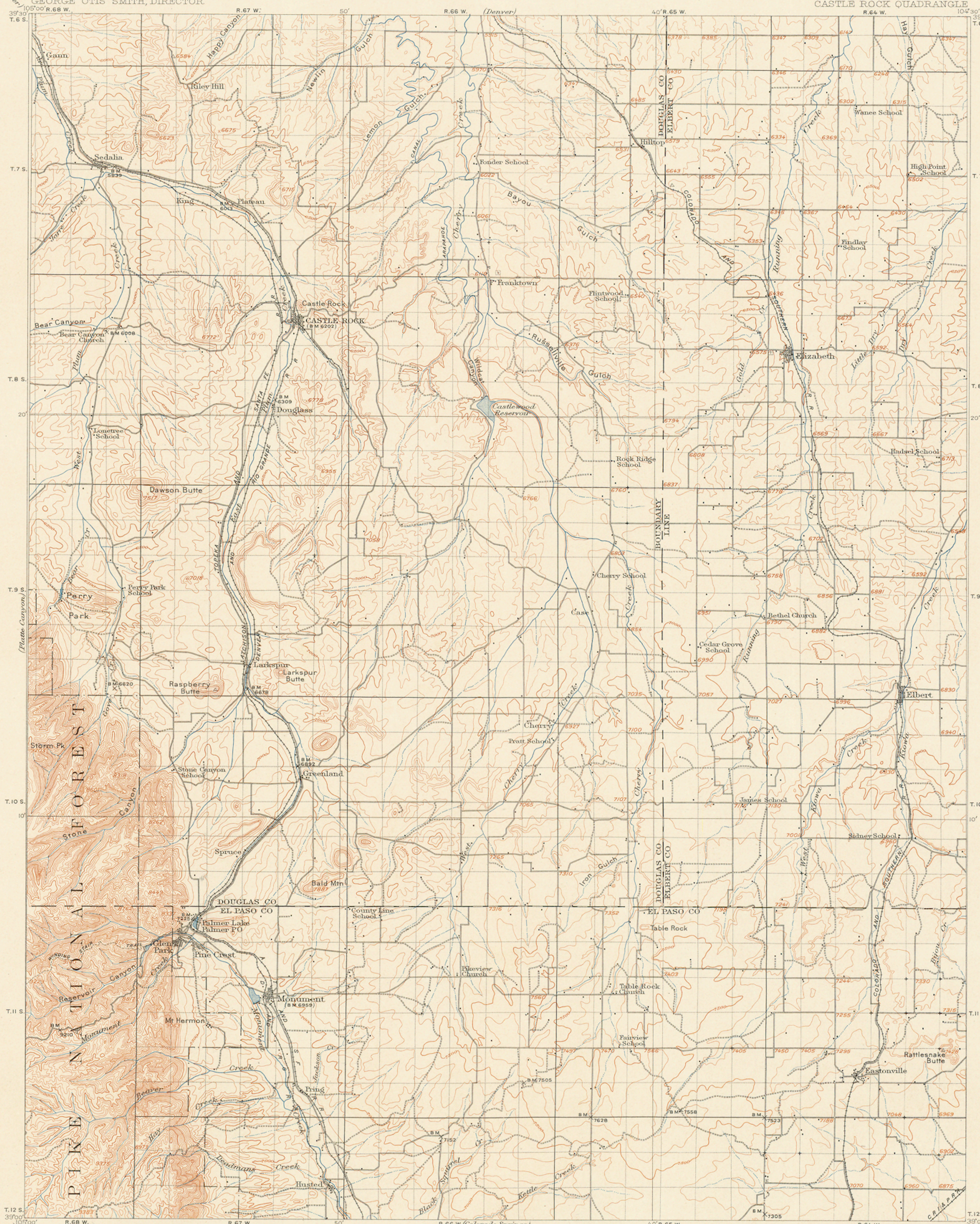
System.	Series.	Richardson (1915).[a]	Stose (1912).[b]	Henderson (1909).[c]	Darton (1905).[d]	Fenneman (1905).[e]	Gilbert (1897).[f]	Emmons, Cross, and Eldridge (1896).[g]	Cross (1894).[h]	Hayden Survey (1869-1876).
Tertiary.	Oligocene.	Castle Rock conglomerate.						Monument Creek formation (Neocene). ["Monument Creek formation" as revealed by recent studies in the Denver Basin.]		Monument Creek group (Miocene).
	Eocene.	Dawson arkose.			Denver formation (Tertiary).			Denver formation (Cretaceous).		Lignitic group: Laramie formation.
					Arapahoe formation (Tertiary).			Arapahoe formation (Cretaceous).		
Cretaceous.	Upper Cretaceous.	Laramie formation.		Laramie formation.	Laramie formation.	Laramie formation.		Laramie formation.		Laramie.
		Montana group: Fox Hills sandstone and Pierre shale.		Montana group: Fox Hills formation.	Fox Hills formation.	Fox Hills formation.		Montana group: Fox Hills formation.	Montana formation.	Fox Hills.
				Pierre formation.	Pierre shale.	Pierre formation.	Pierre shale.	Pierre formation.		Fort Pierre.
		Colorado group: Niobrara and Benton formations.	Niobrara group: Apishapa shale.	Colorado group: Niobrara formation.	Niobrara formation.	Niobrara formation.	Niobrara formation.	Colorado group: Niobrara formation.	Colorado formation.	Niobrara.
			Timpas limestone.							
			Benton group: Carlile shale.	Benton formation.	Benton group: Carlile shale.	Benton formation.	Benton group: Carlile shale.	Benton formation.		Fort Benton.
			Greenhorn limestone.		Greenhorn limestone.		Greenhorn limestone.			
			Graneros shale.		Graneros shale.		Graneros shale.			
		Dakota sandstone.	Dakota sandstone.	"Dakota?" formation (probably in part Comanche).	"Dakota" sandstone (probably includes some Lower Cretaceous).	Dakota formation.	Dakota sandstone.	Dakota formation.	Dakota formation.	Dakota.
	Lower Cretaceous.	Purgatoire formation.	Purgatoire formation.							
Cretaceous or Jurassic.	Lower Cretaceous or Upper Jurassic.	Morrison formation.	Morrison formation.	Morrison formation (Upper Jurassic or Lower Cretaceous).	Morrison formation (Lower Cretaceous).	Morrison formation (Jurassic).	Morrison formation (Juratrias).	Morrison formation (Juratrias).	Morrison formation (Juratrias).	Jurassic.
Jurassic.	Upper Jurassic.			Sundance marine beds.						
Carboniferous.	Permian (?).	Lykins formation.		Lykins formation (upper part Triassic?).	Upper Wyoming formation (Chugwater) (Triassic? or Permian).	(Triassic?): Lykins formation.		Wyoming formation (Juratrias).		Red Beds (Triassic).
	Pennsylvanian.	Lyons sandstone.		Lyons formation.	Lower Wyoming formation (Fountain). (Pennsylvanian).	Lyons sandstone.				
		Fountain formation.		Fountain formation.		Fountain sandstone.	Fountain formation (Juratrias?).[i]		Fountain formation (Carboniferous and Juratriassic?).[j]	
	Mississippian.	Millsap limestone.		Mississippian.	Millsap limestone.		Millsap limestone.		Millsap limestone.	
Ordovician.					Fremont limestone.				Fremont limestone.	
					Harding sandstone.		Harding sandstone.		Harding sandstone.	
	Lower Ordovician.	Manitou limestone.			Manitou limestone.				Manitou limestone.	
Cambrian.	Upper Cambrian.	Sawatch sandstone.			Reddish sandstone.					
Pre-Cambrian.		Pikes Peak granite.		Algonkian.		Algonkian quartzite.	Archean schist and granite.	Archean gneiss, granite, and schist.	Algonkian quartzite, granite, including Pikes Peak granite, and gneiss.	
				Archean.		Archean granite and gneiss.				

[a] Richardson, G. B., U. S. Geol. Survey Geol. Atlas, Castle Rock folio (No. 198), 1915.
[b] Stose, G. W., U. S. Geol. Survey Geol. Atlas, Apishapa folio (No. 186), 1912.
[c] Henderson, Junius, The foothills formations of north-central Colorado: Colorado Geol. Survey First Rept., pp. 145–188, 1909.
[d] Darton, N. H., Preliminary report on the geology and underground water resources of the central Great Plains: U. S. Geol. Survey Prof. Paper 32, 1905.
[e] Fenneman, N. M., Geology of the Boulder district, Colorado: U. S. Geol. Survey Bull. 265, 1905.
[f] Gilbert, G. K., U. S. Geol. Survey Geol. Atlas, Pueblo folio (No. 36), 1897.
[g] Emmons, S. F., Cross, Whitman, and Eldridge, G. H., Geology of the Denver Basin in Colorado: U. S. Geol. Survey Mon. 27, 1896.
[h] Cross, Whitman, U. S. Geol. Survey Geol. Atlas, Pikes Peak folio (No. 7), 1894.
[i] May include Lyons sandstone and Lykins formation.
[j] As mapped in southeastern part of quadrangle it included Lyons sandstone and Lykins formation.

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

TOPOGRAPHY

COLORADO
CASTLE ROCK QUADRANGLE



LEGEND

RELIEF
printed in brown

Altitude
above mean sea level instrumentally determined at point indicated

Contours
showing height above sea, horizontal form, and steepness of slope of the surface

DRAINAGE
printed in blue

Streams

Intermittent streams

Canal or ditch

Lake or reservoir

CULTURE
printed in black

Roads and buildings

Church and cemetery

Public school

Private or secondary roads

Trail

Railroad

U.S. township and section lines

Located section corner

County line

Reservation line

Triangulation station

Bench mark giving precise altitude

R.B.Marshall, Chief Geographer.
Sledge Tatum, Geographer in charge.
Topography by C.G.Anderson and Geo.W Lucas.
Control by Coast and Geodetic Survey, H.L.Baldwin, and C.I.Anderson.
Surveyed in 1911.

APPROXIMATE MEAN DECLINATION 1911.

Scale $\frac{1}{125000}$

Contour interval 100 feet.
Datum is mean sea level.

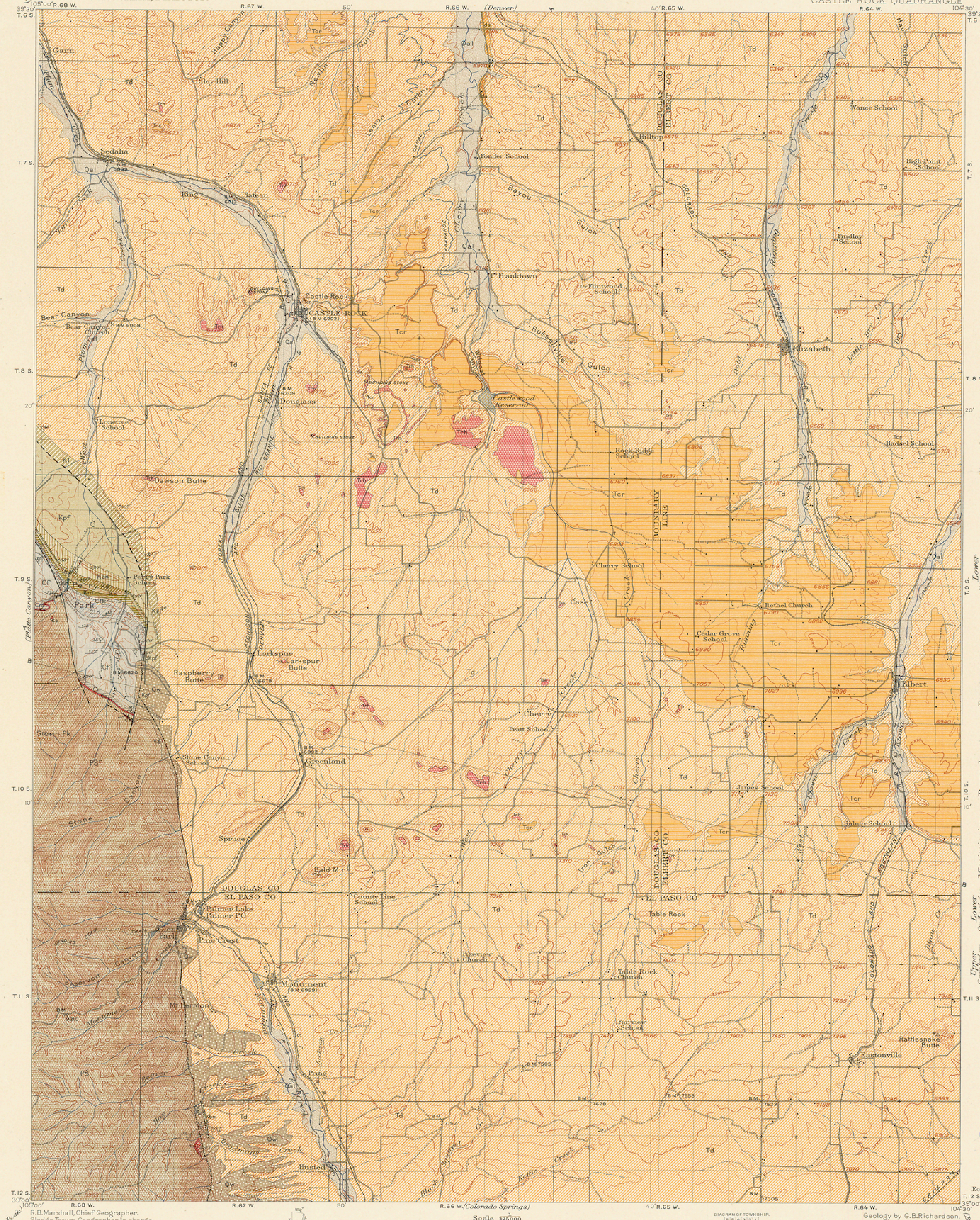
DIAGRAM OF TOWNSHIP.

Edition of Feb. 1913, reprinted April 1914.

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

AREAL GEOLOGY

COLORADO
CASTLE ROCK QUADRANGLE



R.B.Marshall, Chief Geographer.
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Control by Coast and Geodetic Survey, H.L.Baldwin, and C.I.Anderson.
Surveyed in 1911.

APPROXIMATE MEAN DECLINATION 1911.

Scale $\frac{1}{125000}$

Contour interval 100 feet.
Datum is mean sea level.
Edition of Oct. 1914.

Geology by G.B.Richardson, assisted by C.W.Cooke.
Surveyed in 1910 and 1911.

LEGEND

CHIEFLY SEDIMENTARY ROCKS

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

QUATERNARY

- Qal — Stream alluvium *(gravel, sand, and silt in valley bottoms, only the larger deposits shown)*
- Qw — Wash *(sand and gravel washed from the uplands)*

UNCONFORMITY

TERTIARY

Oligocene
- Tcr — Castle Rock conglomerate *(indurated conglomerate and sandstone)*

UNCONFORMITY

Eocene
- Trh — Rhyolite lava and tuff *(interbedded in upper part of Dawson arkose)*
- Td, Tda — Dawson arkose *(varicolored arkosic conglomerate, sandstone, and shale; andesitic sandstone, Tda, interbedded in places)*

UNCONFORMITY

CRETACEOUS

Upper Cretaceous
- Kl — Laramie formation *(sandstone and shale, possibly coal bearing)*
- *Montana group*: Kpf — Pierre shale and Fox Hills sandstone *(dark-gray shale and sandstone)*
- *Colorado group*: Kbn — Benton and Niobrara formations *(shale, limestone, and some sandstone)*
- Kd — Dakota sandstone *(fine-grained quartzose sandstone)*

Lower Cretaceous
- Kp — Purgatoire formation *(light-buff sandstone and dark-gray shale)*

UNCONFORMITY ?

JURASSIC OR CRETACEOUS
- Km — Morrison formation *(varicolored sandstone, shale, and limestone)*

UNCONFORMITY

CARBONIFEROUS

Permian ?
- Clk — Lykins formation *(varicolored sandstone and shale, with some limestone and gypsum)*

Pennsylvanian
- Clo — Lyons sandstone *(fine-grained red and white quartzose sandstone)*
- Cf — Fountain formation *(red arkosic sandstone and conglomerate, in places white)*

UNCONFORMITY

Mississippian
- Cm — Millsap limestone *(thin-bedded gray to purplish limestone with chert nodules)*

UNCONFORMITY

ORDOVICIAN

Lower Ordovician
- Om — Manitou limestone *(reddish and gray magnesian limestone)*

CAMBRIAN

Upper Cambrian
- €s — Sawatch sandstone *(white and red quartzose sandstone, in part calcareous and glauconitic)*

IGNEOUS ROCKS

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

PRE-CAMBRIAN
- pgr — Pikes Peak granite *(batholith of coarsely granular biotite granite)*

Faults

Concealed faults *(covered by younger deposits)*

Strike and dip of stratified rocks
Strike of vertical strata

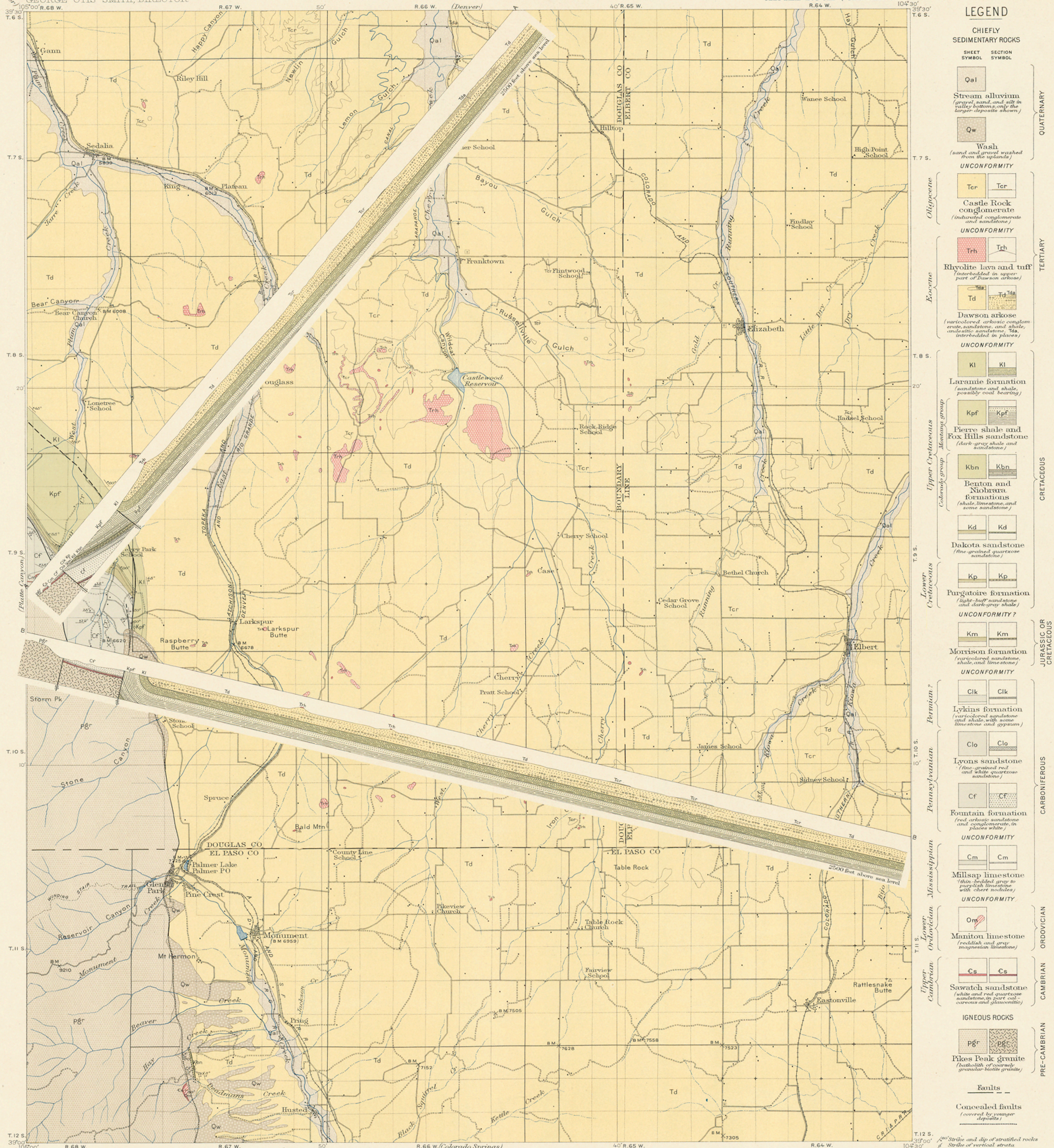
Quarries, *building stone*

Economic data: *Building stone can be obtained from rhyolite in Dawson arkose, from Pikes Peak granite, Lyons and Dakota sandstones, and Purgatoire formation; limestone for lime and cement from Manitou and Millsap limestones, and Lykins, Morrison, and Niobrara formations; gypsum from the upper part of the Lykins formation; sand and gravel from Dawson arkose; clay for brick from Dawson arkose, Colorado and Montana groups, and Purgatoire formation. Coal may be present in the Laramie formation. Gold in small quantity has been found in tributaries of Cherry and Running Creeks. Underground water may be obtained at moderate depth in the flood plains of the larger streams.*

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

STRUCTURE SECTIONS

COLORADO
CASTLE ROCK QUADRANGLE



R.B.Marshall, Chief Geographer.
Sledge Tatum, Geographer in charge.
Topography by G.G.Anderson and Geo.W.Lucas.
Control by Coast and Geodetic Survey, H.L.Baldwin, and G.I.Anderson.
Surveyed in 1911.

Scale 1/125000

Miles

Kilometers

APPROXIMATE MEAN DECLINATION 1911.

DIAGRAM OF TOWNSHIP

Edition of Dec. 1914.

Geology by G.B.Richardson, assisted by C.W.Cooke.
Surveyed in 1910 and 1911.

COLUMNAR SECTION

GENERALIZED SECTION OF THE ROCKS OF THE CASTLE ROCK QUADRANGLE.

SCALE: 1 INCH=1,000 FEET.

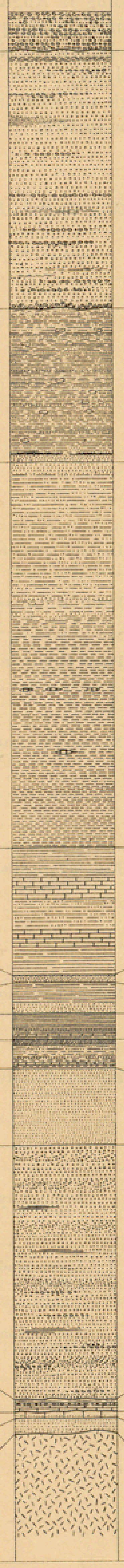
System.	Series.	Formation.	Symbol.	Columnar Section.	Thickness, in Feet.	Character of Rocks and Topography.
TERTIARY	OLIGOCENE	Castle Rock conglomerate.	Tcr		300	Light-colored arkosic conglomerate and conglomeratic sandstone; fragments of rhyolite at base. Caps mesas in the plains.
		UNCONFORMITY				
	EOCENE	Rhyolite lava and tuff.	(Trh)			
		Andesitic sandstone member.	(Tda)			
		Dawson arkose.	Td		2,000±	Chiefly coarse varicolored arkosic grits with lenses of conglomerate and shale throughout formation. Conglomerate at base contains pebbles derived from the rocks of the foothills and of the Front Range. Rhyolite lava and tuff interbedded near the top. A thin bed of andesitic sandstone in upper part expands northwestward and becomes the Denver formation. Occupies most of the surface of the plains in the quadrangle; buttes capped by rhyolite lava.
		UNCONFORMITY				
CRETACEOUS	UPPER CRETACEOUS	Laramie formation.	Kl		1,200±	Drab shale with small nodules of clay ironstone and beds of white and brown fine-grained sandstone and possibly workable beds of coal. Narrow belt near western border of the plains.
	UPPER CRETACEOUS — MONTANA GROUP	Fox Hills sandstone and Pierre shale.	Kpf		3,000±	Upper part sandy shale and sandstone, representing the Fox Hills sandstone. Lower part clay shale and a few thin beds of limestone, representing the Pierre shale. Not separately mapped because of poor exposures. Lowland northeast of hogback ridges.
	UPPER CRETACEOUS — COLORADO GROUP	Niobrara and Benton formations.	Kbn		1,000±	Shale and two limestones. The upper limestone and shale comprise the Niobrara formation; the lower shale and interbedded limestone comprise the Benton formation. Not separately mapped because of poor exposures. Forms low hogback ridges.
	UPPER CRETACEOUS	Dakota sandstone.	Kd		60	Indurated fine-grained quartzose sandstone. Forms a prominent hogback ridge.
	LOWER CRETACEOUS	Purgatoire formation.	Kp		240	Lower part gray sandstone, upper part shale, chiefly black. Occupies inner flanks of Dakota hogback ridge.
		UNCONFORMITY?				
CRETACEOUS OR JURASSIC		Morrison formation.	Km		200	Varicolored shale, sandstone, and limestone. Forms valleys and low ridges.
		UNCONFORMITY				
CARBONIFEROUS	PERMIAN?	Lykins formation.	Clk		225	Brilliantly colored (chiefly red) sandy and clay shale and thin beds of gray limestone and white sandstone. Massive gypsum at the top. Forms low hills and valleys.
	PENNSYLVANIAN	Lyons sandstone.	Clo		600	Fine-grained quartzose sandstone; lower part brick-red, upper part usually white. Forms wall-like ridges and ledges.
	PENNSYLVANIAN	Fountain formation.	Cf		2,000±	Varicolored (chiefly red) coarse-grained cross-bedded arkosic sandstone, some shale, and lenses of conglomerate. Low hills and ridges at the base of the mountains.
		UNCONFORMITY				
	MISSISSIPPIAN	Millsap limestone.	Cm		0-85	Gray to purplish limestone with nodules of chert. Forms outer slopes of hogback ridges.
		UNCONFORMITY				
ORDOVICIAN	LOWER ORD.	Manitou limestone.	Om		0-50+	Gray magnesian and arenaceous limestone. Forms outer slope of hogback ridge.
CAMBRIAN	UPPER CAMB.	Sawatch sandstone.	Ꞓs		115	Fine-textured white quartzose sandstone overlain by calcareous glauconitic sandstone. Forms low hogback ridges.
		UNCONFORMITY				
PRE-CAMBRIAN		Pikes Peak granite.	pgr			Massive, coarse-textured biotite granite. Forms Front Range.

PLATE I.—THE FRONT RANGE FROM HILL EAST OF PALMER LAKE.
The mountains are composed of Pikes Peak granite; the slopes along their base are covered with Quaternary wash. Cliffs of nearly horizontal Dawson arkose in foreground; Palmer Lake at extreme right; Mount Hermon in left center. Photograph by Denver & Rio Grande Railroad Co.

PLATE II.—PENEPLAIN ON TOP OF THE FRONT RANGE AT AN ELEVATION OF ABOUT 9,000 FEET.
View northward along the range west of Mount Hermon. Peneplain is cut on Pikes Peak granite.

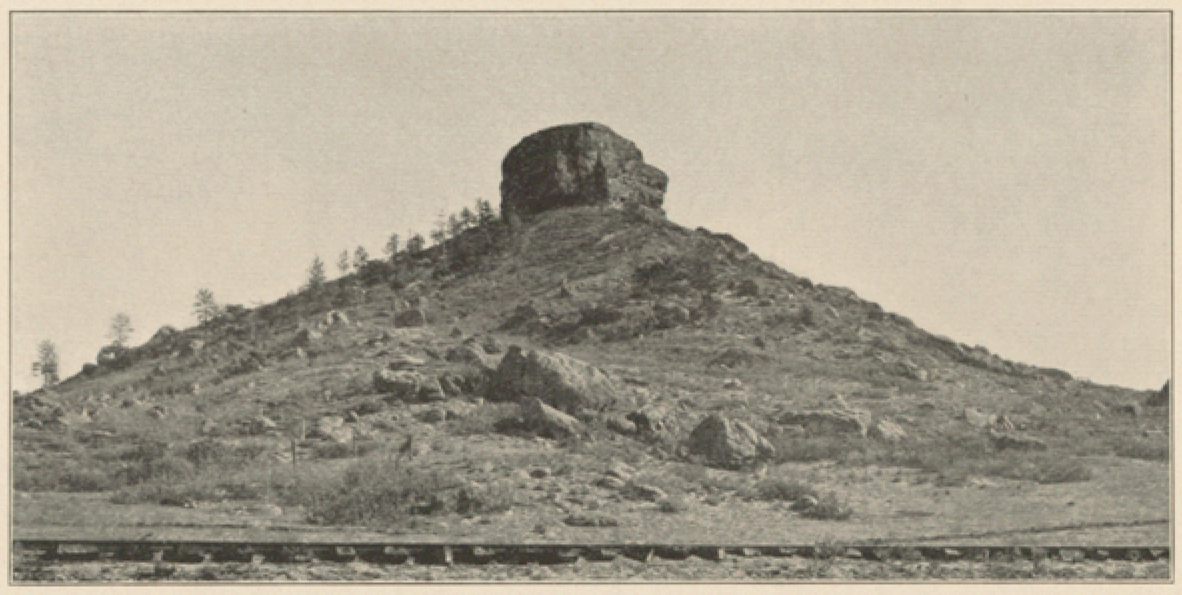


PLATE III.—CASTLE ROCK, A BUTTE CAPPED BY CASTLE ROCK CONGLOMERATE.
Looking east.

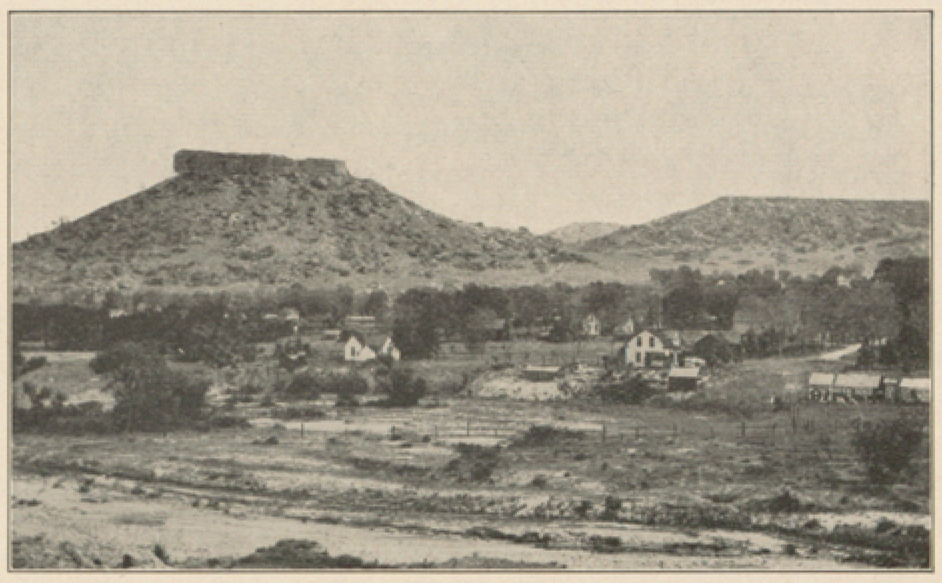


PLATE IV.—CASTLE ROCK AND MESA IN DISTANCE, BOTH CAPPED BY CASTLE ROCK CONGLOMERATE.
Looking north.

PLATE V.—UNCONFORMITY AT BASE OF CASTLE ROCK CONGLOMERATE AT CONTACT WITH DAWSON ARKOSE IN CLIFFS OF CASTLE ROCK.
Shows uneven surface of contact and bowlders of rhyolite in basal conglomerate.

PLATE VI.—CASTLEWOOD RESERVOIR AND MESA TO THE EAST CAPPED BY CASTLE ROCK CONGLOMERATE.
Unconformable contact of Dawson arkose and overlying Castle Rock conglomerate occurs in cliffs at left.

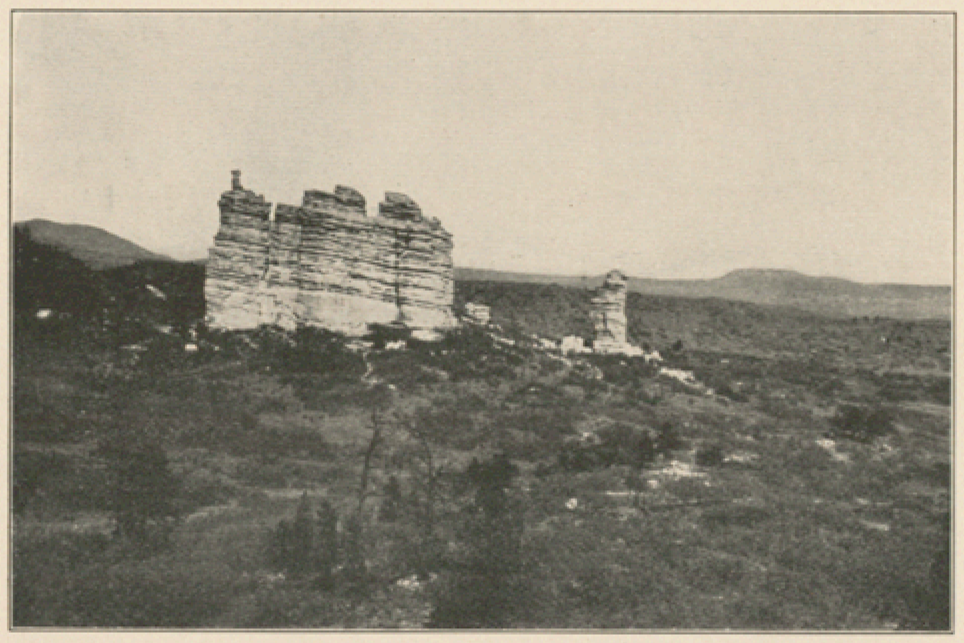


PLATE VII.—CASTLE-LIKE EROSION REMNANT OF DAWSON ARKOSE, JUST NORTH OF DEADMANS CREEK.
Looking northward along Quaternary wash-covered slope at foot of Front Range.

PLATE VIII.—"MONUMENT" OF DAWSON ARKOSE, 2 MILES WEST OF THE TOWN OF MONUMENT.

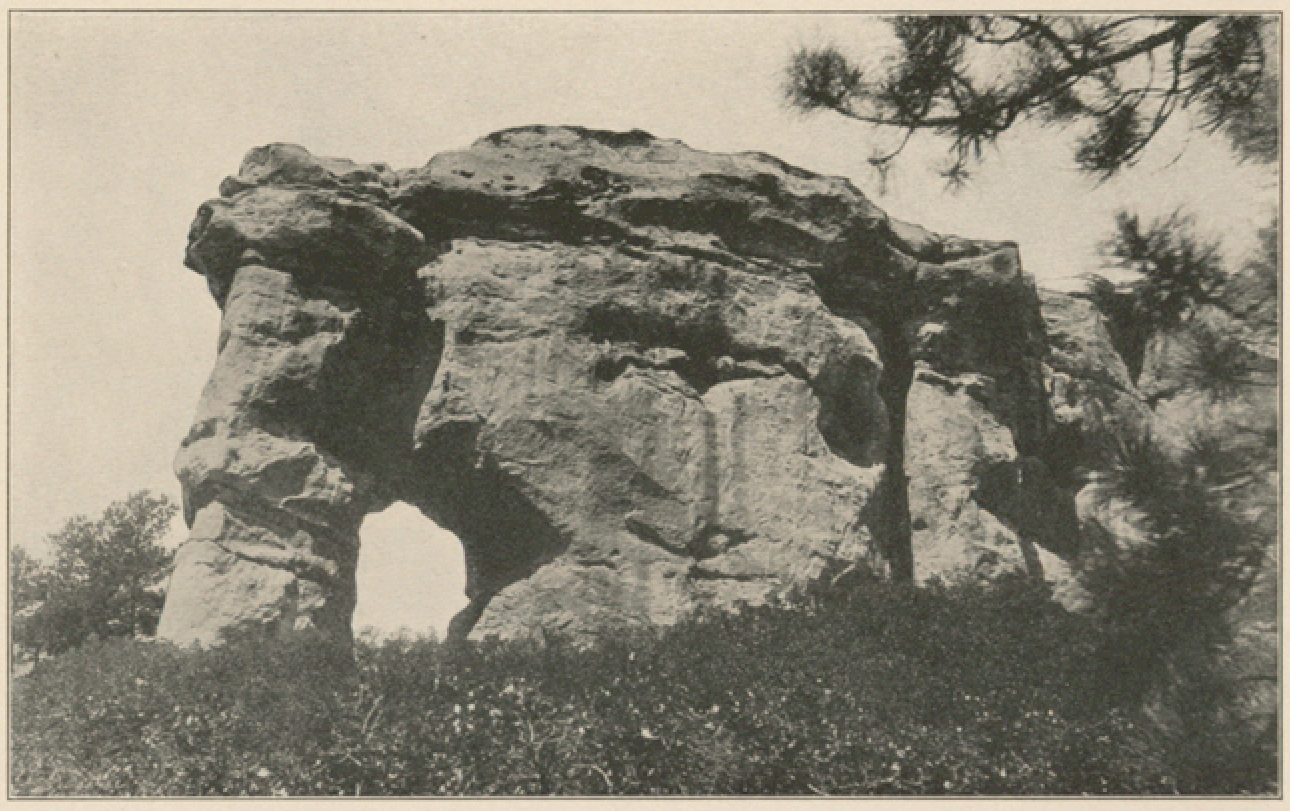


PLATE IX.—GROTESQUE EROSION REMNANT OF DAWSON ARKOSE CALLED "ELEPHANT'S HEAD" EAST OF PALMER LAKE.

PLATE X.—TYPICAL EXPOSURE OF FOUNTAIN FORMATION.
Looking southeast from west side of Gove Creek, Perry Park. Raspberry Butte, capped by rhyolite, in central distance.

PLATE XI.—SCULPTURED EROSION FORMS OF FOUNTAIN FORMATION IN SOUTHEASTERN PART OF PERRY PARK.
"Profile Rock" at right.

PLATE XII.—HOGBACK RIDGES OF PERRY PARK.
Looking northwest across Bear Creek. Curved double row of hogbacks of vertical Lyons sandstone on left and Dakota sandstone on right, separated by valley of softer rock. Sandstone of Purgatoire formation makes shoulder on left slope of Dakota hogback in distance. Gypsum of Lykins formation composes low white ridge in middle ground.

PLATE XIII.—CLOSER VIEW OF HOGBACK RIDGES OF PERRY PARK.
Looking northwest across Bear Creek. Dip of Dakota sandstone, which is nearly vertical on the high knob, becomes less steep toward the right. Sandstone of the Purgatoire, which forms a shoulder on the Dakota hogback, makes the white hill across the lake. Morrison and Lykins formations occupy depression between hogback ridges. Vertical Lyons sandstone makes an almost continuous wall on left.

PLATE XIV.—DAKOTA HOGBACK IN PERRY PARK WEST OF GOVE CREEK.
Looking northwest. Band of white gypsum of Lykins formation in middle ground. Lyons sandstone in foreground. Front Range in distance.

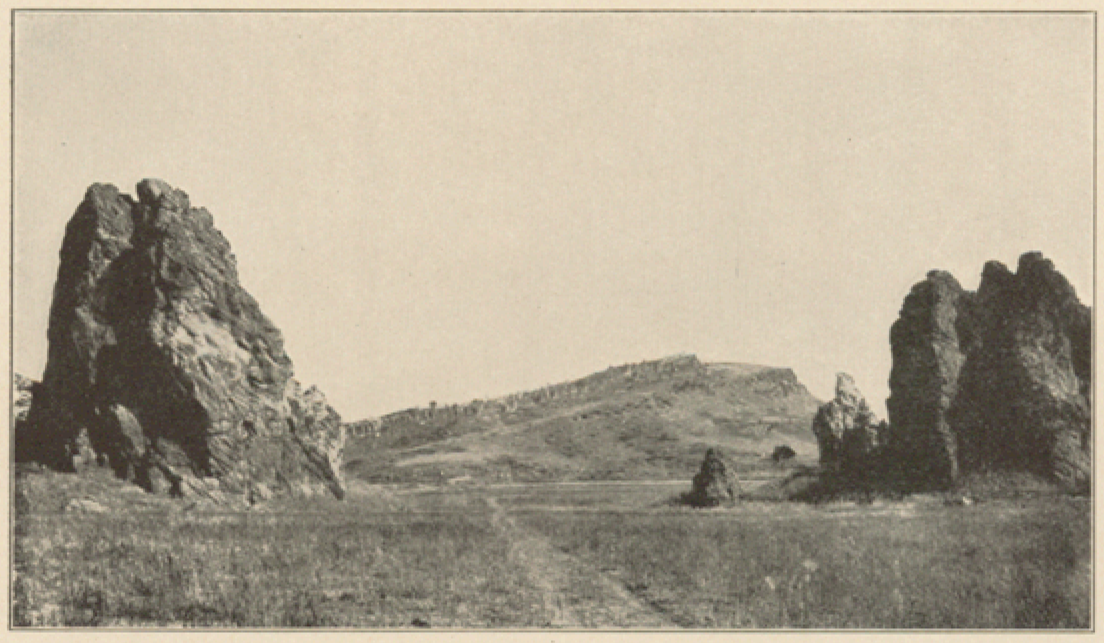


PLATE XV.—GATEWAY TO PERRY PARK.
Looking east from a point near Bear Creek. Nearly vertical Lyons sandstone in foreground. Hogback in distance capped by Dakota sandstone. Sandstone of Purgatoire formation makes lower cliff and slopes.

PLATE XVI.—GENTLY DIPPING PALEOZOIC ROCKS RESTING ON PIKES PEAK GRANITE WEST SIDE OF BEAR CANYON, PERRY PARK.
White Sawatch sandstone in lower part of cliff, thin-bedded Millsap limestone in upper part, and white sandstone of Fountain formation on top of hill.

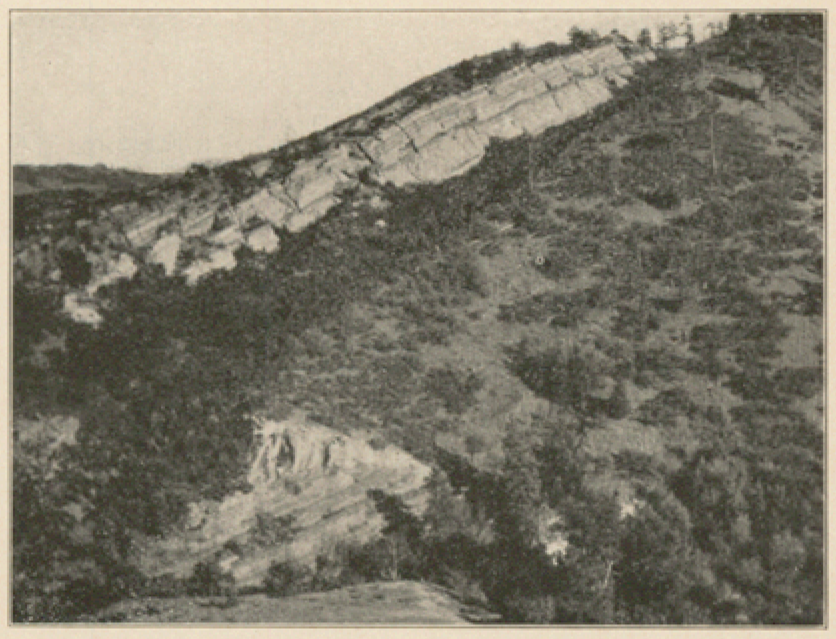


PLATE XVII.—WHITE SAWATCH SANDSTONE RESTING ON PIKES PEAK GRANITE, OFFSET APPARENTLY BY A THRUST FAULT.
Looking southeast across Gove Canyon. Sawatch sandstone cliff capped by thin-bedded Millsap limestone.

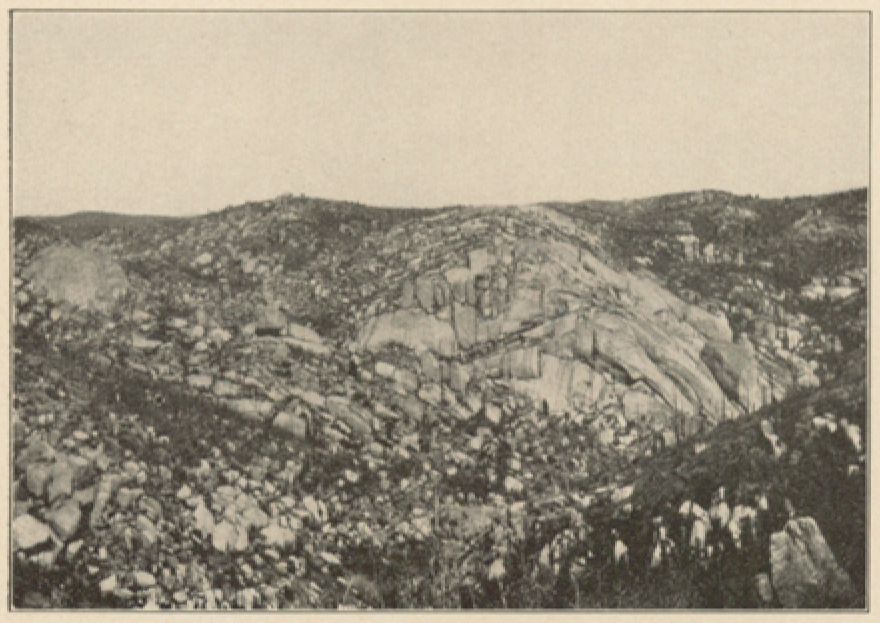


PLATE XVIII.—PIKES PEAK GRANITE ON TOP OF FRONT RANGE SOUTHWEST OF PALMER LAKE.
Showing jointing and rounded weathering of the granite.

PLATE XIX.—SLOPING TERRACE OF QUATERNARY WASH AT BASE OF FRONT RANGE.
Looking south across Beaver Creek.

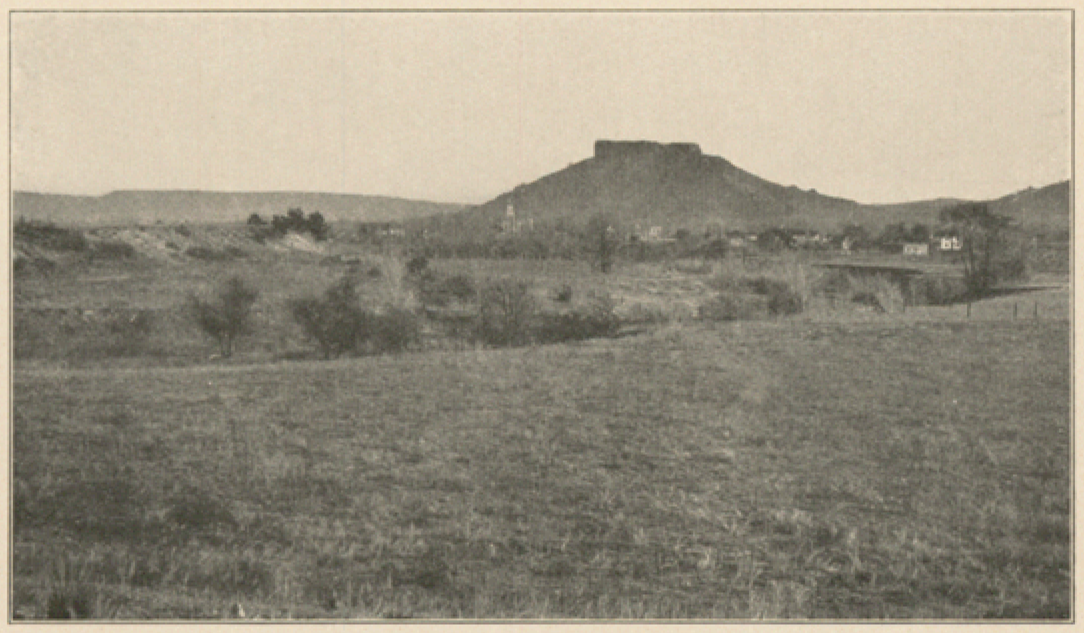


PLATE XX.—QUATERNARY TERRACES IN VALLEY OF EAST PLUM CREEK AT CASTLE ROCK.
Lower terrace in foreground and stream at right; higher terrace at left. Castle Rock in background.

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 in many places difficult or impossible to determine the age of an igneous formation, but the relative age of such a formation can in general be ascertained by observing whether an associated sedimentary formation of known age is cut by the igneous mass or 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		Tr	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.

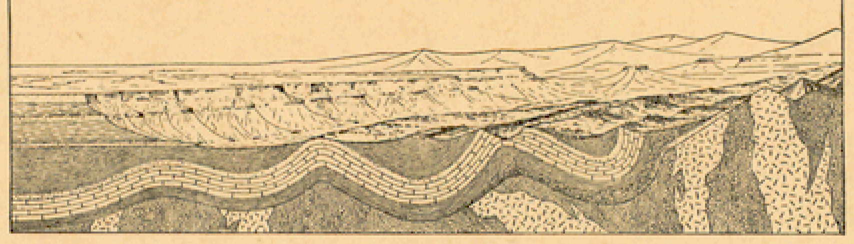


FIGURE 2.—Sketch showing a vertical section at the front and a landscape beyond.

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.

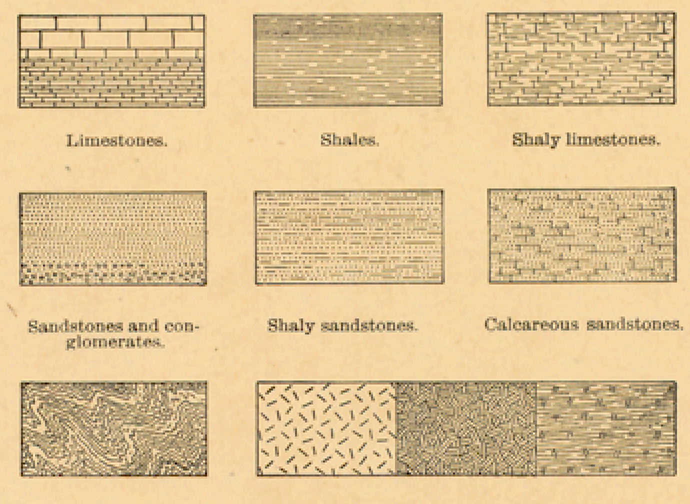


FIGURE 3.—Symbols used in sections to represent different kinds of rocks.

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.

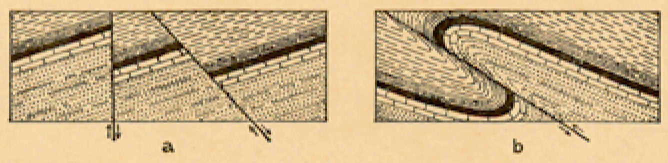


FIGURE 4.—Ideal sections of strata, showing (a) *normal* faults and (b) a *thrust* or *reverse* fault.

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.

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23	Nomini	Maryland-Virginia	5
24	Three Forks	Montana	5
‡25	Loudon	Tennessee	
‡26	Pocahontas	Virginia-West Virginia	
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‡28	Piedmont	West Virginia-Maryland	
‡29	Nevada City Special	California	
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‡31	Pyramid Peak	California	
‡32	Franklin	West Virginia-Virginia	
‡33	Briceville	Tennessee	
‡34	Buckhannon	West Virginia	
‡35	Gadsden	Alabama	
36	Pueblo	Colorado	5
‡37	Downieville	California	
‡38	Butte Special	Montana	
‡39	Truckee	California	
‡40	Wartburg	Tennessee	
‡41	Sonora	California	
42	Nueces	Texas	5
‡43	Bidwell Bar	California	
‡44	Tazewell	Virginia-West Virginia	
‡45	Boise	Idaho	
46	Richmond	Kentucky	5
47	London	Kentucky	5
‡48	Tenmile District Special	Colorado	
‡49	Roseburg	Oregon	
‡50	Holyoke	Massachusetts-Connecticut	
‡51	Big Trees	California	
52	Absaroka	Wyoming	5
53	Standingstone	Tennessee	5
‡54	Tacoma	Washington	
‡55	Fort Benton	Montana	
‡56	Little Belt Mountains	Montana	
‡57	Telluride	Colorado	
58	Elmoro	Colorado	5
‡59	Bristol	Virginia-Tennessee	
‡60	La Plata	Colorado	
61	Monterey	Virginia-West Virginia	5
62	Menominee Special	Michigan	5
‡63	Mother Lode District	California	
64	Uvalde	Texas	5
65	Tintic Special	Utah	5
‡66	Colfax	California	
67	Danville	Illinois-Indiana	5
68	Walsenburg	Colorado	5
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