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UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, DIRECTOR

GEOLOGIC ATLAS

OF THE

UNITED STATES

COLORADO SPRINGS 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.

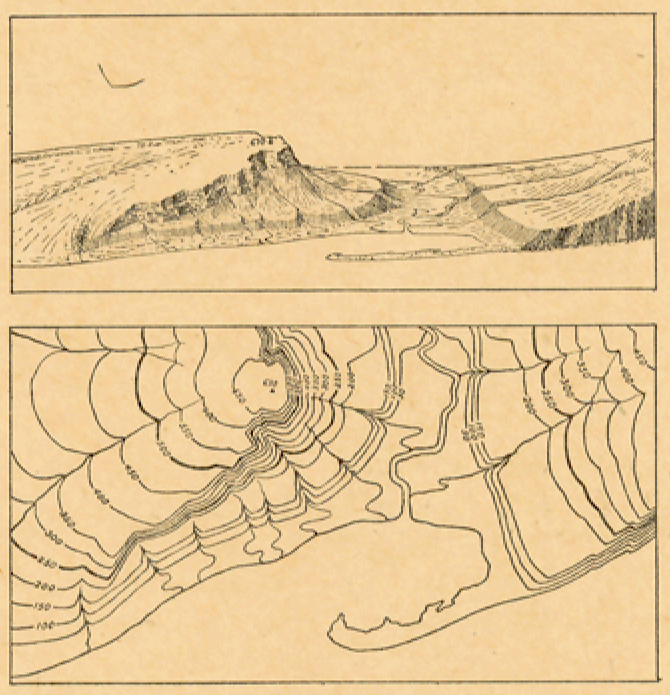

FIGURE 1.—Ideal view and corresponding contour map.

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 COLORADO SPRINGS QUADRANGLE.

By George I. Finlay.

INTRODUCTION.

GENERAL RELATIONS OF THE QUADRANGLE.

The Colorado Springs quadrangle is bounded by parallels 38° 30′ and 39° and by meridians 104° 30′ and 105° and thus covers one-fourth of a "square degree" of the earth's surface, an area, in that latitude, of 931 square miles. It is in east-central Colorado and includes a considerable part of El Paso County and small parts of Fremont, Pueblo, and Teller counties. (See fig. 1.) The city of Colorado Springs, from which the quadrangle is named, is in its northwest-central part.

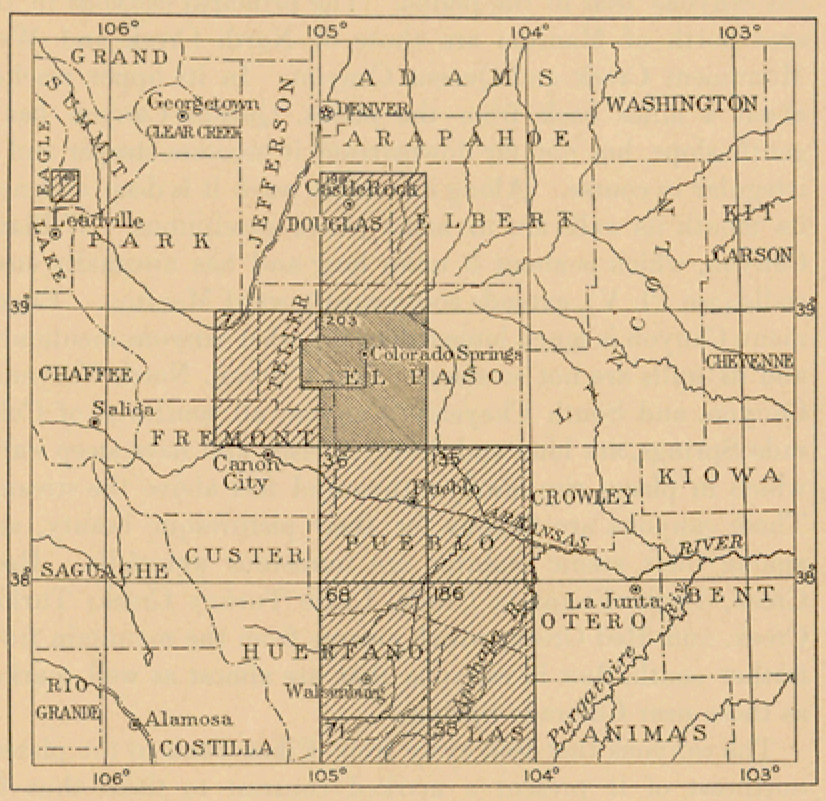

FIGURE 1.—Index map of central Colorado.

The location of the Colorado Springs and Manitou quadrangles is shown by the darker ruling (203). 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; 198, Castle Rock.

This folio contains also maps of the Manitou quadrangle, an area including Pikes Peak, Manitou, and Colorado Springs. This area is bounded by meridians 104° 47′ 30″ and 105° 05′ 45″ and by parallels 38° 43′ 30″ and 38° 54′ and covers a little less than 200 square miles, about 137 square miles of which lies in the northwestern part of the Colorado Springs quadrangle and about 63 square miles—the western part—in the Pikes Peak quadrangle. The area described in this folio therefore covers also the Manitou quadrangle, and wherever in this text the term "the area" is used, it should be understood to include both the Colorado Springs and Manitou quadrangles.

GEOGRAPHY AND GEOLOGY 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 intermontane belt of lowlands. The Park Range towers above North and Middle parks on the west, and its southward continuation is divided by the headwaters of 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 other mountains on the western slope of the Rocky Mountains.

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 occur. Tertiary sediments overlap the older formations at many places and there are numerous occurrences of intrusive and extrusive igneous rocks. During Tertiary time there was great igneous activity. In the Pleistocene epoch the higher peaks were centers of glaciation.

FIGURE 2.—Relief map of central part of Colorado, showing the geographic subdivisions.

The Colorado Springs and Manitou quadrangles cover the area about Colorado Springs shown by the darker ruling in figure 1.

Scale: 1 inch=40 miles, approximately.

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 faults.

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 generally drain 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. (See fig. 2.)

Viewed from elevations above 9,000 feet the range presents a series of flat to gently undulating areas, which in the imagination can be extended across intervening valleys so as to reproduce a former extensive even surface, above which rise a few prominent masses, such as Pikes Peak. (See Pl. I.) These even-topped areas are interpreted as remnants of an old erosion surface—a peneplain—above which the higher peaks now rise as monadnocks.

The greater part of the Front Range is composed of pre-Cambrian rocks consisting of an older group of dynamically metamorphosed 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, west of the Colorado Springs quadrangle, the prevailing rocks are granite, gneiss, and schist. Granite, which incloses blocks of Algonkian quartzite but is older than the Cambrian sediments in Colorado, constitutes the main mass of Pikes Peak. 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 the 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 Mesozoic and Cenozoic age. The constituent materials of these rocks were derived mainly from the west and a part of them was deposited as sediments in the sea, but the larger portion was accumulated on the land. 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.

At times during the Paleozoic and Mesozoic eras a part at least of the Front Range region was submerged in the sea and was covered by sediments that formed 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 (see fig. 5, p. 11), a tributary of South Platte River, just northwest of the Colorado Springs quadrangle, and of Mesozoic strata in the vicinity of Breckenridge, in the heart of the mountains, farther west, show a former greater extension of these sedimentary rocks west of the plains.

GEOLOGIC STRUCTURE.

By a series of uplifts that began early in the Tertiary period and continued at intervals throughout the rest of the Cenozoic era the Rocky Mountain region has been uplifted above the plains. The movement, which was chiefly vertical but was in part lateral, produced a great anticlinal arch and tilted, folded, and faulted strata in the foothill region. The largest of the synclinal folds is 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 northwestward across the trend of the mountains. Other diagonal folds and faults, which cause lesser offsets in the topography, occur elsewhere along the mountain front, one west of Colorado Springs (see fig. 5) and another northwest of Denver.

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 were made 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:[1]

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 cf 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.

PREVIOUS WORK.

The general geology of the Colorado Springs region has long been known, but little has been written about the Colorado Springs 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 by Lindgren and Ransome,[6] on the Breckenridge district by Ransome,[7] 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 region are listed below, in the order of publication.

Hayden, F. V., Third annual preliminary field report of the United States geological survey of Colorado and New Mexico, pp. 39-40, 1869.

——— The geological features of the east slope of the Colorado Range of the Rocky Mountains from Cache a la Poudre River southward to Pikes Peak: U. S. Geol. and Geog. Survey Terr. Seventh Ann. Rept., for 1873, pp. 17-36, 1874.

Peale, A. C., Report of South Park division: U. S. Geol. and Geog. Survey Terr. Seventh Ann. Rept., for 1873, pp. 197-200, 1874.

Cope, E. D., Report on the vertebrate paleontology of Colorado: U. S. Geol. and Geog. Survey Terr. Seventh Ann. Rept., for 1873, p. 430, 1874.

Hayden, F. V., Résumé of the geology along the eastern base of the Front or Colorado Range: U. S. Geol. and Geog. Survey Terr. Eighth Ann Rept., for 1874, pp. 36-37, 40-46, 1876.

White, C. A., Notes on the Laramie fossils collected in the valley of Bijou Creek, Colorado: U. S. Geol. and Geog. Survey Terr. Eleventh Ann. Rept., for 1877, pp. 188-192, 1879.

Cannon, G. L., Jr., On the Tertiary Dinosauria found in Denver beds: Colorado Sci. Soc. Proc., vol. 3, pp. 140-147, 1889.

——— Notes on the geology of Perry Park, Colo.: Colorado Sci. Soc. Proc., vol. 3, pp. 308-315, 1891.

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Mathews, E. B., The granitic rocks of the Pikes Peak quadrangle: Jour. Geology, vol. 8, pp. 214-240, 1900.

Lee, W. T., The areal geology of the Castle Rock region, Colorado: Am. Geologist, vol. 29, pp. 96-109, 1902.

Girty, G. H., The Carboniferous formations and faunas of Colorado: U. S. Geol. Survey Prof. Paper 16, 1903.

Darton, N. H., Comparison of the stratigraphy of the Black Hills, Bighorn Mountains, and Rocky Mountain front range: Geol. Soc. America Bull., vol. 15, pp. 379-448, 1904.

——— Age of the Monument Creek formation: Am. Jour. Sci., 4th ser., vol. 20, pp. 178-180, 1905.

Stanton, T. W., The Morrison formation and its relations with the Comanche series: Jour. Geology, vol. 13, p. 657, 1905.

Fenneman, N. M., Geology of the Boulder district, Colorado: U. S. Geol. Survey Bull. 265, 1905.

Darton, N. H., Geology and underground water resources of the central Great Plains: U. S. Geol. Survey Prof. Paper 32, 1905.

Patton, H. B., Faults in the Dakota formation at Golden, Colo.: Colorado School of Mines Bull., vol. 3, No. 1, pp. 26-32, 1905.

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Lindgren, Waldemar, and Ransome, F. L., Geology and gold deposits of the Cripple Creek district, Colorado: U. S. Geol. Survey Prof. Paper 54, 1906.

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GEOGRAPHY OF THE QUADRANGLE.

GENERAL FEATURES OF THE RELIEF.

Lying as it does across two widely different physiographic provinces, the Colorado Springs quadrangle presents considerable diversity of relief. More than half of it lies in the Great Plains, but the surface is trenched by broad valleys and is more or less rolling, though nearly level areas occur on the main divides. The Front Range rises abruptly 2,000 to 7,000 feet above the plains, forming a great scarp that crosses the northwestern part of the quadrangle, where the surface is mountainous, and culminates, farther west, in the Manitou quadrangle, in Pikes Peak, at an altitude of 14,109 feet above sea level. (See Pl. I.) Along the base of the mountains a belt of low foothills, reaching in one place an altitude of 7,400 feet, forms a zone of transition between mountains and plains. The general upland surface of the plains slopes gently southeastward from an altitude of 6,500 feet or more near the base of the mountains and 7,400 feet near the middle of the north side of the quadrangle to less than 5,100 feet at its southeast corner, the lowest point in the quadrangle.

The quadrangle thus lies in three topographic districts—the mountains, the foothills, and the plains. The relief in each district has certain characteristic features, resulting chiefly from the nature and altitude of the underlying rocks, and each will be described in turn.

THE MOUNTAINS.

A good deal of the mountain area, the highest summits of which are in the Manitou quadrangle, attains altitudes of 11,000 feet or more above sea level. Pikes Peak stands at an altitude of 14,109 feet. Other prominent points are Bald Mountain (12,365 feet), Mount Rosa (11,495 feet), Mount Big Chief (11,220 feet), and Cow Mountain (11,150 feet). Blodgett Peak, in the northwest corner of the Colorado Springs quadrangle, occupies a commanding position on the mountain front. Cheyenne Mountain (9,560 feet), which stands southwest of Colorado Springs, is the highest peak adjacent to the plains in this quadrangle. Blue Mountain, farther south, is part of an elevated block occupying about 11 square miles. Mount Pittsburg (8,210 feet) stands close to the foothills near the south edge of the quadrangle.

A prominent topographic feature along the whole mountain front is the rolling plateau that stands at an altitude of about 9,500 feet and that extends from Blodgett Peak on the north without notable break to Ute Pass, which is traversed by the Colorado Midland Railway. Between this pass and the Pikes Peak mass the surface of the plateau block is less regular, but its general character is fairly distinct. This plateau is also a conspicuous feature of the Blue Mountain region.

The Pikes Peak mass rises boldly above this plateau. (See Pl. I.) Its most striking feature is its linear, precipitous northeastern face. From "The Crags," at its northwestern end, to Windy Point the edge of the mountain fronting the plateau is sharply defined by deep valleys. Bald Mountain and Mount Big Chief, separate masses farther southeast, form continuations of the ridgelike northeast crest of Pikes Peak. The southwestern slope of Pikes Peak is gentle and along the upper edge of this slope is laid the track of the last few miles of the railroad that climbs the mountain. The top of the mountain is dome-shaped (see Pl. II), and the descent on the south and west for about a thousand feet is smooth down to the heads of several well-marked valleys.

Much of the mountain area shows mature dissection, and along the mountain front from the north line of the quadrangle to Cheyenne Mountain there are at many places bold scarps that face the foothills and the plains. At the south end of the mountain area there is no scarp, yet the slope from the mountains to the plains is steep. Along the mountain front sharply cut canyons lead to the plains. The principal canyons in the area north of Manitou are those of North Creek and West Monument Creek and Queens Canyon. In its upper reaches, about 4 miles back from the plains, Queens Canyon has a gentle slope, but not far downstream it becomes steeper and is irregular in course. Along its middle reach it is deep, and near its mouth its walls are in many places precipitous. Williams Canyon, which is about 3 miles long and has unusually steep walls (see Pl. V), extends southward toward Manitou. Engelmann Canyon is much longer than the other canyons mentioned, and its walls are not so steep. Bear Canyon, North Cheyenne Canyon, and South Cheyenne Canyon, all southwest of Colorado Springs, are long and deeply incised and have steep walls, which in places rise nearly a thousand feet above the streams. These canyons are famous for their picturesque beauty, and among their scenic features are numerous waterfalls. Rock Creek, Little Fountain Creek, Little Turkey Creek, Turkey Creek, and Red Creek, which emerge from the mountain front farther south, flow in canyons that are almost as well marked as those near Colorado Springs.

The canyons that lead away from Pikes Peak to the plateau northeast of it present a marked contrast to those thus far described. Glen Cove, the Bottomless Pit, the sharp valley known as The Crater, the prominent valley at Windy Point immediately southeast of The Crater, and the valley in which Lake Moraine lies, unlike the canyon valleys leading from the mountain front eastward to the plains, have gently sloping beds along their lower courses and precipitous rock walls about their heads. These valleys owe their forms to glacial erosion, and their mode of origin is discussed on page 14. From the crest line of Pikes Peak, which marks the head of each of these valleys, to the gently rolling plateau block below, the drop is at some places not less than 2,000 feet and at others as much as 2,500 feet. The sides of many of these valleys are straight-walled and their cross section is U-shaped. Irregularities occur around the precipitous heads of these valleys at places where long spurs extend down into them from the crest line of Pikes Peak.

The valleys that run southwestward from points near the summit of Pikes Peak show similar U-shaped cross sections, but nowhere about their heads do walls of sheer descent of more than a thousand feet appear. Their side walls are sharply cut, notably those of West Fork of West Beaver Creek, and the floor in this valley and in that of East Fork of West Beaver Creek has a step and tread form. Boehmer Creek, which leads down to Seven Lakes, flows in a long, gently sloping valley, not so deeply incised in the mountain block as the valleys just named.

The eastward-facing mountain front is very bold from the north line of the quadrangle to the mouth of Queens Canyon, where it is interrupted by the deep embayment in which stands the town of Manitou. (See Pl. I.) This is a marked topographic feature and similar embayments are found in the Perry Park region, north of the quadrangle, and near Canon City, southwest of it. The striking topographic feature of the Manitou embayment is the presence of many small, nearly parallel rocky ridges, along the most picturesque of which lies the Garden of the Gods. The embayment is bounded by relatively gentle mountain slopes on its northern edge and steep mountain slopes on its southwestern margin. These steep slopes continue southward to the south end of Cheyenne Mountain. From Cheyenne Mountain southwestward no such abrupt transition from the foothill region to the mountain tops is observed.

The topography of small areas northeast of Bison Reservoir and in Cathedral Park is remarkable for its sharp forms. The granite stands in many small columns, each of which is capped by a remnant of an original surface that had been made more resistant by the deposition of secondary quartz.

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

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[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.

THE FOOTHILLS.

The foothills in and north of the Manitou embayment are unlike the foothills in Deadman Canyon and those still farther south, in Table Mountain. Ragged lines of low hills extend from near Blodgett Peak southward to the Garden of the Gods, where bold masses of rock make sheer wall-like ridges that rise more than 200 feet above the surrounding country. (See Pls. VII, VIII, and XI.) The crests of these ridges show many small, sharply cut peaks. In the Manitou embayment, south of Fountain Creek and between Manitou and Bear Creek, the ridges exhibit nearly perfect alignment. The Table Mountain region is unlike the foothill zone of the Manitou embayment in the fact that its bordering foothill ridge has an even crest line and is much higher. From the bottom of the interior valley to the top of Table Mountain the relief amounts to 1,200 feet. Deadman Canyon shows features common to both the Manitou embayment and the Table Mountain region. Its western foothills have a sharply rectilinear arrangement. Its eastern side is formed by a nearly level table top, almost 400 feet higher, from which the ground drops away abruptly eastward, toward the small tributaries of Fountain Creek.

Close to the foothill ridges along the whole line of the mountains lie gently sloping mesas, which begin among the foothills and extend several miles eastward with very gentle slopes down to the plains. They appear on both sides of West Monument Creek near the north line of the quadrangle and extend as far eastward as Monument Creek. Near Glen Eyrie the gently sloping, flat-topped hill that has been named The Mesa extends southeastward for about 4 miles with a slope of somewhat less than 100 feet to the mile. (See Pls. I and IV.) It is a nearly plane surface marked by gentle rolls but is everywhere sharply cut along its margin. A similar prominent mesa is the site of the town of Broadmoor. Another, nearly 7 miles long, lies north of Rock Creek and extends from the mountains to a point 3 miles south of Fountain. Its slopes are comparable to those of The Mesa near Colorado Springs, being on the average somewhat less than 100 feet to the mile. A less marked mesa lies in the Deadman Canyon region. Its area is about 6 square miles. A long, narrow mesa extends from the south end of this area near Lytle for a distance of more than 10 miles to the south line of the quadrangle.

THE PLAINS.

The Great Plains extend from the foothills of the Rocky Mountains to the Mississippi Valley on the east. About half the quadrangle lies in the plains region, which extends westward as far as the line of the mesas. This part of the quadrangle is divisible into two distinct topographic areas, one, with relief of 1,000 feet, lying north of a series of low irregular escarpments that extend from Pulpit Rock through Austin Bluffs and Corral Bluffs to the east boundary of the quadrangle, the other occupying the remainder of the plains area. The low escarpments that form the line of demarkation between the two areas are due to the outcrop of a coarse sandstone, the Dawson arkose, which is more resistant than the rocks in the plains area on the south. In the region northeast of this line the plains are gently rolling and are nowhere deeply eroded by streams, though long, low dividing ridges stand between the valleys, distinguishing them from those in the southern plains area. In Corral Bluffs there is a drop of about 300 feet to the smoother surface of the southern area.

The only marked topographic feature on the generally level surface of the southern plains area consists of scores of little conical hills, called "tepee buttes" because of their resemblance to Indian wigwams or tepees, most of them less than 50 feet high. They are clustered together in small groups along a line extending from a point about 4 miles south of Fountain to a point on the southern boundary of the quadrangle 3 miles east of Henkel. Two of these hills have suggested the names applied to Little Butte and Butte stations, on the Denver & Rio Grande Railroad.

DRAINAGE.

The entire area is drained southeastward to Arkansas River, one of the principal tributaries of the Mississippi. All parts of the area are well drained except some tracts at the heads of mountain valleys on or above the old plateau, at altitudes greater than 9,000 feet, where there are a few small swampy tracts. A number of mountain tarns lie in hollows south and southeast of Pikes Peak, and a score or so of artificial lakes or reservoirs are scattered over the plains near the base of the mountains.

STREAMS.

The greater part of the area is tributary to Fountain Creek, which enters the quadrangle from the west 5 miles south of its northwest corner, flows diagonally across it, and leaves it 6 miles west of its southeast corner. In the part of its course that lies in the mountains the creek falls from 7,600 feet above sea level at the place where it enters the quadrangle to 6,100 feet at the place where it emerges upon the plain below Manitou. In the lower part of Ute Pass its grade is steep, for it descends 300 feet in little more than half a mile through a stretch that includes a waterfall. From Colorado City the stream descends another thousand feet in crossing the plains and leaves the quadrangle at an altitude of about 5,100 feet. The principal tributary of Fountain Creek within the quadrangle is Monument Creek, which enters the area from the north and flows nearly due south to Colorado Springs, where it joins the main stream. Other branches from the northeast are Sand and Jimmy Camp creeks, both of which drain considerable parts of the plains area. From the west Fountain Creek receives the waters of Little Fountain, Cheyenne, and Bear creeks and of some smaller streams that rise in the mountains and flow out upon the plains. In the parts of their courses that lie in the mountains all these streams, as well as Fountain Creek, flow swiftly in rather straight, steep, and narrow valleys, and in the parts that lie on the plains they flow in meandering courses in rather broad, open valleys. Only the principal streams are perennial, and their flow is subject to considerable seasonal variation, determined by the rate of melting of the snow on the mountains. During the greater part of the year the beds of most of the streams are stretches of dry sand, but occasionally during the summer they are filled to a depth of a few feet by sudden torrential rains.

The southwestern part of the area is drained by Turkey and Red creeks and the middle-western side by branches of Beaver Creek, all of which flow south to the Arkansas. A strip several miles wide along the east side of the area is drained by tributaries of Black Squirrel Creek, which joins the Arkansas some distance to the southeast.

LAKES AND SWAMPS.

All the lakes of the Colorado Springs region except those in the mountains have been made by building dams across the waters of small streams. The level of the glacial lakes near Pikes Peak has been raised by dams built to obtain a water supply for Colorado Springs and Victor. These lakes are shallow, none of them reaching a depth of 50 feet. The largest are Lake Moraine, Bison Reservoir, and the lakes known as Reservoirs Nos. 2, 4, 5, 7, and 8. Prospect Lake, southeast of Colorado Springs, is a shallow body of water about one-third of a mile long and about one-sixth of a mile wide. Farther southeast are the Fountain Valley Reservoir, near Skinners station on the Santa Fe Railway, and the large reservoir 2 miles east of Widefield, which covers about half a square mile.

In many of the valleys that lead southward from Pikes Peak there are swampy places. One swamp extends a mile upstream from Reservoir No. 8, in the valley of the East Fork of West Beaver Creek. Swampy areas along the headwaters of Boehmer Creek south of Reservoir No. 2, in Bull Park, and notably at the upper end of the valley of Lake Moraine indicate the existence of former shallow lakes or the wider extension of the lakes that are now used as reservoirs for the Colorado Springs water system. Along Gould Creek and Middle Beaver Creek and about their headwaters there are areas of swampy ground.

PRECIPITATION AND RUN-OFF.

The effect of altitude on precipitation is clearly shown in the Pikes Peak region. During most of the year the prevailing winds are from the west and northwest. As the moisture-laden clouds strike the western slope of Pikes Peak they are deflected upward and their moisture is condensed and precipitated, the precipitation increasing with the altitude. In the summer there are long periods when easterly winds prevail and when the clouds from the plains on striking the eastern slope of the mountains are deflected upward and their moisture is precipitated.

The United States Weather Bureau has maintained precipitation stations at Cripple Creek since 1903 and at Victor since 1905, both southwest of Pikes Peak; on the summit from 1874 to 1887; at Lake Moraine since 1895 and at Fremont Experiment Station since 1910, both on the eastern slope; at Glen Eyrie, in the foothills, from 1892 to 1909; and at Colorado Springs, on the edge of the plains, since 1886. The records taken at these stations show that the mean annual precipitation at altitudes ranging from 9,500 to 10,000 feet southwest of Pikes Peak is about 17 inches and that it increases to 29.5 inches on the summit of Pikes Peak (elevation 14,109 feet). The precipitation on the eastern slope does not decrease so rapidly with decrease in altitude as on the western. It is 25 inches at an elevation of 10,200 feet (Lake Moraine), 19 inches at 8,850 feet near Manitou, 16 inches at 6,500 feet, and 15 inches at 6,100 feet, on the edge of the plains. In other words, the precipitation is heavier on the eastern than on the western slope at the same altitude.

The United States Geological Survey has made no records of discharge in the Pikes Peak region, but for several years the Colorado Springs water department has maintained weir stations at certain points on the southern and eastern slopes of Pikes Peak. To show the run-off at different altitudes the records of three of these stations, furnished by the water department, have been selected and are given in the next column.

The first station is at the Strickler tunnel, in sec. 25, T. 14 S., R. 64 W., at an altitude of 11,500 feet, and shows the run-off from an area of 3.2 square miles above the tunnel, comprising the headwaters of West Beaver Creek, which lie at altitudes ranging from 11,500 to 14,000 feet. The sum of the inflow into the tunnel and the flow over the Victor weir give the run-off from the entire area. The second station, known as the Boehmer Creek weir, is in sec. 30, T. 14 S., R. 68 W., at an altitude of 11,150 feet, and shows the run-off from 7.1 square miles, comprising the area above Strickler tunnel and the headwaters of Boehmer Creek, which stand at altitudes ranging from 11,150 to 14,000 feet. The third station, known as the Ruxton Creek weir, is in the SW. ¼ sec. 11, T. 14 S., R. 68 W., at an altitude of 8,600 feet. To the flow at the weir is added the flow over the seepage weir below the Seven Lakes and the flow over the Victor weir to show the entire run-off from the area above the Ruxton Creek weir, which comprises 17.1 square miles, including the area above the Strickler tunnel and Boehmer Creek weirs. The altitudes range from 8,600 to 14,000 feet.

As Colorado Springs operates a series of reservoirs in this area all the records are affected by storage and do not show the natural run-off. By averaging the record at each station for the entire period the effect of storage is nearly eliminated except for the relatively small loss by evaporation from the surfaces of the reservoirs, which cover 0.7 square mile, or 4 per cent of the entire drainage area.

The following table shows the monthly and annual flow at the three weir stations:

Discharge in second-feet at weir stations in Pikes Peak region.

	Strickler tunnel.			Boehmer Creek.			Ruxton Creek.		
	1911	1912	1913	1911	1912	1913	1911	1912	1913
January	0.0	0.1	0.10	1.5	1.6	1.2	8.4	9.0	8.9
February	.16	.3	.10	1.8	1.8	1.0	8.3	7.7	8.6
March	.40	.4	.20	1.5	1.9	1.0	8.0	8.6	8.1
April	.48	.6	.43	4.0	2.1	1.5	8.5	9.0	8.1
May	1.7	.7	.83	12.4	9.0	2.7	9.7	7.9	8.7
June	7.2	9.4	1.4	7.6	17.5	4.6	12.8	7.0	9.2
July	3.9	2.4	6.5	6.3	6.1	8 2	8.4	9.4	10.7
August	6.4	4.1	6.2	4.8	8.2	7.8	9.1	11.1	9.1
September	3.0	2.1	8.5	3.6	3.3	10.6	11.9	8.9	8.9
October	7.6	4.7	3.4	9.6	4.5	5.5	9.4	7.3	8.8
November	.52	7.9	.65	1.1	8.1	2.3	9.1	6.6	6.2
December	.29	1.4	.54	1.1	1.5	1.9	9.6	7.4	6.5
Mean	2.63	2.84	2.40	4.61	5.47	4.02	9.43	8.32	8.48
Mean per square mile	.82	.89	.75	.65	.77	.57	.72	.49	.50
Mean for 3 years	0.82			0.67			0.57		

The above records cover a period too short to show conclusively the effect of altitude on the run-off in the Pikes Peak region, but they show in general that the run-off per square mile increases with the altitude. In connection with the Ruxton Creek records it should be noted that the average yearly run-off of 0.57 second-foot per square mile includes the heavier run-off from the higher altitude of 0.67 second-foot for the area above Boehmer Creek and 0.82 second-foot for the area above the Strickler tunnel. Therefore the run-off from the lower portion of the area below Boehmer Creek must be considerably less than 0.57 second-foot. The effect of altitude is still further obscured by the relatively heavier precipitation on the southeastern slope than that on the western.

SETTLEMENT AND INDUSTRIES.

Colorado Springs is the chief city in the quadrangle. Colorado City adjoins Colorado Springs on the west, and Manitou lies 3 miles west of Colorado City. The combined population of these places is about 40,000. The most populous suburb of Colorado Springs is Broadmoor, and the town of Fountain lies 11 miles southeast of the city. The plains region east and southeast of Colorado Springs supports a scanty population, whose chief occupation is ranching. Except for a few permanent dwellings, occupied chiefly during the summer, the mountains are almost unsettled. The Santa Fe and the Denver & Rio Grande railroad lines cross the quadrangle. A branch of the Chicago, Rock Island & Pacific Railway starts from Colorado Springs and connects with the main line running eastward from Denver at Limon Junction, about 80 miles northeast of Colorado Springs. The Colorado Midland Railway operates along the Ute Pass, the line extending from Colorado Springs to Grand Junction. The Manitou & Pikes Peak Railway runs from Manitou to the summit of Pikes Peak. The Colorado Springs & Cripple Creek District Railway, about 45 miles long, is the chief means of communication between Cripple Creek and Colorado Springs.

Valuable agricultural land lies along Fountain Creek but is confined to the valley bottoms. The lack of water in the region east of the mountains makes the cultivation of the soil practically impossible. Within the quadrangle, however, there are large areas of land that are well adapted to cattle raising. Coal has been mined extensively between Manitou Junction and Pikeview. Colorado Springs and Manitou are famous health resorts and are peculiarly fitted by their climate for sufferers from pulmonary complaints.

GEOLOGY.

STRATIGRAPHY.

GENERAL FEATURES.

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 are of two different kinds and of widely different ages. They consist of granite and associated varieties of intrusive rocks of pre-Cambrian age and intrusive phonolite of Tertiary age. The sedimentary rocks comprise more than 10,000 feet of indurated strata, ranging in age from late Cambrian to early Tertiary—although the Silurian and Devonian systems are not represented and the Triassic and Jurassic are only doubtfully represented together with some glacial deposits and considerable unconsolidated gravel and alluvium, of Quaternary age. In the mountains there are a few small bodies of ancient metamorphic rocks, of uncertain origin, probably in part igneous and in part sedimentary, and several sandstone dikes of supposed Cambrian age filling crevices in the granite.

A generalized section of the rocks of the quadrangle, showing the succession and grouping of the formations and their average thickness and character is given on the columnar-section sheet. In the geologic literature dealing with the region diverse names have been applied to some of the formations. The various names used and their correlation as at present determined are given in the table on page 16.

PRE-CAMBRIAN ROCKS.

METAMORPHIC ROCKS.

Small, irregular masses of metamorphic rocks that are included in the Pikes Peak granite are exposed here and there in the mountains. Such rocks are abundant in some parts of the Front Range, as in the Pikes Peak quadrangle, on the west, but they are scarce in this area and are not separately mapped. Some are regarded as remnants of an older granite and others as of sedimentary origin.

Gneiss.—Well-foliated granitoid crystalline pink or light-red gneisses crop out at several localities in Queens Canyon, at the southern end of Cheyenne Mountain, and about the headwaters of Turkey and Little Turkey creeks. Their boundaries are indistinct and their aggregate mass is small. Similar rocks are widely distributed in the Pikes Peak quadrangle, on the west, and are believed to be at least in part remnants of a granite older than the Pikes Peak granite.

A study of thin sections shows that the gneiss is made up chiefly of two kinds of feldspar, with which are associated much smaller amounts of quartz and biotite and a little apatite, zircon, and magnetite. The dominant feldspar is oligoclase, in crystals 2 millimeters or less in diameter, closely twinned according to the albite law. A few of the crystals are clear and glassy but most of them are somewhat kaolinized. With the oligoclase are associated small amounts of glassy microcline. Quartz, which forms clear grains that carry abundant fluid inclusions, makes up less than 15 per cent of the rock. Biotite, in irregular flakes and patches, is much less abundant, and the accessory minerals are present only in minute amounts.

Schist.—The schist crops out in narrow dark-gray bands, which are commonly associated with the gneiss. It is well foliated and easily cleavable and consists chiefly of quartz and biotite, which are accompanied by some feldspar and minute amounts of zircon and magnetite.

A study of thin sections shows that quartz is the chief constituent, forming glassy grains a millimeter in diameter and generally containing inclusions arranged in lines. Albite, altered and containing secondary muscovite, makes up about 10 per cent of the rock in irregular patches that generally show polysynthetic twinning. Light-brown biotite in irregular shreds and flakes is the only abundant dark silicate. Zircon forms minute subhedral prismoidal individuals, grouped together; minute needles associated with the biotite are probably rutile; and magnetite, in part altered to hematite, is sparingly present.

IGNEOUS ROCKS.

GENERAL RELATIONS.

Practically the whole of the mountainous portion of the area is occupied by igneous rocks, chiefly granite, and all except the phonolite are of pre-Cambrian age. By careful field study ten types of granite have been discriminated, chiefly by means of differences in texture. The several types are strikingly similar in mineralogic character and chemical composition, and a number of them are closely related local facies of a single granite mass. Partly for this reason and partly because of the irregularity of the contacts and the difficulty of tracing them, only four types are mapped—the Pikes Peak, Cripple Creek, Windy Point, and Mount Rosa granites. The Pikes Peak granite is remarkably uniform in texture and composition throughout large areas, but the minor varieties differ in these respects even in the same small mass. A few dikes of pegmatitic and lamprophyric rocks that cut the granite in some places have also been mapped.

PIKES PEAK GRANITE.

Distribution.—Nearly the whole of the mountainous area is occupied by the Pikes Peak granite, which forms all of Pikes Peak except some relatively small intrusive masses and is well exposed on the mountain slopes. (See Pl. II.) It is of widespread occurrence throughout the Front Range for some distance north and south of Pikes Peak.

Character.—The rock is a coarse-grained granite composed of alkalic feldspar, quartz, and biotite, and its color, mostly light pink, is due to the abundance of the feldspar. Quartz is much less abundant, and biotite is relatively rare. The feldspar crystals average one-fourth inch in length but range from grains no larger than the accompanying grains of quartz to what appear to be phenocrysts 1 or 2 inches long. In places the development of large feldspars has been accompanied by the almost total disappearance of other constituents, as near Windy Point, on Pikes Peak, where a syenitic phase of the granite is exposed. The quartz is generally milky white or gray and opaque, but much of it is perfectly transparent. It occurs in oval grains one-fourth inch or less in diameter. Biotite, in flashing black crystals rarely half an inch across, is only here and there prominent. Where it is abundant, as at several points on Cheyenne Mountain, the rock is uncommonly dark.

Weathering.—The granite weathers in huge round masses like cyclopean masonry (see Pl. II), so characteristic that they may be recognized from a distance. They are prominent on the northwest slope of Cheyenne Mountain. Great scales break away from the domelike outcrops, and in Engelmann Canyon, west of Manitou, smoothly rounded masses 20 feet in diameter have fallen from the ledges. The mesh of coarse interlocking grains is easily ruptured by frost, and the rock goes to pieces by disintegration, forming a characteristic angular gravel that is widely distributed as a mantle on long, low divides. In places the surface of the rock, which has been hardened and glazed by the deposition of secondary silica, is not so easily disintegrated and forms a protecting cap over portions that are altogether broken up and on the point of falling away.

Biotite is the most easily decomposed of the constituent minerals of the granite, and as it weathers iron is set free, staining the other minerals and intensifying the pink tint of the feldspar. Where quarrying has been carried on and unweathered granite laid bare, as near St. Peters Dome, the feldspar is dull green, suggesting the presence of ferrous iron as an impurity. The weathered rock shows every gradation from green through pink to deep red, the most brilliantly colored reddish granite being near Rainbow Falls, in Ute Pass.

Petrography.—The rock is holocrystalline and medium to coarse grained, the average size of the grains being about 5 millimeters, but the texture is not everywhere uniform. Microcline, in anhedral irregular crystals, is the most abundant feldspar, but perthitic intergrowths with albite are common. The characteristic twinning is developed, resembling a fine-meshed grating. Oligoclase is present in subordinate quantity. Quartz is about half as abundant as feldspar. The grains are anhedral, equant, or irregular, and contain numerous thin inclusions, irregularly massed or in long thin lines. Among them are the hairlike needles frequently seen in quartz and regarded as rutile. Biotite, brown and yellow and strongly pleochroic, occurs in irregular clusters and flakes. The accessory minerals are apatite in the common euhedral prismoid forms, grains of magnetite, small euhedral equant crystals of zircon, titanite, and the rare minute brown pleochroic prisms referred to allanite.

Chemical composition.—An analysis of the rock gave the following results:

Analysis of Pikes Peak granite from Sentinel Point.

[W. F. Hillebrand, analyst.]

SiO_2	77.03
Al_2O_3	12.00
Fe_2O_3	.76
FeO	.86
MgO	.04
CaO	.80
Na_2O	3.21
K_2O	4.92
H_2O+	.30
H_2O-	.14
TiO_2	.13
P_2O_5	Trace.
MnO	Trace.
BaO	Trace.
F	.36
Li_2O	Trace.
	100.55
Less O=F	.15
	100.40

The norm computed from the above analysis shows that the rock is alaskose.

CRIPPLE CREEK GRANITE.

Distribution.—The Cripple Creek granite is so named because it occupies large areas west of Cripple Creek. In the Colorado Springs and Manitou quadrangles it occurs in a few small irregular masses and in numerous thin dikes that cut the Pikes Peak granite. The principal outcrops are near Glen Cove, on the northwest shoulder of Pikes Peak; north of Mountain View, on the eastern flank of the Peak; between Summit and Saderlind, on the Colorado Springs & Cripple Creek District Railway, and in South Cheyenne Canyon east of Stove Mountain. The most prominent dikes are immediately northeast of St. Peters Dome.

Character.—The granite is pink or reddish and consists essentially of microcline, with quartz and biotite. Some of the microcline is in well-formed crystals from one-quarter to one-half inch across. The rock contains practically the same constituents as the Pikes Peak granite, although it is of much finer and more even grain. Chemical analyses show that the two are strikingly alike, exhibiting no greater difference than that between specimens collected from the same intrusive mass. It is believed that the two varieties of granite are genetically closely related.

Weathering.—The rock breaks into small subangular plates on weathering. It does not weather into large rounded bowlders nor break down into coarse angular gravel, like the Pikes Peak granite, and on the whole it appears to be more resistant, for unreduced ledges of it stand out prominently in the midst of areas of the other rock.

Petrography.—The rock is fine grained, its individual crystals averaging about one-half millimeter in diameter. It is holocrystalline and inequigranular, and its fabric is marked by the occurrence of grains in few different sizes but with very different numbers of grains in the respective sizes. Microcline, in anhedral crystals, much of it greatly altered, is the most abundant constituent. Microcline-microperthite is rare, and it is not known whether the feldspar intergrown with the microcline is albite or orthoclase. Orthoclase and subhedral plagioclase are both present, and each is abundant in places. The extinction angles of the plagioclase indicate both albite and oligoclase. The twinning lamellæ are very fine.

Quartz occurs in equant or irregular anhedral grains and in places constitutes one-third of the rock. It is clear and glassy and some of it is free from inclusions, but many grains, besides containing the minute needles and black dots that are characteristic of the inclusions in the quartz of the Pikes Peak granite, carry small, well-formed individuals of zircon. The rock contains biotite, some of it chloritized and some altered to muscovite. Muscovite is in some places an original constituent, but it is nowhere equal in quantity to the biotite. Among the accessory minerals are zircon in euhedral equant grayish crystals, magnetite, apatite, tourmaline, and allanite.

Chemical composition.—The following analysis shows that in composition the rock is strikingly like the Pikes Peak granite:

Analysis of rock from a dike of Cripple Creek granite at Duffields station, near St. Peters Dome.

[George Steiger, analyst.]

SiO_2	77.31
Al_2O_3	12.45
Fe_2O_3	.43
FeO	.33
MgO	None.
CaO	.50
Na_2O	4.72
K_2O	3.84
H_2O+	.42
H_2O-	.40
TiO_2	.06
ZrO_2	None.
CO_2	None.
P_2O_5	None.
SO_3	None.
F	.15
MnO	.01
BaO	None.
	100.62
Less O=F	.06
	100.56

The norm computed from the above analysis shows that the rock is kallerudose.

WINDY POINT GRANITE.

Distribution.—The Windy Point granite forms a number of small masses in the western part of the Manitou quadrangle, the largest of which occupies the summit of Pikes Peak. Other small areas lie along the ridge extending southeastward to Windy Point. The rock does not extend into the Colorado Springs quadrangle. It appears to be a thin remnant of a sheet that overlies the Pikes Peak granite, for on the precipitous northeast face of the mountain it is underlain by that rock. It is doubtless younger than the Pikes Peak granite, into which it appears to have been intruded, but its relation to the other granites has not been determined.

Character.—The rock is brownish red and is made up of scattered crystals of feldspar a few millimeters in diameter and less conspicuous grains of quartz and biotite in a paste that resembles closely woven feldspars. It is distinguished from the other granites of the region by its extremely close grained texture. It is almost everywhere deeply weathered and breaks down into angular masses and platy pieces.

Petrography. — The granite is holocrystalline and fine grained, the average individual crystal being less than one-fifth millimeter in diameter. Its essential constituents are microcline, orthoclase, oligoclase, quartz, and biotite, which make up 97 per cent of the rock. Fluorite, zircon, and magnetite are accessories.

The feldspars, which constitute more than a third of the rock, are notably altered. Microcline is the most abundant and, as estimated by Rosiwal's method, constitutes 90 per cent of the feldspars. It forms anhedral grains in the web of the rock and larger subhedral porphyritic crystals, a few being 4 or 5 millimeters in diameter. Much of it is intergrown with quartz. About 40 per cent of the rock is quartz, in clear anhedral equant or irregular grains and in larger individuals only less conspicuous than the microcline phenocrysts. Biotite, in brown tabular irregular flakes, much of it chloritized, forms about 10 per cent of the rock. Fluorite occurs in clear anisotropic anhedral grains and zircon in nearly colorless euhedral to subhedral crystals. Magnetite in very small amount is the only other accessory observed.

Chemical composition.—The chemical character of the rock is shown by the two analyses given below. Analysis A represents rock from the ridge between Middle Beaver and North Beaver creeks. Analysis B represents rock from Middle Beaver Creek.

Analyses of Windy Point granite.

[W. F. Hillebrand, analyst.]

	A	B
SiO_2	75.17	73.51
Al_2O_3	12.66	13.28
Fe_2O_3	.23	.94
FeO	1.40	.97
MgO	.05	.05
CaO	.82	1.11
Na_2O	2.88	3.79
K_2O	5.75	5.22
H_2O-	.66	.62
H_2O+	.16	.16
TiO_2	.10	.18
P_2O_5	.03	Trace.
MnO	Trace.	Trace.
BaO	.03	Trace.
F	.31	.55
SrO	Trace?	None.
Li_2O	Trace.	Trace.
	100.25	100.38
Less O=F	.13	.22
	100.12	100.16

The norms computed from the above analyses indicate that the rock is liparose.

MOUNT ROSA GRANITE.

Distribution and character.—The Mount Rosa granite is most extensively developed on the slopes of Mount Rosa, from which it is named. Another mass crops out in the valley of North Cheyenne Creek. The rock is intruded into the Pikes Peak granite in irregular masses, sheets, and dikes. It is a fine-grained nonporphyritic bluish-gray rock made up chiefly of microcline, quartz, and riebeckite. It is rather resistant to weathering and generally stands out boldly in relief in the midst of the Pikes Peak granite.

Petrography. — Quartz and microcline are the dominant minerals and together make up about three-fourths of the rock, quartz being slightly the more abundant. Riebeckite, which forms about one-fifth of the rock, is the only other essential mineral. The crystals average about one-fifth millimeter in diameter but differ rather widely in size, and the numbers of the grains of the several sizes also differ considerably.

The crystals of microcline, which form about one-third of the rock, are generally the largest, reaching a diameter of one-half millimeter. They are anhedral or subhedral, tabular or irregular, and were formed earlier than the riebeckite. Carlsbad twins are very common. Perthitic intergrowths with albite are rare, but micropegmatitic intergrowths with quartz are abundant. Orthoclase seems to be lacking. The small grains of plagioclase, which make about 2 per cent of the rock and average about one-fourth millimeter in diameter, are albite in prismoid forms.

The quartz, which forms about two-fifths of the rock, occurs in clear glassy anhedral irregular individuals and in mosaics of small grains. It includes some of the minute needles usually regarded as rutile. The abundant quartz produces the highly siliceous appearance of the rock. Some of the riebeckite forms small subhedral crystals with the faces commonly seen on hornblende, but most of it occurs in irregular patches. The amphibole cleavage is as a rule well marked. The pleochroism is strong: X = dark indigo-blue; Y = yellowish green; Z = golden brown.

Zircon is the most abundant accessory mineral. The largest crystals are less than one-fourth millimeter in diameter and are generally euhedral and equant. Their color is faint brown. Apatite forms minute prisms, and magnetite, pyrite, hematite, and rutile are occasionally seen in the thin sections.

Chemical composition.—An analysis of the rock is given below. The norm computed from the analysis shows that the rock is liparose.

Analysis of Mount Rosa granite from a point near Rosemont.

[George Steiger, analyst].

SiO_2	73.82
Al_2O_3	10.59
Fe_2O_3	2.18
FeO	2.98
MgO	.04
CaO	.28
Na_2O	4.20
K_2O	4.57
H_2O+	.49
H_2O-	.39
TiO_2	.13
ZrO_2	None.
CO_2	None.
P_2O_5	.02
SO_3	None.
F	.06
S	None.
MnO	None.
BaO	None.
	99.75
Less O=F	.02
	99.73

PEGMATITE DIKES.

Distribution and character.—Dikes of pegmatite are widely distributed throughout the area of granite, especially northeast of St. Peters Dome and along the valley of South Cheyenne Creek. Many of the dikes are rich in sodic amphibole and appear to be associated with the Mount Rosa granite. At only one place was an amphibole-bearing pegmatite dike found to be intimately connected with the main body of that granite, but the evidence strongly favors the view that the two rocks are genetically related. Pegmatite dikes without amphibole are abundant throughout the Pikes Peak granite east of Cameron Cone and north of Cascade. All the dikes tend to be coarse grained, with single crystals not uncommonly several inches long. The pegmatite dikes have yielded many valuable specimens to collectors, chiefly the accessory minerals described under the following heading.

Petrography.—Microcline is the commonest of the feldspars, which in places constitute as much as 40 per cent of the rock. Some of the crystals are well bounded, displaying six or more forms, and both Carlsbad and Baveno twins are developed. The mineral is pink, flesh-colored, or green. Plagioclase forms subhedral equidimensional twins, and the extinction angles fix its composition as that of albite. It is commonly intergrown with deeply weathered and turbid orthoclase. Quartz is as a rule much less abundant than the feldspars. It forms large irregular masses, some of them transparent, but most of them milky white. Graphic intergrowths with feldspar are abundant.

The most abundant dark silicate in many of the dikes is riebeckite, which in places forms 15 per cent of the rock. Some of the larger crystals are 2 inches across and a foot long. The prismatic cleavage is uncommonly well developed and is conspicuous in hand specimens. The color is black or black with a faint tinge of indigo. The pleochroism is similar to that of the riebeckite in the Mount Rosa granite: X = dark indigo-blue; Y = yellowish green; Z = golden brown. Both biotite and muscovite are found in small amounts in some dikes but are altogether wanting in others and are to be regarded as accessories. Grayish-brown glassy crystals of zircon are especially abundant in places.

Among the rare minerals locally developed in the dikes are cryolite, astrophyllite, and columbite. Cryolite is found in the immediate neighborhood of St. Peters Dome. It forms pure masses, some of which are 2 or 3 inches in diameter. It is dull white, grayish white, or pinkish and is more cloudy than the Greenland variety. Cleavages in three directions are well developed, and several twinning laws are exemplified. The alteration products identified by Cross include pachnolite, thomsenolite, prosopite, and gearksutite. Golden-brown astrophyllite is in some places abundant in stellate forms and in aggregates associated with quartz and zircon. It forms bladed crystals, some more than an inch long.

SYENITIC DIKES.

Distribution and character.—Dikes of dense black, generally aphanitic rock cutting the Pikes Peak granite are abundant in the valleys west and northwest of Cheyenne Mountain. One of them, about 18 feet wide, is exposed along the road in Bear Creek canyon half a mile east of Jones Park. Others are exposed below Tenney Crags, in Bear Creek canyon. A thin dike of unusual length extends from Mount Buckhorn to Bruin Inn, a distance of three-fourths of a mile. Many others are exposed in Cheyenne Canyon and on the divide between it and Bear Creek canyon. Numerous small dikes outcrop northeast of St. Peters Dome and near the headwaters of Beaver Creek. A coarse-grained dike of the same character has been prospected in the valley south of Summit station on the Colorado Springs & Cripple Creek District Railway. The dikes are generally not more than a few feet thick, and their outcrops are generally short. They are probably the youngest igneous rocks, except the phonolite, in the quadrangle, for no other rock cuts them.

The rock of the dikes consists essentially of feldspar, hornblende, and lepidomelane, rarely with small phenocrysts of flesh-colored feldspar. It is distinctly richer in ferromagnesian minerals than the other igneous rocks and on weathering becomes stained brown by iron oxides.

Petrography.—The study of thin sections shows that the essential minerals are alkalic feldspars, hornblende, and lepidomelane, with quartz, magnetite, apatite, and zircon as accessory minerals. In general the light and dark minerals are in nearly equal amounts, although in some specimens dark constituents distinctly preponderate. The rocks are holocrystalline and invariably fine grained, the average diameter of the individual crystals being but a few hundredths of a millimeter. A notable characteristic is the universal tendency toward automorphic development of the feldspars, with attendant clustering together of the dark silicates.

The feldspars are almost invariably subhedral, tabular parallel to the clinopinacoid, and older than the ferromagnesian minerals. They are very generally altered. Orthoclase, with almost universal Carlsbad twinning, is present and in some of the dikes it forms conspicuous phenocrysts up to a quarter of an inch in diameter. The chief feldspar, however, is a sodic plagioclase. Twinning after the albite law is shown by excessively thin lamellæ. Symmetrical extinctions in the zone at right angles to (010) are invariably low and serve to fix the feldspar as oligoclase.

Among the dark constituents green hornblende in anhedral irregular individuals is the most abundant. Subhedral prismoidal crystals bounded by the two pinacoids are rare. The usual cleavage is present. The hornblende is closely intergrown with seal-brown to brownish-yellow pleochroic lepidomelane. The amphibole and mica occur most commonly in clusters of intermingled grains that fill the spaces between the feldspars. The dark silicates are invariably fresh.

In some of the dikes there is no quartz; in others quartz in irregular mosaics is an abundant accessory constituent. Zircon was not observed in most of the dikes, but in some it is conspicuous in subhedral or anhedral grayish-brown crystals a few hundredths of a millimeter in diameter. Apatite and magnetite are both abundant.

Chemical composition.—An analysis of the rock is given below in column A. Its similarity in composition to syenite is striking, and for comparison an analysis of syenite from Yogo Peak, Mont,[1] is placed beside it in column B.

Analyses of rock from dike in Bear Creek canyon half a mile east of Jones Park.

[A, by George Steiger; B, by W. F. Hillebrand.]

	A	B
SiO_2	61.46	61.65
Al_2O_3	14.55	15.07
Fe_2O_3	2.30	2.03
FeO	5.78	2 25
MgO	.50	3.67
CaO	2.74	4.61
Na_2O	4.71	4.35
K_2O	4.88	4.50
H_2O-	.54	.26
H_2O+	.74	.41
TiO_2	1.07	.56
ZrO_2	.02	--------
P_2O_5	.27	.33
F	.14	--------
S	.01	--------
MnO	.25	.09
BaO	.17	.27
SrO	--------	.10
	100.13	--------
Less O	.06	--------
	100.07	100.15

The norm computed from analysis A indicates that the rock is monzonose.

CAMBRIAN SYSTEM.

SAWATCH SANDSTONE.

Occurrence.—The Cambrian system is represented in the Colorado Springs quadrangle by a relatively thin deposit of sandstone of probable Upper Cambrian age. So far as known the Lower Cambrian series is not represented in Colorado, but the determinations by Walcott make clear the presence of Middle Cambrian strata along the Front Range and in the western part of the State. The Upper Cambrian beds probably underlie a great area east of the mountains, and their upturned edges crop out at several places along the Front Range. Sections in widely separated areas are strikingly similar, all having pure quartz sandstone, conglomeratic in places, at the base, overlain by iron-stained and glauconitic sandstone.

Definition.—The rocks here called Sawatch sandstone consist of white or cream-colored quartz sandstone below, with reddish calcareous and glauconitic sandstone and a little limestone above. The thickness of the formation in the quadrangle is not more

[1] Washington, H. S., Chemical analyses of igneous rocks: U. S. Geol. Survey Prof. Paper 14, p. 254, 1903.

than 45 feet. Because of lithologic character and stratigraphic position it is correlated with the Sawatch quartzite (Upper Cambrian) of the west side of the Front Range, which is named from the Sawatch Mountains, along the flanks of which it is typically exposed.

Distribution.—The principal area of the formation in the Colorado Springs quadrangle is along the northwest side of the Manitou embayment, where it crops out in a narrow zigzag band at the base of the sedimentary series, upon or in contact with the granite. In the valley of Fountain Creek above Manitou there are a few small outliers of the formation, two of which are large enough to be mapped. The formation also crops out in a small area at the base of the mountains a mile north of Blair Athol. South of the Manitou embayment the formation is not exposed in sufficient thickness to be shown on the map as a separate unit.

Character.—The lower part of the formation is a bed of white or cream-colored sandstone 11 feet thick, at the base of which in a few places there is a thin conglomeratic sandstone. The pebbles of the conglomerate are almost invariably quartz, although a very few are granite, and most of them are much less than an inch in diameter. The conglomerate is not found at many places and is nowhere conspicuous. The mass of the basal bed of sandstone is even grained, more or less friable, and without prominent jointing. The constituent grains are prevailingly quartz, but the quartz grains are accompanied by a little feldspar, and many of them are nearly spherical.

The upper 30 feet or so of the formation consists of beds of coarse reddish-brown gritty sandstone deeply stained by iron oxide. The beds near the middle are blotched with green, due to the presence of glauconite. In places the grains of feldspar are more abundant and the sandstone is calcareous. In typical sections a bed of clear-red limestone 2 feet thick lies in the middle of the red sandstone. The single layers of sandstone are 3 to 10 inches thick. The sandstone gradually becomes more calcareous toward the top, where it is succeeded by the Ordovician limestone.

Relations.—The formation lies on a remarkably even surface of granite. (See Pl. VI.) The contact is exposed almost continuously from Fountain Creek to Glen Eyrie, and at scarcely any place is there a departure of more than a foot or two from a perfectly even surface. In the sections in the canyon the contact nearly everywhere forms a straight line.

The formation passes upward without marked lithologic break into the Manitou limestone, of Lower Ordovician age, the two being separable only by paleontologic evidence.

Age and correlation.—Because of its lithologic character and stratigraphic position the sandstone has been correlated with the Upper Cambrian Sawatch sandstone on the western slope of the Front Range. It contains fossils at a point about 4 miles northwest of Pikeview, where the brachiopod Lingulella has been collected. Poorly preserved fragments of trilobites were found in the Ute Pass near Manitou. Cross states that the form Ptychoparia was obtained from exposures of the same rock at Manitou Park. No beds of Lower or Middle Cambrian age are known in the Colorado Springs quadrangle.

ORDOVICIAN SYSTEM.

FORMATIONS INCLUDED.

The Ordovician system is represented in the Colorado Springs quadrangle by the Manitou limestone. In the Canon City embayment there are two younger Ordovician formations, the Harding sandstone and the Fremont limestone, but the limestone does not extend into the Colorado Springs quadrangle, and the sandstone is represented by only a few feet of strata that overlie the Manitou limestone in the southwestern part of the quadrangle. The Ordovician formations were probably at one time much more widely distributed but have been eroded from large areas, so that only disconnected remnants are now preserved along the base of the Front Range.

MANITOU LIMESTONE.

Definition.—The Manitou limestone is named from Manitou Springs, where it is typically developed. It consists of red, purplish, and gray limestone containing Lower Ordovician (Beekmantown) fossils. Its maximum thickness in the quadrangle is 250 feet, but at some places in the southwestern part of the quadrangle, where much of it was removed by erosion before the overlying beds were deposited, only 50 feet remains.

Distribution.—The formation is found principally on the northwest side of the Manitou embayment, where it caps the ridges on both sides of Fountain Creek at the southeast end of Ute Pass and occupies the mountain slopes between the mouths of Queens Canyon and Williams Canyon. (See Pl. V.) It is well exposed in the steep walls of both canyons. A small mass is exposed on the steep slope a mile north of Blair Athol.

In the southwest part of the quadrangle a thin strip of the formation crops out along the base of the Front Range from Little Fountain Creek to Turkey Creek and from Red Creek to the west margin of the quadrangle.

Character.—The base of the formation consists of 6 feet of clear-red limestone overlain by about 50 feet of thin-bedded purplish and reddish-gray limestone, followed in turn by 100 feet of clear-gray massive limestone, in part granular. The top of the formation consists of nearly 100 feet of thick-bedded dove-colored limestone, rich in cherty layers half an inch thick and cut by prominent vertical joints. The upper half of the formation contains massive beds of dense bluish limestone, and at the top is a zone of coarsely brecciated rock, much stained by limonite and hematite. The highest beds exposed are a foot or more thick and are drab or in places clear red. The limestone of the formation is at most places magnesian.

Relations.—The formation rests conformably on the Sawatch sandstone, which grades into it to some extent, as the upper 20 feet of the Sawatch contains some beds of red limestone similar to that at the base of the Manitou. The top of the Manitou is an irregular surface upon which different younger formations rest in different places.

Age and correlation.—The red limestones at the base of the Manitou limestone at the "Narrows," in Williams Canyon, contain fossils of species similar to those obtained in Queens Canyon and in the adjoining Pikes Peak quadrangle at Manitou Park.

The species includes the following forms:

Lingulella desiderata.	Eoorthis nympha.
Schizambon manitouensis.	Syntrophia nundina.
Eoorthis desmopleura.	

The Manitou limestone is therefore of Lower Ordovician age and is assigned to the horizon represented in the East by the Beekmantown limestone and in Texas by the El Paso limestone.

HARDING SANDSTONE.

The Harding sandstone extends a short distance into the southwest part of the quadrangle, where a wedge of it, only a few feet thick, lies on the Manitou limestone north of Table Mountain. It consists of light-gray saccharoidal quartz sandstone. It is so thin that it is not practicable to show it separately on the map, and it is included in the band of undifferentiated Manitou limestone and Harding sandstone mapped in that locality.

The evidence furnished at the type locality near Canon City, Colo., indicates that the Harding sandstone is of Black River age.

CARBONIFEROUS SYSTEM.

The Carboniferous system is represented in the quadrangle by strata of Pennsylvanian and of Permian (?) age, but none of Mississippian age are known. The Fountain formation and Lyons sandstone are assigned to the Pennsylvanian series, and the Lykins formation is doubtfully assigned to the Permian series. All but the lowest member of the Fountain formation are part of the "Red Beds" of Colorado, the age of which was long in doubt but which are now regarded as Carboniferous.

PENNSYLVANIAN SERIES.

FOUNTAIN FORMATION.

Definition.—The Fountain formation is named from Fountain Creek, along which it is well exposed near Manitou. It consists of arkose and conglomerate with a little interbedded sandstone and shale, most of it bright red. It is the most prominent formation of the "Red Beds" in the quadrangle and is best developed in the Manitou embayment, the type locality. The formation is equivalent to the lower part of the "Lower Wyoming" as that term has been used in the monograph on the Denver Basin.

It is highly irregular in thickness because of its unequal deposition in different places. Its maximum thickness, 4,500 feet without observed reduplication by faulting, is in the Manitou embayment, but north of Blodgett Peak its thickness is not more than 800 feet, the greater part of it being cut out by faulting. Along Red Creek, in the southwest part of the quadrangle, its thickness is 2,000 feet.

Distribution.—The formation occupies an area 2½ miles wide between Manitou and Colorado City and extends northward in a narrow belt passing through Glen Eyrie and Blair Athol and along the slope of Blodgett Peak to the north margin of the quadrangle. In the southwestern part of the quadrangle it occupies a considerable area extending from the divide between Rock Creek and Little Fountain Creek southward into the valley of West Fork of Red Creek and thence westward outside the quadrangle.

Character.—The formation is made up almost wholly of arkose and conglomerate. The materials composing it have been derived directly from the granite mass on the west, and the fragments of granite, quartz, feldspar, and mica are but little worn. (See Pl. X.) The pebbles and bowlders of the conglomerate range in diameter from 2 to 5 inches and are sharply angular or subangular. They consist of granular vein quartz, coarse and fine granite, pegmatite, schist, and some sandstone and feldspar. Many of the beds are clear white, being free from iron oxide, and maroon and purplish-red beds alternate with beds having the prevailing vermilion or light-red hue. Although the formation includes some fine-grained shaly sandstone the strata are chiefly coarse grained and some single massive beds are several feet thick. Calcareous beds crop out near the base of the formation at Glen Eyrie.

The section of the formation between Manitou and Colorado City illustrates particularly well the several characteristic facies. Some single beds may be traced for miles, but the variability along the strike that is a nearly constant feature of extensive coarse-grained red-bed strata finds expression in the Colorado Springs quadrangle.

The lowermost 90 feet, which has been separately mapped as the Glen Eyrie shale member, consists of gray sandstone and sandy shale with thin beds of black fossiliferous shale containing traces of coal. This member is strikingly unlike the great body of the formation, although transitional beds occur at its top. It is important not only because it is a readily separable lithologic unit but because its flora throws light on the history of the Colorado Springs region in early Pennsylvanian time. This member is found only in the Manitou embayment, where it crops out between Glen Eyrie and Manitou.

The overlying 25 feet of the formation at Manitou is purplish-red sandstone, in places micaceous, with intercalated gray or light-pink arkose beds less than a foot thick. The next zone, 50 feet thick, comprises more massive beds, 3 to 5 feet thick, of white and red mottled pebbly arkose. The pebbles, of granite, schist, and quartz, are small. Brick-red clay partings separate the beds. The next 50 feet is made up of alternate beds of clear pinkish-white arkose and white or mottled coarse sandstone with prominent brownish laminæ. The beds contain no pebbles more than 2 inches in diameter.

The next 100 feet consists of massive beds of distinctly laminated white arkose, some of them 8 feet thick, marked by clear-cut vertical joints. Secondary silica deposited between the grains is a feature of many exposed surfaces. Irregular angular quartz pebbles, 2 to 3 inches across, are common. Among the white layers are coarsely conglomeratic portions in which the pebbles make up half the bulk of the rock. Subangular cobbles of ocher-yellow quartz 5 inches in diameter, with others of opaque white quartz, granite, and schist, are abundant.

A persistent zone about 250 feet thick, next above, is marked by numerous alternations among its beds and by the prominence of shale. Regularly mottled layers of brick-red arkose give place to white arkose, with little pockets of shale and at intervals pebbly streaks, and to numerous layers of very fine grained shaly sandstone and shale in beds 2½ feet or less thick. The shales are purplish red, sage-green, or mottled red and green and contain a few pebbly layers 6 inches or less thick. They are sparingly fossiliferous and of marine origin.

The next zone, about 300 feet thick, differs from those thus far described in being made up of uniformly coarser rock, in containing few white beds and no shaly layers, and in showing locally prominent beds of massive conglomerate. It is also characterized by unusual forms of weathering. At some places undercutting of the more massive beds by solution is prominent; at other places, where beds of different resistance have been attacked, weathering has developed mushroom-shaped pillars of rock. (See Pl. X.) The "Balanced Rock" in the Garden of the Gods is such a mass, 15 feet high. Rounded residual bowlders of arkose a few feet in diameter are scattered over the surface. The lowest bed of this zone, 18 feet thick, is reddish and pinkish, regularly laminated coarse arkose with unevenly bedded massive conglomeratic portions containing bowlders, the largest a foot in diameter, and angular fragments of granite, pegmatite, mica schist, brownish-red sandstone, and white and blackish-gray quartz. The conglomerate gives place to massive, regularly laminated pebbly beds that are finer grained toward the top. Beds of massive conglomerate occur in this zone and at intervals throughout the succeeding 1,500 feet of the formation. The massive conglomerates gradually die out higher up and only scattered lenses of bowlders and sheets of pebbles occur in the arkose. Pieces of feldspar, of dike sandstone, of ocher-stained granular quartz, and a few of black chert are found, in addition to pebbles of granite. The arkose weathers in typical huge rounded forms unlike those at other horizons, illustrating the uniformly coarse-grained character of the sediments.

The uppermost 800 feet of the formation includes few layers of conglomerate or of white arkose. The prevailing color is light red. Here and there beds of fine-grained sandstone occur. This part of the formation is exposed in some of the huge thin vertical slabs of rock that are so prominent in the Garden of the Gods. (See Pls. VIII, IX, and XI.)

Relations.—The formation lies unconformably upon the Manitou limestone in the Manitou embayment. At one or two localities in the southwestern part of the quadrangle it lies on the Pikes Peak granite.

At the top the formation appears to pass conformably into the overlying Lyons sandstone. A transition zone 25 feet thick is well exposed at several places. This transition zone is indicated in the Lyons sandstone.

Age and correlation.—From the black shaly layers near the base of the Glen Eyrie shale member in Quarry Canyon were collected fossil plants that were identified by David White as Asplenites sp. indet., Sphenopteris cf. *S. browni*, Corynepteris cf. *C. corallioides*, *Lepidodendron obovatum*, *L. aculeatum*, Lepidostrobus sp., *Lepidophyllum campbellianum*, and *Stigmaria verrucosa*, together with shells of Lingula. The material examined, though not sufficient to determine accurately the age of the beds, is referable to the lower part of the Pennsylvanian and probably represents a stage in the upper Pottsville.

Inarticulate brachiopods are found in several layers of brownish-red and green shale about 400 feet above the base of the formation in Black Canyon. They are identified by G. H. Girty as species of Lingulidiscina, perhaps *L. manhattanensis*. No fossils have been found in the upper part of the formation in the quadrangle, but in northern Colorado fossils of Pennsylvanian age have been obtained from limestones that are in part equivalent to the upper portion of the Fountain formation; hence the whole formation is regarded as Pennsylvanian.

LYONS SANDSTONE.

Definition.—The Lyons sandstone is named from Lyons, Colo., its type locality. It consists of fine-grained red and white sandstone having a maximum thickness in the quadrangle of 850 feet. The formation is equivalent to the upper part of the "Lower Wyoming" as that name was applied in the monograph on the Denver Basin.

Distribution.—The formation crops out in the northern part of the quadrangle as a narrow band extending southward along the foothills as far as Bear Creek, west of Colorado City, but interrupted at several places by cross faults and more or less concealed by wash. In the southwestern part of the quadrangle it occupies an area increasing in width southward from a very narrow strip at Rock Creek to a belt 2 miles wide at the southern margin of the quadrangle, where it doubles back northwestward and westward and leaves the west side of the quadrangle just north of Table Mountain. The southern area is continuous.

Character.—In the Garden of the Gods the formation is 850 feet thick and rises in huge vertical sheets of rock to a height of 250 feet. (See Pls. III, VII, and VIII.) The sandstone is homogeneous and fine grained and of remarkably even texture. It is composed of notably rounded grains of quartz cemented by iron oxide. Cross-bedding is a prominent feature of the rock. The lower 550 feet is clear brick-red, and the uppermost 300 feet is white, as is well shown in the gateway to the Garden of the Gods (Pl. VII). The transition from red to white is rather gradual, white beds appearing in increasing numbers above the middle of the formation. At the base are transitional beds a few feet thick which closely resemble the underlying Fountain formation.

A massive conglomerate occurs near the middle of the formation in the Garden of the Gods and in Glen Eyrie but not in the southern areas. It has a maximum observed thickness of 35 feet and is in several respects remarkable. The bowlders, some of which are 2 feet in diameter, are much larger than any in the Fountain formation and are well rounded, whereas the cobbles in the conglomeratic beds of the Fountain are angular or subangular. They include many kinds of rock—fine-grained biotite granite, coarse Pikes Peak granite, pegmatite, gneiss, schist, and quartzite, and some fragments of Manitou limestone and red calcareous sandstone of the Fountain formation—but the most abundant pebbles are of white quartz or of the ocher-yellow quartz common in certain beds of the Fountain formation. The matrix, which is coarse grained, is made up of quartz and a little feldspar. Within the Colorado Springs quadrangle the Lyons sandstone is a much weaker and less distinctly laminated rock than the strong, crisp, sharply banded sandstone at Lyons, Colo.

The sandstone at the top of the formation is fine grained, is composed of pure quartz, and is for the most part friable. It differs from the brick-red sandstone below the conglomerate in its characteristic weathering. The cause of the difference is the presence of veinlike lines or thin layers of secondarily deposited silica, giving the weathered rock surface a crinkly, roughened look that is not characteristic of the lower beds of the formation, which in the huge weathered masses in the Garden of the Gods show innumerable solution hollows and cavernous openings a foot or more deep.

Relations.—The Lyons sandstone conformably overlies the Fountain formation, and at its base there is a transition zone about 25 feet thick, which so closely resembles the Fountain that it is difficult to determine the exact contact. At its top it passes conformably into the overlying Lykins formation, the two being separated on lithologic character.

Age and correlation.—No fossils have been found in the formation in the Colorado Springs quadrangle. In northern Colorado fossils of Pennsylvanian age have been found in the upper part of a lenticular bed of limestones which lies between sandstones having the lithologic character of the Fountain and Lyons formations. The upper part of the limestone is interbedded with sandstones similar to those of the Lyons, and it has consequently been included in that formation. For this reason the Lyons sandstone of the Colorado Springs quadrangle is regarded as of Pennsylvanian age. Darton[1] has called attention to the close resemblance between the uppermost zone of white sandstone in the Garden of the Gods and the Tensleep sandstone of the Black Hills of South Dakota.

PERMIAN (?) SERIES.

LYKINS FORMATION.

Definition.—The Lykins formation consists of less than 200 feet of thin-bedded, prevailingly red sandstone and shale with gypsum at the top. The type locality of the formation is Lykins Gulch, about 9 miles north of Boulder, Colo. The formation is equivalent to the "Upper Wyoming" as that name was used in the monograph on the Denver Basin.

Distribution.—The formation is exposed in a narrow, interrupted belt parallel to and above the Lyons sandstone, extending from the north margin of the quadrangle southward to Bear Creek, west of Colorado City. In the southern part of the quadrangle it occupies a sinuous ribbon-like area having an average width of about 1,000 feet and extending from Rock Creek southward to the south margin of the quadrangle and thence northwestward and westward to the west margin, north of Table Mountain. Its area of outcrop follows the margin of that of the Lyons sandstone but is not so broad, and it is also exposed in a small inlying butte surrounded by the Lyons and capped by the Morrison formation.

Relations.—The formation rests conformably on the Lyons sandstone, from which it is separated at the horizon where the brick-red, pink, or white sandstone of the Lyons gives way to fine-grained red and green shale. It is limited above by an unconformity, although overlain everywhere in the quadrangle by the Morrison formation.

Character.—In the section at Quarry Spur, west of Colorado City, the base of the formation consists of 24 feet of fine-grained friable red shale, spotted green where the ferric iron pigment appears to have been reduced to the ferrous state, and is overlain by 12 feet of finely laminated close-grained pinkish sandstone, which in turn is overlain by 2½ feet of white calcareous sandstone with wavy banding and small inclusions of reddish chert. The sandstone is left in prominent relief by weathering. Next above is 25 feet of fine-grained thinly bedded sandy shale resembling that at the base of the formation. The overlying bed, 18 inches thick, consisting of brecciated white sandstone intermingled with fine-grained red sandstone, is succeeded by 18 inches of finely laminated thin-bedded white sandy limestone. Above is a zone, 48 feet thick, of homogeneous brick-red sandstone alternating with much more thinly bedded fine-grained red and green mottled sandy shale. The uppermost part of the section consists of 65 feet of gray and pinkish sandstone in beds a few inches thick. At Quarry Spur the formation includes no gypsum, but just north of it, across Fountain Creek, the topmost zone of sandstone is absent and its place is occupied by gypsum. (See Pl. VII.) In the valley of Red Creek the gypsum reaches a maximum thickness of 90 feet.

The formation as a whole is easily eroded, and the sandy shales that make up the greater part of it are rapidly worn away, leaving the calcareous layers in relief. At most localities a bed of limestone 3 feet thick, the equivalent of the bed of white calcareous sandstone 36 feet above the base of the Quarry Spur section, is a prominent horizon marker. Its distance above the base of the formation is not uniform, however, being in some places not more than 15 feet, and the 3-foot bed is generally accompanied by one or two other beds of limestone, from 2 to 4 feet thick. The rock is gray or dove-colored and contains reddish chert inclusions. Its weathered surface is marked by wavy banding. These calcareous beds may be traced for miles by their conspicuous outcrops. Where the dip is slight they form low benches in which the more resistant limestone at the top stands out prominently above the red sandy shale below.

Age and correlation.—No fossils have been found in the formation in the Colorado Springs quadrangle, but in the Castle Rock quadrangle, on the north, a few fossils, identified by Girty and regarded by him as probably Permian, were collected from a thin bed of limestone a few feet above the base of the formation. The Lykins appears to be the equivalent of the Rico formation of the San Juan region, and it has been correlated by Darton on stratigraphic grounds with the Chugwater formation of Wyoming. Its upper part may possibly be Triassic, but there is no evidence either for or against such a view.

JURASSIC OR CRETACEOUS ROCKS.

MORRISON FORMATION.

Definition.—The Morrison formation consists essentially of fresh-water marl that includes many lenticular bodies of limestone and thin beds of sandstone. It reaches its maximum thickness in the quadrangle near Colorado City, where it measures 245 feet. It takes its name from the town of Morrison, Colo., where it is typically exposed. A part of the formation contains numerous dinosaurian fossils and has therefore been called the "Atlantosaurus beds."

[1] Darton, N. H., U. S. Geol. Survey Prof. Paper 32, p. 162, 1905.

Relations.—The formation rests unconformably upon the underlying Lykins formation, a relation that is not very apparent in the Colorado Springs quadrangle, although it is evident elsewhere. It is overlain in apparent conformity by the Lytle sandstone member of the Purgatoire formation. At some other places in Colorado there is evidence of a slight unconformity at the top of the formation, but it is probably not extensive.

Distribution.—In the foothills in the northern part of the quadrangle the formation crops out in a narrow band lying just above and parallel to the Lykins formation and extending southward from the north margin of the quadrangle to Bear Creek. A small area is exposed at the southeast base of Cheyenne Mountain. In the southwestern part of the quadrangle the formation occupies several areas, the largest being a band lying parallel to that occupied by the Lykins formation and extending from Rock Creek southward to the south margin of the quadrangle and thence westward and northwestward, and again westward, along the north face of Table Mountain, to the west margin of the quadrangle. A prong projects southward from this belt down Salt Canyon for more than 2 miles, and a small area occupies a part of Patton Canyon, in the extreme southwest corner of the quadrangle. A small inlying butte surrounded by Lyons sandstone is capped by the Morrison.

Character.—The formation is made up of light olive-green, maroon, or purplish chalky-looking clay and marl, a small amount of gray friable sandstone, and thin beds of gray or drab limestone. The basal part, not more than 20 feet thick, consists of sandstone and limestone. At the bottom fine-grained gray friable sandstone, weathering yellowish or brownish, gives place to fine-grained light-drab, sparingly fossiliferous fresh-water limestone. This limestone is generally free from siliceous impurities, but where they are present they give a peculiar character to the weathered surface of the rock. A fairly persistent 2-foot bed of limestone lies just above the basal sandstone. It is dark gray and contains siliceous concretionary grains that are stained bright red on their outer surfaces and constitute in places 25 per cent of the whole rock.

The upper part of the formation consists of variegated marls and interbedded sandstones. In places, as near the Garden of the Gods, single beds of gray friable sandstone reach a thickness of 30 feet. Thin conglomeratic beds, containing well-rounded siliceous pebbles one-fourth inch in diameter, are rare. The marls and clays are broken by innumerable joints and go to pieces immediately when handled. The formation is readily recognized by the weathered green and red clays in outcrops.

Fossils.—The sandstones and marls of the formation, especially near Morrison, have yielded many dinosaurian remains. The formation has by some authors been regarded as Jurassic and by others as Cretaceous, but owing to the Cretaceous affinities of these reptilian remains the view that it is of early Cretaceous age is gaining ground. In the Colorado Springs quadrangle two species of fossil gastropods have been found in the basal limestones. They were determined by T. W. Stanton as *Planorbis veternus* Meek and Hayden and *Valvata scabrida* Meek and Hayden, both of which are found in the Morrison elsewhere.

CRETACEOUS SYSTEM.

Nearly half the Colorado Springs quadrangle is occupied by Cretaceous strata, both the Lower and the Upper Cretaceous series being represented. In addition to the Morrison formation, possibly of Lower Cretaceous age, that series is represented by the Purgatoire formation. The Upper Cretaceous is very fully represented, as the Dakota sandstone, the Colorado and Montana groups, and the Laramie formation all crop out within the quadrangle.

LOWER CRETACEOUS SERIES.

PURGATOIRE FORMATION.

Definition.—The Purgatoire formation is named from Purgatoire River, in southeastern Colorado, along which it is typically exposed. It consists of sandstone and overlying shale, the whole having a maximum thickness in the quadrangle of nearly 300 feet.

The strata constituting the formation were formerly not differentiated from the Dakota sandstone and were mapped as part of that formation in the monograph on the Denver Basin and in the Pikes Peak and Pueblo folios, although it was known that they comprise two sandstones and an intervening shale. Recent work by Stanton has shown that the lower sandstone and the shale are of Lower Cretaceous age and contains marine fossils, and in the Apishapa folio Stose separated them from the Dakota under the name Purgatoire formation. In this folio the two are mapped separately as members of the Purgatoire formation and are called the Lytle sandstone member and Glencairn shale member.

Relations. — The Purgatoire formation here overlies the Morrison formation in apparent conformity, although in other parts of the State a slight unconformity is recognized at the horizon of separation. The formation is limited above by an unconformity, of slight extent, and at every point in the quadrangle is overlain by the Dakota sandstone.

Distribution.—The formation crops out in a narrow interrupted belt extending along the foothills from the north border of the quadrangle southward to Bear Creek and also in a small area at the southeast base of Cheyenne Mountain. In the southern part of the quadrangle it occupies an irregular belt extending from the ridge south of Rock Creek southward along the ridge between Turkey and Red creeks beyond the quadrangle. In the southwest corner of the quadrangle it occupies the divide between Red Creek and Salt Canyon, forms the top of Table Mountain, and extends southward along the divide between Salt Canyon and Patton Canyon.

Character.—The Lytle sandstone member, which is named from Lytle, in the valley of Turkey Creek, consists of sandstone and intercalated beds of grit and shale. Its base is generally marked by a coarse massive sandstone 15 feet or less thick, composed of prevailingly siliceous white, yellowish-brown, or blackish grains. The average diameter of these grains is about an eighth of an inch, but the largest fragments are an inch across. In some places, as near Colorado City, the base of the member consists of fine-grained white or cream-colored sandstone 100 feet thick. The Lytle member contains pebbly beds at several horizons and scattered lenses of greenish or reddish clay near the top. The pebbly layers, which are separated by beds of fine-grained white sandstone, are abundant in the uppermost 50 feet. The average thickness of the member is 145 feet.

The Glencairn shale member, so named from a tract of land a few miles north of Lytle, consists of dark shale and a little sandstone and is rather sharply separated from the Lytle member. The best section is in the railroad cut near Bear Creek. The base of the member consists of 12 feet of purplish-black shale, much cracked and broken, having veins of gypsum, the largest a quarter of an inch thick in the cracks. The succeeding 18 feet consists of grayish sandy shale with layers of fine-grained gray or yellow sandstone an inch thick. Above is 40 feet of purplish-black shale like that at the base, succeeded by 15 feet of drab clay. About 110 feet above the base is a bed of friable fine-grained ocher-stained sandstone 18 inches thick, overlain by a few feet of light-brown clay. The uppermost 25 feet consists of paper-thin layers of purplish-black shale with gypsum-filled cracks. The member attains its maximum thickness near Colorado City, where it is 145 feet thick, but in the southern part of the quadrangle it is much thinner and in places measures less than 10 feet.

Age and correlation.—No fossils have been found in the Lytle sandstone member in the quadrangle. The Glencairn shale member has yielded fossils from several beds, which have been identified by Stanton as a species of Lingula. He regards them as the same as those found on Oil Creek north of Canon City in shale that he has correlated with beds of Comanche age in the southern part of the State. Stanton considers the fauna as belonging to the horizon of the Washita group in Texas.

UPPER CRETACEOUS SERIES.

DAKOTA SANDSTONE.

Definition and relations.—The Dakota formation consists of light-colored quartz sandstone having an average thickness in the Colorado Springs quadrangle of 100 feet. It lies unconformably on the Purgatoire formation, although the unconformity is probably not extensive. As a rule it is conformably overlain by the Graneros shale, of Benton age, but near the north side of the quadrangle the intervening formations are overlapped by the Dawson arkose, which there lies unconformably on the Dakota.

Distribution.—The largest area occupied by the formation in the quadrangle is along the slope west of Turkey Creek, near the south side of the quadrangle. It extends northward in a narrow belt as far as the divide north of Little Fountain Creek and appears again at the head of Limekiln Valley southeast of Cheyenne Mountain. Another area extends in a narrow interrupted belt from Bear Creek northward nearly to the north side of the quadrangle. At several points along the belt the outcrop is marked by the hogbacks that are characteristic of the highly inclined or vertical beds of the Dakota along the base of the Front Range. These hogbacks are especially prominent just west of Colorado City and just southeast and also half a mile northeast of the Garden of the Gods. (See Pl. III.)

Character.—The rock is light-colored, nearly pure quartz sandstone of even grain but commonly cross-bedded. In many places weathering brings out a concretionary structure, which is developed on a large scale. In much of the quadrangle the rock is buff, yellowish, or gray; in Deadman Canyon many layers are pinkish, and south of that place the rock is reddish, its color being due to small quantities of hematite. Purplish and blackish markings indicate manganese. Concretions an inch across, partly limonite and partly hematite, are common, and some are nearly perfect spheres. Many weathered surfaces are ripple-marked. In certain localities quartz veinlets, which stand out sharply on weathered surfaces, form a nearly constant feature of the sandstone. Northwest of Colorado Springs the rock is weak and friable, but in the southern part of the quadrangle it is greatly indurated by siliceous cement. The fracture is in places conchoidal, but as a rule characteristic rectangular slabs a foot or less across weather out from the rock.

The section at Bear Creek, which may be regarded as typical, shows at the base 35 feet of massive sandstone, partly cream-colored, partly pinkish, overlain by 5 feet of alternate layers of thin sandstone and blue-black shale, with 4 feet of slate-colored shale next above. At the top is 55 feet of massive cream-colored cross-bedded ripple-marked sandstone containing numerous limonitic concretionary balls of all sizes, the largest an inch across.

The formation includes much fine-grained clay, a variable mixture which is eagerly sought for making fire brick. The maximum thickness of these beds is 20 feet. The clay is purplish gray and exhibits irregular conchoidal partings. At some places it is lumpy and brownish, and at others it contains traces of coal.

Age.—On account of its flora the Dakota sandstone has been assigned to the base of the Upper Cretaceous series. Impressions of leaves, stems, and branches are common, but as a rule they are poorly preserved. The best-preserved remains of plants found in the quadrangle were collected in Deadman Canyon. Bird tracks have been found, and at one point on Turkey Creek, near the south side of the quadrangle, remarkable dinosaur tracks were discovered by Dr. F. W. Cragin. The three-toed footprints, repeated several times in the sandstone, are each 18 inches long. They are the only dinosaur tracks found in the Dakota sandstone.

COLORADO GROUP.

In the Colorado Springs quadrangle the Colorado group is divisible into four formations, which, in order of age, from oldest to youngest, are known as the Graneros shale, Greenhorn limestone, Carlile shale, and Niobrara formation. The first three formations are the equivalent of the Benton shale of other areas.

GRANEROS SHALE.

The Graneros shale, the basal formation of the Colorado group in this region, consists, as its name implies, almost wholly of shale. The lowest beds are fine grained and purplish or slate-colored. The transition from the Dakota sandstone is rather gradual. Near the middle of the formation there is a bed of sandstone, 4 feet thick, resembling the Dakota, and the shale above it is noticeably darker. Some beds near the top have been leached, leaving whitish layers, a few inches thick, rich in kaolin. The thickness of the formation ranges from 175 feet in the northern part of the quadrangle to 220 feet in the southern part. At Colorado City the shale has been dug for brickmaking and the section is well exposed. The area occupied by the Graneros shale is characteristically barren of timber. The formation was named from Graneros Creek, in the Pueblo quadrangle.

GREENHORN LIMESTONE.

The Greenhorn limestone consists of light bluish-gray or dove-colored limestone, in massive beds alternating with layers of fissile shaly limestone and of shale. Most of the beds are less than a foot thick, although some measure 2 feet or more. The limestone weathers with a characteristic cleavage, breaking into plates, half an inch or less thick, which stand at right angles to the bedding. The Greenhorn limestone is arbitrarily separated from the Graneros shale at the lowest bed of limestone, so that the thickness of the Greenhorn in this quadrangle is 50 feet. The Greenhorn is more resistant than the underlying and overlying shales and forms a low ridge or bench between the two narrow valleys or flats occupied by the Graneros and Carlile shales. The formation is characterized by abundant remains of *Inoceramus labiatus*, which, together with its peculiar cleavage, makes it easy to identify. The area occupied by the Greenhorn limestone is marked by a growth of piñon and juniper. The formation was named from Greenhorn Creek, in the Pueblo and Walsenburg quadrangles.

CARLILE SHALE.

The Carlile shale consists of about 60 feet of black thin-bedded shale capped by a thin bed of yellow sandstone, which sharply separates it from the limestone of the overlying Niobrara formation. The formation is best exposed in the cut at the reservoir southeast of the Garden of the Gods, where the rock is bluish black and becomes brownish on weathering.

The top sandstone, which is in places 20 feet thick, though only 10 feet on the average, is extremely persistent and is at many localities an important horizon marker. It is a fine-grained yellow calcareous sandstone weathering light brown. On fresh fractures it presents a surface of rounded grains of quartz and specks of limonite. The sandstone becomes more calcareous toward the top. The uppermost richly calcareous beds contain abundant fossils, the commonest being *Ostrea lugubris* and *Prionocyclus wyomingensis*. The formation was named from Carlile Spring, about 20 miles west of Pueblo.

NIOBRARA FORMATION.

Definition and relations.—The Niobrara formation consists of limestone below and calcareous shale above, the total thickness in the Colorado Springs quadrangle ranging from 400 to 500 feet. It is the upper formation of the Colorado group. In some areas south of the Colorado Springs quadrangle the limestone and shale are mapped separately as the Timpas limestone and the Apishapa shale, but they have not been separated in this folio.

The formation rests conformably upon the Carlile shale, from which it is sharply distinguished lithologically. It is conformably overlain by the Pierre shale, and in the southern part of the quadrangle, where the top of the Niobrara is defined by a thin bed of limestone, the two formations can be easily separated. Near Colorado Springs, however, the two intergrade to some extent and must be separated chiefly by means of their fossils.

Distribution.—The principal area of the formation in the quadrangle is in its central-southern part, where it occupies a belt about 4 miles wide, extending as far north as Little Fountain Creek. It is exposed in a small area at the head of Limekiln Valley and in another at the mouth of Cheyenne Canyon. In the northern part of the quadrangle it occupies a narrow belt extending from Bear Creek northward to the northern boundary.

Character.—The base of the formation consists of 50 feet of bluish-gray limestone in beds that in places reach a thickness of 2 feet and that are separated by a few inches of calcareous shale. The beds of limestone are crossed by innumerable tiny veins of calcite. The beds exhibit a rude, more or less conchoidal fracture, parallel to the lines of stratification, and here and there contain ferruginous limonitic concretions, resembling those in the Dakota sandstone but much smaller. These basal beds in places form low ridges parallel to the Dakota hogback ridges. (See Pl. IV.)

The limestone grades into shale through a zone of alternate beds of limestone and shale in about equal amount. At a few places near the middle of the formation there are fine-grained sandy beds. The rock of the upper two-thirds of the formation is bluish-black, finely laminated calcareous shale, which on weathering breaks into thin papery flakes between which lie thin layers of gypsum.

Fossils.—Fish scales a fraction of an inch in diameter are common everywhere in the shale of the Niobrara, and with them are associated a few shark teeth. Single thin calcareous layers of the formation are made up entirely of oyster shells. In the basal limestone the most abundant and characteristic fossil is *Inoceramus deformis*.

MONTANA GROUP.

PIERRE SHALE.

Definition and relations.—The Pierre formation consists of dark shale having a thickness in the Colorado Springs quadrangle of 2,500 feet. It is the lower formation of the Montana group. It rests conformably upon the Niobrara formation and is conformably overlain by the Fox Hills sandstone. At some places it is clearly separated from those formations by distinct lithologic differences; at other places it grades into one or the other of them through transitional beds.

Distribution.—The formation occupies a greater part of the quadrangle than any other, covering all its southeastern and most of its central part, in all about 350 square miles. It occurs in a wedge-shaped area from the point of which, just west of Monument Park, it broadens southeastward across the center of the quadrangle to the southeast corner.

Character. — The formation presents the same general features throughout. Its lowermost 500 feet is leaden-gray shale which contains gypsum in crevices and larger cracks that cross the beds. Numerous layers of clayey limonite-stained fossiliferous limestone concretions, some of them 2 or 3 feet in diameter, are found in this zone. When broken open they exhibit many radiating veins of amber-colored calcite. The shales of the middle zone are darker and contain numerous sandy layers.

At the top of the formation is a zone, about 500 feet thick, marked by limestone cores, which resist weathering more than the surrounding shale and form the small, sharp conical hills, about 50 feet in diameter, called by Gilbert tepee buttes. They are abundant east of the railroads, in the southeastern part of the quadrangle. The limestone cores of the buttes are cylindrical or lenticular. Smaller limestone concretions are abundant in the same general zone. At some places the uppermost beds of the formation contain sandy layers similar to those lower down. These upper sandstone beds form a sort of transition zone to the overlying Fox Hills sandstone, but at some places the upper part of the Pierre consists wholly of shale, so that the transition to the Fox Hills is abrupt.

The Pierre is perhaps the least resistant to erosion of the several formations in the quadrangle, and its area is nearly everywhere a rolling plain. On weathering it forms the clay known locally as adobe.

Fossils.—About the middle of the formation *Lucina occidentalis* and *Baculites compressus* occur abundantly, and the original shell substance is preserved in many places. Many other characteristic Pierre species are distributed through the shale. In the Pueblo folio this part of the formation was called the Baculites zone because of the abundance of this characteristic fossil. In eastern Colorado the Pierre contains an abundant marine fauna.

FOX HILLS SANDSTONE.

Definition and relations.—The Fox Hills sandstone, greenish and brownish, is about 600 feet thick in the quadrangle. It is the upper formation of the Montana group. It lies conformably on the Pierre shale and is conformably overlain by the Laramie formation, from which it is not sharply distinguished in lithologic character.

Distribution.—The formation occupies a belt extending from the west end of Monument Park southeastward past Colorado Springs to a point a little south of the middle of the east side of the quadrangle. From Monument Park to the south end of Popes Bluffs the belt is narrow, but from that point on it widens, and southeast of Colorado Springs it is 2 to 4 miles wide. The formation is well exposed along Monument Creek north of Colorado Springs, and near Franceville Junction. Its outcrop is, however, generally inconspicuous, being covered by detritus from the overlying formations.

Character.—The sandstone is quartzose but everywhere contains a little mica, in part muscovite and in part biotite, and scattered grains of feldspar. Clay is a noticeable constituent of the lower two-thirds of the formation, making it shaly. The sandstone is commonly friable, and its fresh surfaces are dull greenish. On weathering it generally becomes rich brown. It is even grained, finely laminated, and well bedded and shows clearly defined horizontal jointing.

The basal part, about 50 feet thick, consists of beds of greenish-gray sandstone, 2 or 3 inches thick, separated by layers of shale. The higher beds contain sandstone concretions, the largest 4 feet in diameter.

Fossils.—The fossil plant *Halymenites major* is found in the formation at a few places in the quadrangle, and impressions of fucoid stems are numerous. The upper beds contain the following species of marine invertebrates, which occur also in the Fox Hills sandstone of other areas:

- Nucula sp.
- Cardium speciosum Meek and Hayden.
- Protocardia subquadrata Evans and Shumard.
- Sphæriola cordata Meek and Hayden.
- Callista deweyi Meek and Hayden.
- Mactra holmesi (Meek).
- Dentalium sp.
- Lunatia sp.

LARAMIE FORMATION.

Definition and relations.—The Laramie formation consists of quartz sandstone, sandy and clay shale, and some beds of lignite. Its thickness in the quadrangle is from 250 to 300 feet. It rests conformably on the Fox Hills sandstone, from which it is not everywhere clearly distinguishable. It is limited above by an unconformity and in the Colorado Springs quadrangle is overlain by the Dawson arkose.

Distribution.—The formation occupies a belt of irregular width extending from the west end of Monument Park southeastward to the middle of the east side of the quadrangle. It is well exposed along the road leading northward from Colorado Springs, in the bed of Monument Creek north of Pikeview, and in Popes Bluffs.

Character.—The lower half of the formation consists of white fine-grained quartz sandstone in massive homogeneous beds separated by irregular layers of sandy shale. Coal beds, some of them 8 feet or more thick, occur at several horizons. In addition to the quartz, the rock contains conspicuous grains of black chert and rare particles of feldspar and mica. The sandstone is generally clear white, but at its base it is stained yellowish by iron.

The upper half of the formation consists of brownish-black or black clay shale with interbedded irregular beds of sandstone. The shale is arenaceous and lignitic. At certain horizons thin beds of extremely fine grained ferruginous sandstone are conspicuous. The upper part of the shale has been removed by erosion and the thickness of the part remaining reaches a maximum of 150 feet.

Fossils.—The flora of the formation in the Colorado Springs quadrangle includes the following species, identified by F. H. Knowlton from material collected by several members of the United States Geological Survey:

- Ficus spectabilis? Lesquereux.
- Ficus trinervis Knowlton.
- Ficus lanceolata Heer.
- Ficus latifolia (Lesquereux) Knowlton.
- Ficus planicostata Lesquereux.
- Pistacea oblanceolata Lesquereux.
- Rhamnus salicifolius Lesquereux.
- Viburnum marginatum Lesquereux.
- Dombeyopsis platanoides? Lesquereux.
- Myrica torreyi Lesquereux.

Mr. Knowlton states that most of these species occur in the Laramie formation of the Denver Basin, though two species (*Rhamnus salicifolius* and *Myrica torreyi*) are found also in lower beds, and one, possibly two, in the Denver formation. A number are also found in the so-called "Lower Laramie" of Custer County, Wyo., which Mr. Knowlton holds is of the same age as the Laramie of the Denver Basin.

TERTIARY SYSTEM.

DAWSON ARKOSE.

Definition. — The name Dawson arkose was applied by Richardson in 1912 to the series of arkose sediments that lie above the Laramie formation and in the Castle Rock quadrangle are overlain by the Castle Rock conglomerate. Their total thickness is about 2,000 feet. About half of this amount appears in the northern part of the Colorado Springs quadrangle.

Relations.—The formation is limited below by an unconformity which separates it from the Laramie and earlier sediments of the Colorado Springs region. Its top does not appear within the quadrangle. Farther north, in the Castle Rock area, the Dawson arkose is delimited at its top by an unconformity between it and the overlying Castle Rock conglomerate. Local unconformities appear within the formation.

Distribution.—The Dawson arkose extends from the northeast corner of the quadrangle to a line beginning about 5 miles from its northwest corner and running southeastward through Monument Park, Pulpit Rock, Manitou Junction, and Franceville School to its eastern boundary. The total area occupied by the formation in the Colorado Springs region is about 225 square miles. It is therefore one of most widely distributed formations within the quadrangle.

Character.—Immediately above the unconformity at the top of the Laramie near Colorado Springs there appear at two localities lenses, about 35 feet thick, of fragile, fine-grained siliceous sandstone with characteristic wavy banding and frequent cross-bedding. Conglomeratic layers of well-worn pebbles occur in the lower half of these sandstone lenses. The pebbles average less than half an inch across, and most of them consist of black, red, and ocher-yellow chert, though pebbles of quartzite, white quartz, limestone, and granite are also found. Overlying the two sandstone lenses above described and elsewhere resting on the eroded surface of the Laramie is a remarkably uniform series of fine-grained friable sandstones made up almost entirely of fragments of andesite. Their outcrop is clearly traceable across the quadrangle from a point just south of Monument Park to Franceville School, but they are nearly everywhere covered by overlying wash between this locality and the eastern margin of the quadrangle. These andesitic beds, which are about 90 feet thick, occupy a stratigraphic position similar to that of the Denver formation of the Denver Basin, and they have been mapped as a separate lithologic unit—the andesitic member of the Dawson arkose. Conglomeratic layers are present near the middle of the series. Few of the pebbles are more than an inch in diameter, and most of them are less. Variable amounts of quartz occur in the fine andesitic matrix in which the pebbles lie.

Above are the massive beds of arkose which constitute the great body of the Dawson formation. Their prevailing color is grayish white. The lowest arkosic beds in the quadrangle differ considerably in the coarseness of their constituents and in the relative amounts of their interbedded carbonaceous clays. Immediately above the andesitic strata near Austin Bluffs is a bed, 20 feet thick, of unusually well rounded pebbles, the largest measuring 2 inches across. Granite, pegmatite, schist, quartzite, quartz, and chert of many colors appear among them.

The rock that makes up the higher massive beds of the Dawson, many of which are 5 or 6 feet thick, is friable arkose consisting of angular or subangular fragments of quartz, white kaolinized feldspar, and deeply weathered granite. Here and there throughout the series there are thin interbedded white quartz-rich sandstones and lenses of whitish or buff-colored clay. The sediments are interpreted as continental deposits, chiefly of fluviatile origin, although some parts of them were plainly laid down in bodies of standing water. The occurrence of plant remains supports this view.

Near the base of the formation there are occasional layers of arkose whose grains have been cemented together by limonite. This has been deposited secondarily in large quantities. Such beds are very firm and strong, and the parts of them that are still unreduced by weathering form protecting caps for the weaker arkose below. Many columns and castellated forms have been produced in this way. They may be seen in their most striking forms in Monument Park. (See Pls. XII to XIV.) At many places cavernous openings have been worn into the bases of cliffs by solution.

Age and correlation.—The rocks now referred to the Dawson arkose were treated as a part of Hayden's Monument Creek group in all geologic descriptions of this area published prior to 1912. Because of "the modern appearance of the group of coarse sandstones and conglomerates above the true Cretaceous beds," that group was considered by Hayden as "modern Tertiary" and later, on the evidence of a few vertebrate fossils, was determined to be of the same age as the White River group. This group is now referred to the Oligocene but was formerly considered Miocene. Recent work has shown that these Oligocene fossils all came from that part of the "Monument Creek group" which is now described as the Castle Rock conglomerate, and that the lower part, constituting the Dawson arkose, is in part approximately the equivalent of the Denver and Arapahoe formations of the adjacent area on the north. All the evidence bearing on the age of these two formations is therefore applicable to the Dawson arkose.

Some of the facts cited to show the Cretaceous age of the Dawson, Arapahoe, and Denver formations are (1) the Mesozoic affinities of the reptilian fauna, which includes Triceratops and two or three other genera of dinosaurs; (2) the evidence from both the flora and the reptilian fauna that the three formations mentioned are not younger than the Lance formation of Wyoming and adjacent States, which has a much larger vertebrate fauna, closely related to earlier faunas of known Cretaceous age, and brackish and fresh water invertebrate faunas, also much more closely related to preceding Cretaceous faunas than to the succeeding Eocene faunas; (3) the Cretaceous character of the invertebrate fauna in the Cannonball marine member of the Lance formation in North and South Dakota, which, according to Stanton, is very closely related to and probably directly derived from the Cretaceous Fox Hills fauna, although it occurs in beds that overlie 400 feet of nonmarine deposits containing Triceratops and other representatives of the typical Lance reptilian fauna; (4) the evidence for practically continuous sedimentation from the acknowledged Cretaceous into the Lance in the Dakotas and in several other areas.

Briefly stated the principal facts in favor of the Eocene age of these formations are (1) the lithologic and other evidence of a post-Laramie period of uplift and long-continued erosion prior to Arapahoe and Dawson sedimentation; (2) the very great difference between the Laramie flora on the one side and the flora of the Arapahoe, Denver, and Dawson on the other, the two having only a few species in common; (3) the close relationship which Knowlton's unpublished studies have shown to exist between the Denver and Dawson flora and the flora of the Raton formation, which, as Lee has proved, rests unconformably on the underlying Cretaceous formation; (4) the identity of many species of the Raton and related floras, as established by unpublished investigations of Knowlton and Berry, with species in the floras of the Eocene Midway and Wilcox formations of the Gulf Coastal Plain, whose age is well determined by stratigraphic position and marine invertebrate faunas; (5) the discovery in the Dawson arkose of a mammal bone which, according to Gidley, belongs to a creodont of a type not known to be older than Wasatch. Those who support this view also maintain that the dinosaurs and the fossils of the Cannonball marine member, which resembles the Cretaceous fauna, may have survived into the Eocene.

It is not now possible to harmonize all the known facts relating to the Cretaceous-Tertiary boundary in the Rocky Mountains and Great Plains regions, but many geologists believe that the available evidence indicates the Eocene age of the Dawson arkose and it is accordingly so classified in this folio.

Fossils.—A number of collections of fossil leaves have been obtained from the Dawson arkose in the Colorado Springs quadrangle by members of the United States Geological Survey. These fossils were identified by F. H. Knowlton and are listed below.

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

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

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

- Platanus rhomboidea Lesquereux.
- Cinnamomum affine Lesquereux.
- Ficus denveriana? Cockerell.
- Rhamnus goldianus? Lesquereux.
- Ficus sp., new 5-ribbed, large.
- Berchemia multinervis (Al. Braun) Heer.
- Palmocarpon commune? Lesquereux.

East bank of Jimmy Camp Creek, in the NW. ¼ sec. 10, T. 14 S., R. 65 W.:

- Ficus spectabilis? Lesquereux.
- Ficus trinervis Knowlton.
- Palmocarpon sp.?
- Rhamnus rectinervis? Heer.

Branch of Jimmy Camp Creek, in the southeast corner of sec. 9, T. 14 S., R. 65 W.:

- Rhamnus salicifolius Lesquereux.
- Fern, new.
- Ficus planicostata? Lesquereux.
- Ficus irregularis? Lesquereux.
- Magnolia tenuinervis? Lesquereux.

Lower part of gully on west side of Pulpit Rock, east of Pikeview, Colo., in sec. 17, T. 13 S., R. 66 W.:

- Dryopteris lakesii (Lesquereux) Knowlton.
- Nelumbo lakesii? (Lesquereux) Knowlton.
- Viburnum marginatum Lesquereux.
- Ficus planicostata Lesquereux.
- Ficus planicostata clintoni Lesquereux.
- Ficus lanceolata? Heer, of Lesquereux.
- Aralia? sp.

Same locality as the last, but higher in the section:

Sequoia acuminata Lesquereux.	Ficus lanceolata Heer, of Lesquereux.
Juniperus? sp.	Magnolia ovalis Lesquereux.
Dryopteris lakesii (Lesquereux) Knowlton.	Cissus lobato-crenata Lesquereux.
Platanus raynoldsii integrifolia Lesquereux.	Laurus? sp.
	Aralia sp.

Pulpit Rock, east of Pikeview, Colo., NW. ¼ sec. 20, T. 13 S., R. 66 W.:

Populus arctica Heer, of Lesquereux.	Rhamnus salicifolius Lesquereux.
Sabal? ungeri (Lesquereux) Knowlton.	Viburnum sp. (probably new).
Dombeyopsis obtusa? Lesquereux.	Ficus sp.
	Ficus? sp.

Palmer's ranch, Templeton Gap, 4 miles northeast of Colorado Springs, Colo.:

Carpites sp.	Sequoia sp.?

Same locality as last but half a mile farther east:

Rhamnus salicifolius? Lesquereux.	Platanus? sp.
	Viburnum sp. (probably new).

Bluffs back of Dr. Sturgis's residence, west of Templeton Gap:

Sequoia obovata? Knowlton ined.	Salix sp.
Sequoia acuminata Lesquereux.	Ficus trinervis Knowlton.
Dammara sp.	Rhamnus salicifolius Lesquereux.
Cyperacites sp.	Carpites sp. (Palmocarpon?).

Mr. Knowlton refers all these forms, which came from the lower half of the Dawson arkose, to the Denver flora. He notes, however, that *Sequoia obovata?*, in the last lot, had not previously been recognized as occurring above the Laramie and calls attention to the fact that it is represented by a single rather poorly preserved branchlet and may not be correctly determined.

At a higher horizon, estimated to be at about the middle of the formation, the following leaves were obtained, concerning which Mr. Knowlton says:

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

From cut at railroad crossing 1 mile southwest of Falcon, Colo., 10 miles southwest of Eastonville:

Asplenium sp., new.	Quercus sp., new.
Hemitelia? sp., new.	Ficus? sp., new.
Pteris? sp., new.	Several fragmentary dicotyledons.

A few fragmentary vertebrate remains have been found in the Dawson arkose, and these, too, were obtained from the lower part of the formation. All the bones except one mammalian fragment are remains of turtles, Ceratopsia, and other dinosaurs, presumably like those obtained from the Arapahoe and Denver formations.

Many years ago O. C. Marsh [1] found "fragments of vertebrate remains, evidently of this same characteristic fauna [fauna of the Lance formation or "Ceratops beds"] in the well-known rock columns [composed of Dawson arkose] of Monument Park." 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 Richardson 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 about 600 feet above the base of the formation. This is approximately the place at which Lee and Gilmore later obtained the above-mentioned reptilian fragments, the association of which with mammalian remains is an interesting fact. Although the mammalian bone was found loose on a hillside, it was presumably very near 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, though 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 and the considerable development of a median ridge denote a specialized type of hind foot leading toward the true carnivores. Our present knowledge of the creodonts indicates that such a type could not be older than Wasatch.[3]

SANDSTONE DIKES.

Distribution.—Prominent sandstone dikes occur in the granite near its eastern border at several places between Cheyenne Mountain and Cascade. They are a continuation of those in the northeastern part of the Pikes Peak quadrangle, to which Cross first directed attention. Dikes are numerous northwest of Engelmann Canyon, but they are relatively small and inconspicuous compared with those mapped in the Pikes Peak folio. Larger dikes are, however, prominent southeast of Manitou, between Engelmann Canyon and Redrock Canyon, and at the mouths of North Cheyenne and South Cheyenne canyons. Another set, less conspicuous, occurs near Mount Pittsburg, in the southwest part of the quadrangle. These, however, are not mapped.

The larger dikes are at or near the Ute Pass fault and follow the same general trend, though the ends of some of them curve slightly away from it. The smaller dikes, some of which are half a mile away from the fault, trend in various directions, but many of them are nearly parallel to it.

Character.—The dikes are made up chiefly of fine grains of quartz and a little feldspar, firmly cemented by limonite and secondary silica. They contain some small masses of granite. The material is remarkably homogeneous and shows banding at only a few places. Its ordinary color is brownish red mottled with white.

The dikes are of various sizes: the smallest are mere veins filling small cracks; the largest are hundreds of feet wide. The longest is more than a mile long, and several are nearly half a mile long. Many are conspicuous because they are more resistant than the inclosing granite and weather in relief. A few dip steeply southwestward, but most of them are vertical or nearly vertical. Branching forms and small apophyses are abundant, and in some places the smaller dikes form a network. The actual contact between the dike sandstone and the granite is exposed at many places but at others is obscured by talus or wash.

Origin and age.—The origin and age of these dikes are not certainly known. The fact that they lie in a zone parallel to the Ute Pass fault indicates a genetic relation to the fault. It appears that many small fissures were formed near the fault and in general parallel to it and were filled with sand, which was later hardened by the deposition of secondary silica. The fact that the inclosing rock is granite seems to preclude the possibility that the sand filling the fissures came from below. The material that forms the dikes is of the same texture and composition as the lowest Cambrian sandstone—the Sawatch—and shows no distinct sedimentary banding. Crosby has suggested that fissures along the fault line and parallel to it were filled by plastic sand as soon as they were opened, during Cambrian time. The dikes, however, so clearly show a genetic relation to the faulting that this suggestion must meet the objection that the faulting was later than the Niobrara epoch; yet faulting along the same general line may have taken place during the Cambrian period. The dikes are therefore regarded as probably of Tertiary age.

A possible explanation of their formation in connection with the post-Cretaceous faulting is shown in figure 3. The monoclinal uplift of the mountain area, which resulted in sharply upturned beds at its margin and in normal faulting between the granite and the sedimentary beds, is shown in figure 3, *a* and *b*. The basal Sawatch sandstone, being friable and granular, would yield most readily to the shearing stresses, so that the fault movement would tend to take place within it, and its sand grains, more or less cushioned in water, would act as a lubricant of the fault movement. The sand would afterward be hardened into sandstone dikes filling the crevices along the fault contact between the granite and the sedimentary rocks, as shown in figure 3, *c*. Dikes in the granite parallel to the fault contact may represent the lubricant sand that descended in a fault zone below the sediments, which have been removed by erosion. The sand was probably also transported to some extent along the fault crevices by circulating waters.

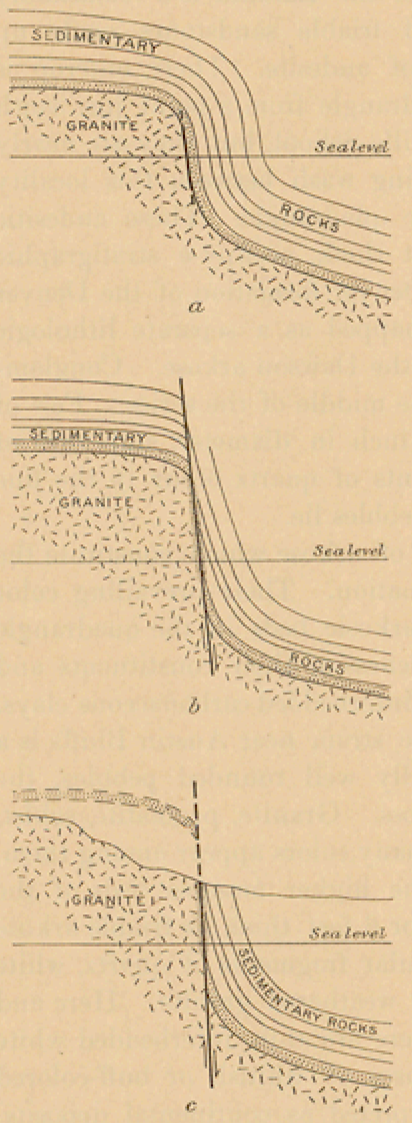


FIGURE 3.—Ideal sections showing possible origin of the sandstone dikes along the mountain front.

a, Monoclinal fold, representing the Rocky Mountain uplift and beginning of normal faulting; *b*, sand from basal Sawatch sandstone left in fault zone between the granite and sedimentary rocks; *c*, resultant sandstone dike at fault contact.

TERTIARY IGNEOUS ROCKS.

PHONOLITE.

Distribution.—A few small masses of phonolite are exposed in the southwest corner of the Manitou quadrangle. Their total volume is small, and all are peripheral masses directly connected with the near-by Cripple Creek volcanic center. The largest single mass, which occupies an area of about one-fourth square mile, is on Cow Mountain. The rock also crops out prominently on the hill south of Bull Park, and smaller areas, less than 200 yards across, are on Little Cow Mountain and on Bison Creek 2 miles above Cathedral Park. On the southeast side of Bison Reservoir several small dikes have been exposed in prospect holes. The larger masses are parts of extruded sheets, but the conduits from which they issued have not been found. The caps on Cow Mountain and on Little Cow Mountain may be parts of the same sheet, and the two areas may once have been continuous with those east of Bison Creek, though they lie at altitudes differing by more than 500 feet.

Character.—The rock is dense, fine grained, and nearly aphanitic and consists chiefly of feldspar, nephelite, and ægirite. It is sparingly porphyritic. Where unweathered it is generally dark drab and greasy looking, but where weathered it is brownish gray or gray. A marked fissility, which weathering makes more apparent, causes the rock to break into innumerable thin plates.

Petrography.—A study of thin sections shows that the rock is holocrystalline and is made up of feldspar, nephelite, and ægirite, more or less sodalite and noselite, and accessory zircon, biotite, titanite, and magnetite. A trachytic texture is common and is due to the arrangement in flow lines of small feldspar individuals in the groundmass. The average diameter of the grains is not more than a few hundredths of a millimeter.

Feldspar is abundant, in phenocrysts some of which are 0.6 millimeter in diameter. Carlsbad twinning is common, and a well-marked cleavage parallel to the clinopinacoid is noticeable. Some of the mineral is fresh and glassy, but most of it is turbid from kaolinization. Its composition appears to differ from center to periphery but seems to be chiefly that of the potash-soda feldspar anorthoclase. Small lath-shaped subhedral feldspars, twinned after the Carlsbad law, make up a large part of the groundmass and by their arrangement in flow lines give the rock its peculiar texture.

Nephelite is abundant in euhedral or subhedral crystals a few hundredths of a millimeter across, with square or rectangular cross sections. The mineral is older than the surrounding ægirite. Noselite forms euhedral crystals, some as much as 0.7 millimeter across. Small inclusions arranged in definite lines are common. Another abundant isotropic mineral having the same dodecahedral form is probably sodalite. The crystals are only a few hundredths of a millimeter across but are easily recognized by their cloudy inclusion-filled centers and clear and glassy peripheral portions.

Ægirite, the only abundant dark silicate, forms subhedral prismoid or anhedral irregular individuals. The pleochroic colors are yellowish green, clear emerald-green, and grayish green. The characteristic forms are long, ragged individuals surrounding nephelite, stubby prisms, and irregular wisps. Among the accessory minerals are zircon in minute subhedral prismoid crystals of grayish-brown color, rare grains of titanite 0.1 millimeter or less across, minute flakes of biotite, some of them euhedral, and magnetite in irregular netlike areas.

Chemical composition.—The phonolite of the Colorado Springs area is so closely similar in mineral composition to that at Cripple Creek that the average (given below) of four analyses of the latter may be taken as typical of its chemical composition. The norm computed from the analyses shows that the rock is miaskose.

Average of four analyses of phonolite from Cripple Creek.[1]

[W. F. Hillebrand, analyst.]

SiO_2	58.85
Al_2O_3	20.06
Fe_2O_3	1.83
FeO	.51
MgO	.18
CaO	.95
Na_2O	9.01
K_2O	5.43
H_2O-	.27
H_2O+	1.74
TiO_2	.25
ZrO_2	.16
CO_2	.12
P_2O_5	.04
SO_3	.10
Cl	.31
MnO	.18
BaO	Trace.
SrO	Trace.
Li_2O	Trace.
	99.98

QUATERNARY SYSTEM.

The Quaternary deposits of the area comprise glacial drift, outwash gravel, and terrace gravel of Pleistocene age and alluvial deposits of Recent age. All are unconsolidated and are derived from the waste of older rocks, largely from the pre-Cambrian rocks of the mountains, though the stratified rocks have contributed some material. Much of the later gravel is reworked material, originally a part of the drift or of the older gravel that was cut away and redeposited in its present form. Some of it may have been reworked more than once, and all the gravel, both Pleistocene and Recent, belongs to an essentially continuous series of deposits.

[1] Geology of the Denver Basin in Colorado: 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] Richardson, G. B., The Monument Creek group: Geol. Soc. America Bull., vol. 23, pp. 267-276, 1912.

[1] U. S. Geol. Survey Prof. Paper 54, p. 66, 1906.

PLEISTOCENE SERIES.

GLACIAL DRIFT.

Distribution.—Glacial drift is found in each of the larger valleys leading away from Pikes Peak, within 5 miles of the summit. The largest deposits lie along the East Fork of West Beaver Creek, southeast of the peak, and at the headwaters of the North Fork of French Creek, north of it. There is a great accumulation of glacial gravels in the valley of the "Bottomless Pit," and smaller deposits in the cirque valleys called Glen Cove and The Crater, as well as in the cirque valley north of Windy Point. In the valley leading to Seven Lakes, near Reservoir No. 2 and between reservoirs Nos. 4 and 5, there are several areas of these gravels. Glacial drift nearly surrounds Lake Moraine, and a small area of ice-laid gravel begins at the lower end of the valley of the West Fork of West Beaver Creek and extends beyond the western border of the Manitou quadrangle.

Form and thickness.—Glacial drift in the form of lateral moraines is not common in the Pikes Peak region. The most conspicuous lateral moraines are on the north side of the valley of the North Fork of French Creek and on the sides of the valley of Lake Moraine. Their upper ends lie at points where the rim of the valley begins to open out or flare away. Their slope toward the center of the valley is longer and gentler than that on the opposite side. Their crest lines are even, and they fall away rapidly downstream. Prominent long or tabular terminal moraines extend across the glaciated valleys. The highly irregular distribution of the drift gives rise to hummocks, hollows, uneven short ridges, and long depressions. Many of the moraines have steep fronts on their downstream sides and gentle slopes upstream.

The most pronounced terminal moraine lies north of Bison Reservoir. It is nearly a mile long and is in places half a mile broad. The compound terminal moraine at the point where The Crater and the cirque valley southeast of it come together is remarkable for its irregular surface and steep front. The terminal moraine at Seven Lakes consists of many small ridges, which extend across the valley.

The thickness of a few of the terminal moraines on the northeast side of Pikes Peak can not be less than 300 feet. The moraine near Bison Reservoir, however, is only about 150 feet thick at a maximum, and the moraine at Seven Lakes is in many places still thinner.

Character.—The glacial drift is made up almost wholly of the Pikes Peak granite and contains only small amounts of the Cripple Creek and Windy Point granites. The material consists of angular fragments of many sizes, the largest 8 or 10 feet in diameter. Few pieces of the drift show striations indicating ice work, and much of it is relatively fresh and unweathered.

MESA GRAVEL.

Distribution.—The mountains are at many points flanked by long tables of gravel whose surfaces, if they were extended across the low valleys that cut through them, would form a continuous sloping plain. These gravel-covered surfaces slope gently from the mountains at angles of 3° or less. At many places along their western edges the gravel is 25 to 50 feet thick, and on the east it thins away to 10 feet or less at a distance of 5 or 6 miles from the mountains. Where the gravel abuts against the mountains it is thickened by talus.

These mesa gravels lie along the flanks of the mountains from the northern to the southern boundary of the quadrangle. They occur at many points north of Queens Canyon and in the Manitou embayment. West of Colorado Springs lies the prominent area called "The Mesa," shown in Plates I and IV, which is capped by these gravels. A still larger mass lies along the eastern face of Cheyenne Mountain. Areas of these gravels appear on both sides of Rock Creek and the area on the north extends eastward nearly as far as Fountain Creek. A similar long tongue of the same material runs from Deadman Canyon to the southern border of the quadrangle. Smaller areas appear at several places along Fountain Creek.

Character.—This gravel was brought to its present positions by streams that deposited it on the gentle slopes at the foot of the mountains. It consists mainly of fragments of granite that are prevailingly angular, though the larger pieces, by their rounded surfaces, show the wear and tear of stream work. They are of many sizes. The larger are 3 or 4 feet across, but most of the grains measure not more than a fraction of an inch. The deposits include a few unusually large blocks of granite, which have rolled down from the steeper mountain slopes, as from the flanks of Cheyenne Mountain. All the fragments of granite, large and small, are rudely sorted and interbedded with abundant sandy layers. Not only the granite but every other rock has made its contribution, so that the deposit includes many fragments of gneiss, schist, sandstone, and limestone, as well as quartz and pegmatite. Probably 90 per cent of the whole mass, however, is made up of Pikes Peak granite. The gravel and sand are nearly everywhere unconsolidated, although in places a calcareous cement seems to unite the grains, and the surfaces of many particles are coated by a chalky film.

Fossils and age.—Few fossils are found in the mesa gravels, the only important one being a molar tooth of *Elephas columbi*, found near the base of the deposit known as "The Mesa," west of Colorado Springs. The crown surface of the the tooth is 1 foot long and 5 inches wide and shows twelve ridges. The tooth is not waterworn and can not have traveled far. It fixes the age of the lowest (youngest) mesa gravel as Pleistocene and therefore contemporaneous with the glacial deposits in the higher valleys on Pikes Peak and near Seven Lakes. The higher mesa gravels are in part equivalent in age to the Nussbaum gravels, mapped in the Pueblo folio, which are regarded as of late Tertiary age.

TERRACED STREAM GRAVEL.

Terrace gravel of late Pleistocene age extends for more than 4 miles along the east bank of Monument Creek upstream from its junction with Fountain Creek. A large part of the city of Colorado Springs has been built on this deposit. The gravel is composed of fine-grained fragments of granite and a variable quantity of particles of quartz, which represent in great part worked-over earlier Pleistocene outwash gravel. At many places these terrace gravels are 12 feet thick.

Similar areas of fine-grained terrace gravel, a few feet wide, occur along the west bank of Monument Creek southwest of Pikeview, but their limits are not clearly defined and it has not seemed feasible to map them separately. They are not known farther south along the course of Fountain Creek.

TALUS AND LANDSLIDES.

Fragments and masses of rock accumulate as talus at the bases of most cliffs and steep rock slopes, but such deposits are generally not large enough to justify their representation on the map. Two broad areas along Fountain Creek above Manitou, however, are shown on the map of the Manitou quadrangle. As these have been dissected by the creek, they are regarded as older than Recent and therefore Pleistocene. A small landslide on the southern border of the phonolite mass composing Cow Mountain is also shown on the Manitou map.

RECENT SERIES.

ALLUVIUM.

Thin deposits of gravel, sand, and clay form narrow flood plains in the valleys of some of the larger streams but are not mapped. Grains of quartz and small pieces of granite, together with fine silt and sand, constitute almost the whole of the deposit along such streams as Monument and Fountain creeks. Bowlders of many sizes, the largest 18 inches in diameter, have worked down from the mesa gravel into the narrow flood plains, but they form only a small fraction of the total detrital material.

STRUCTURE.

GENERAL FEATURES.

Two-thirds of the Colorado Springs quadrangle is an area in which the beds have a gentle monoclinal dip. The plains are underlain by sedimentary rocks that have not been notably disturbed since they were laid down. The rocks in the narrow foothills zone, however, show great disturbance. Many of the beds near the mountains are vertical, and nearly all show high dips. Faulting is general either at the contact between the pre-Cambrian granitic rocks and the sediments or a short distance east of the boundary between them. (See fig. 4.) The uplift of the Front Range of the Rocky Mountains, which finds expression in these dislocations, is the great structural feature of the region. The mountain block itself suffered dislocation in a large way along the Ute Pass fault, and the Pikes Peak mass south of the fault was raised several thousand feet above the region to the north.

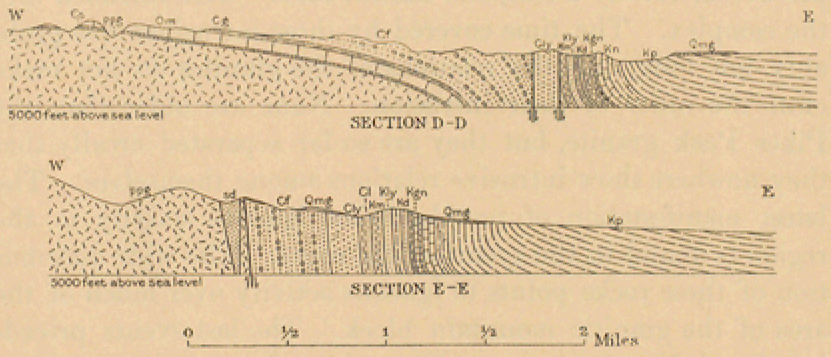


FIGURE 4.—East-west sections in the foothill regions along the lines D-D and E-E on the areal-geology map of the Colorado Springs quadrangle.

Section D-D, which crosses the embayment north of Manitou, shows the gentle dip of the strata where the monoclinal fold is but little faulted. Section E-E, south of Manitou, shows the Ute Pass fault, and an associated sandstone dike. Letter symbols representing the rock formations are the same as those on the geologic maps and the structure-section sheet.

FOLDING.

Northern area. — The main folding in this part of the quadrangle is monoclinal and, except in the foothills region, is marked by gentle dips. In the embayment at Manitou (an east-west section across the northern part of which is shown in section D-D, fig. 4), the monoclinal dip, which is about 11° E. near Manitou, increases to 20° in Mushroom Park, and half a mile farther east dips of 35° are the rule. Within a quarter of a mile farther east the dips rapidly become vertical. Still farther east the dip decreases until just northeast of Colorado Springs it is not greater than 5° or 6°. Very gentle local anticlinal folding characterizes the Pierre shale beds, the weakest in the sedimentary series.

Along a zone in the foothills, slightly less than half a mile wide, from Bear Creek to the north line of the quadrangle, the sedimentary beds in the series between the upper members of the Fountain formation and the Pierre shale are vertical or nearly so and are at some places slightly overturned. (See section A-A, structure-section sheet.) In the midst of this zone there are many faults, the throw of several of which is considerable. It is in this zone that the uplift of the mountains finds its chief expression.

Southern area.—The southern part of the area differs from that farther north in the relatively small development of high dips in the foothills along the mountain range. (See section B-B, structure-section sheet.) In Deadman Canyon the conditions are locally the same as they are north of Bear Creek except that only minor faults are observed in the steeply upturned zone. In the southwest corner of the quadrangle the parklike area of Red Creek resembles somewhat the eroded central portion of a dome, because of the low radial dips of the rocks away from a curving mountain front. (See section C-C.)

FAULTING.

Ute Pass fault.—The most conspicuous structural feature of the Colorado Springs quadrangle is the Ute Pass fault, which enters it from the northwest. This is the fault to which Cross refers in the Pikes Peak folio. The sedimentary rocks in the depression forming Ute Pass, northwest of the Colorado Springs quadrangle, are faulted against the granite on the southwest. (See fig. 5.) Their edges are upturned by faulting near Iron

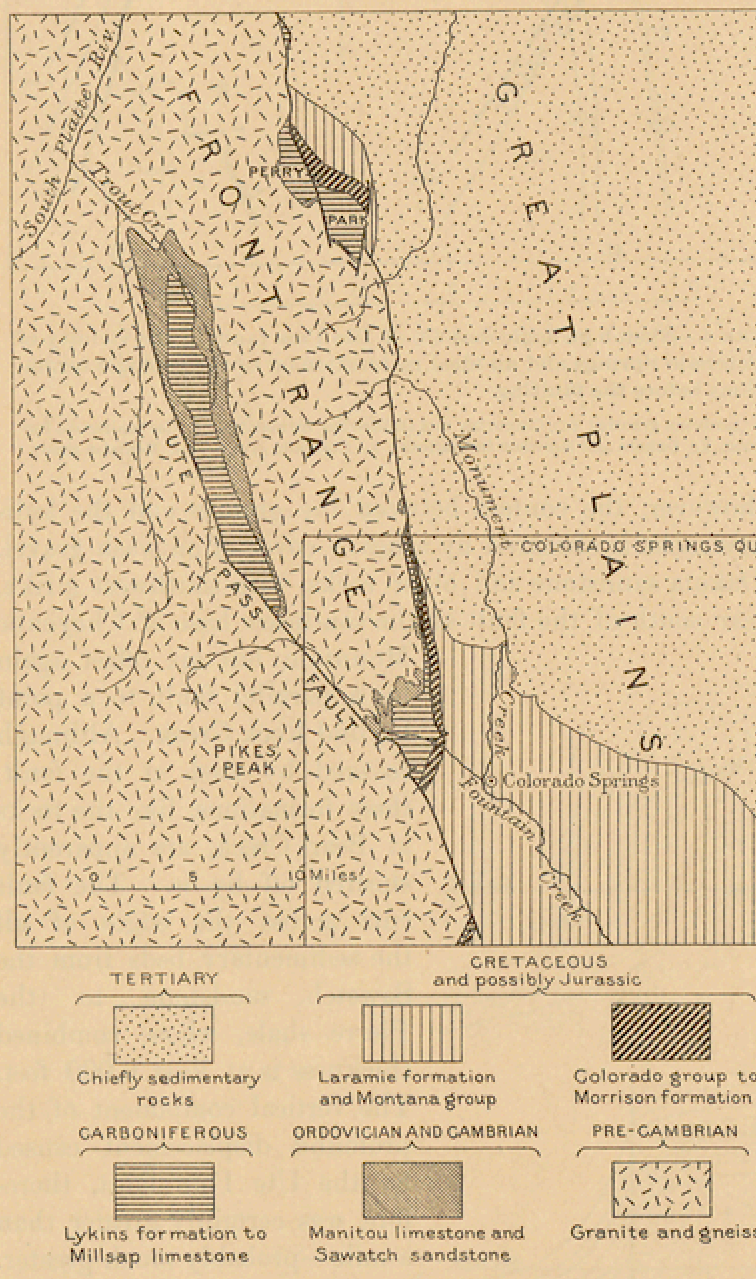


FIGURE 5.—Sketch geologic map showing the relation of the rocks in the Colorado Springs area to those in the adjacent region on the northwest and the continuation of the Ute Pass fault into that area.

Spring station, on the Colorado Midland Railway. For 3 miles southeast of the mouth of Engelmann Canyon, where a small cross fault offsets its line, the Ute Pass fault is the boundary between the Fountain formation and the granite, and the effects of faulting are seen in the disturbed dips of the Fountain formation. The fault plane dips steeply to the southeast and along it at many points there are slickensided and brecciated surfaces. At one place a small anticline in the sandstone of the Fountain formation is caused by the forward thrust of the granite mass, possibly after the block was upthrown. (See fig. 7.) The uppermost beds of the Fountain and the overlying nearly vertical sediments up to the Dakota abut sharply against the granite near the mouth of Bear Creek, as is clearly shown on the geologic map. Here there is a slight flexure, together with minor transverse dislocations in the Dakota sandstone. The weak shales of the Niobrara formation, on the other hand, have been turned aside, broken, and drawn out along the fault for a distance of more than 3 miles. Outcrops of the heavier limestones at the base of the formation are found in the railroad cuts between Bear Creek and Cheyenne Canyon, along the slope under Point Sublime, in the bed of

North Cheyenne Creek, and along the northeastern slope of Cheyenne Mountain, all showing southeast strike, parallel to the fault. The Niobrara formation appears between Bear Creek and Cheyenne Mountain at every point where the overlying gravel has been worn away.

The steep eastern slope of Cheyenne Mountain is covered by much talus at almost every point, but the evidence along the whole eastern front of the mountain points to the continuance of the Ute Pass fault. Beyond the southern end of the mountain, however, the contact between the granite and the sedimentary rocks is obscured by a heavy cover of outwash gravel. The Dakota sandstone and older rocks, with southwest strike, reappear south of the fault at the southeast base of Cheyenne Mountain but are offset again by a parallel fault to a point beyond Rock Creek. Although covered by wash at the fault, these formations, like the rocks at Bear Creek, are apparently sheared off by it. The fault cuts across the edges of all the sedimentary beds from the Sawatch sandstone to the Pierre shale, whose combined thickness is at least 6,000 feet. The vertical component of the profound displacement caused by the Ute Pass fault, therefore, was certainly greater than a mile—probably much greater. In addition to being upthrown the granite mass south of Ute Pass has evidently been thrust southeastward, probably as much as 4 miles. This horizontal offset of the formation is shown in figure 6, together with a restoration of beds before faulting occurred.

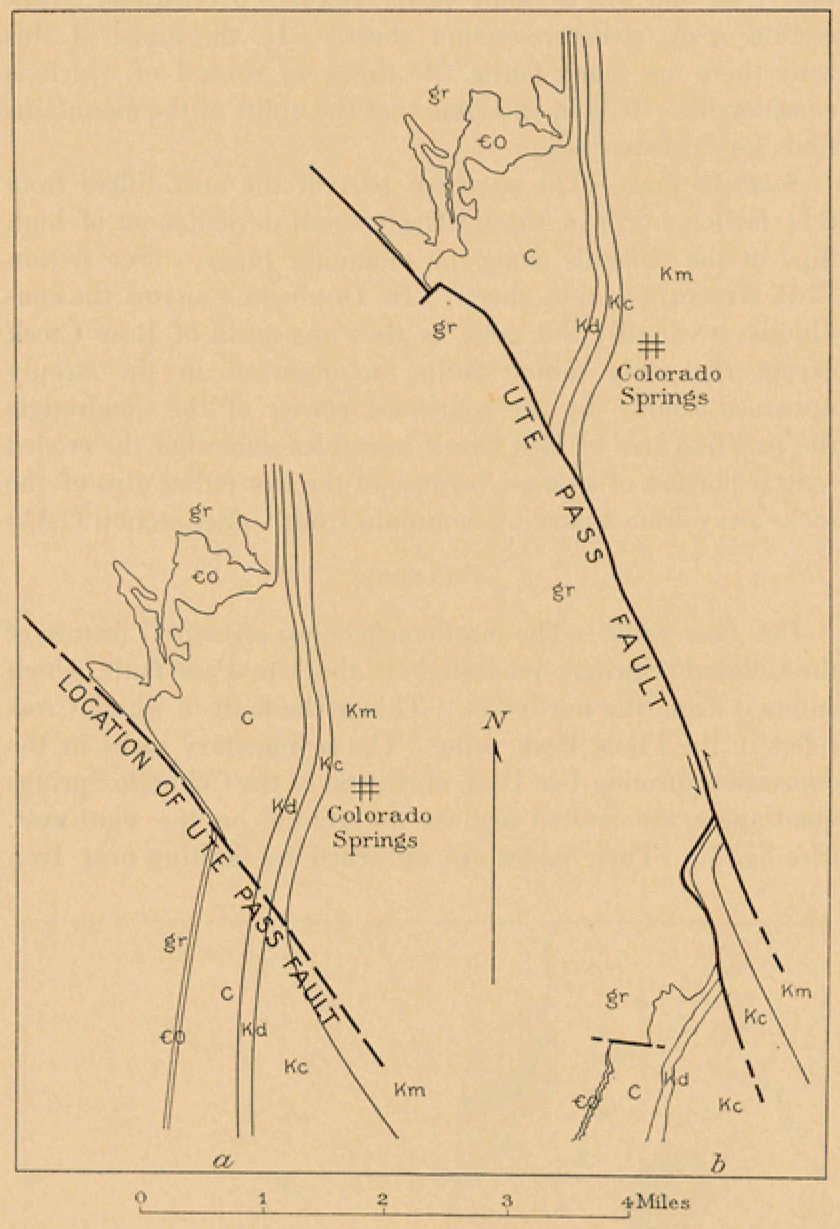


FIGURE 6.—Sketch geologic map (*b*) of Ute Pass fault in the vicinity of Colorado Springs and an ideal restoration (*a*) of the geologic formations before the faulting.

gr, pre-Cambrian granite; €O, Cambrian and Ordovician formations; C, Carboniferous formations; Kd, Dakota and Morrison formations; Kc, Colorado group; Km, Montana group.

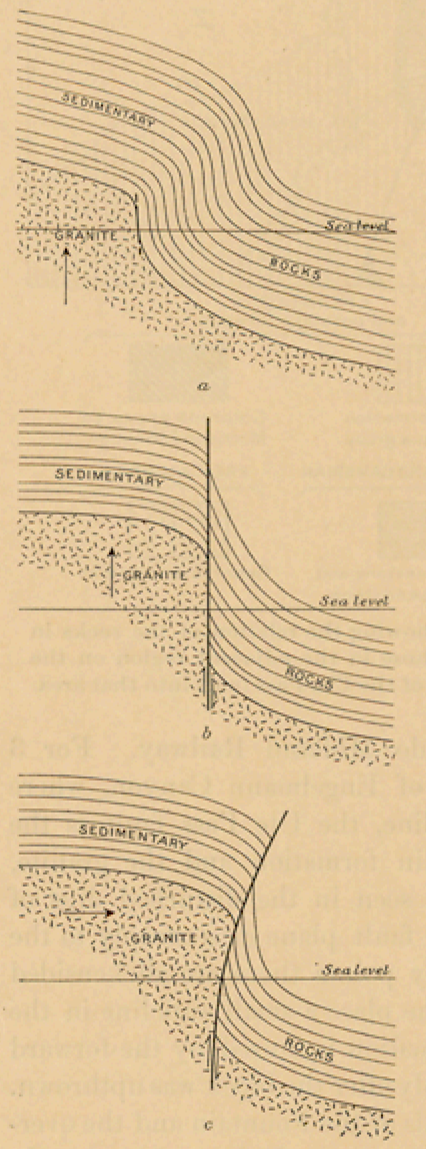


FIGURE 7.—Ideal sections showing the possible development of overturned faults with apparent overthrust relations in the foothills belt.

a, Monoclinal fold and incipient normal fault caused by vertical uplift; *b*, normal fault resulting from continued vertical uplift; *c*, overturned fault plane caused by later horizontal compression and movement of the granite mass.

Foothill belt.—The uplift of the granitic mountain block in the region north of Ute Pass caused the strata between the Fountain and Niobrara formations to be steeply upturned and faulted, and it produced hogback ridges in this zone. The major fault along this line has been traced from a point near Fountain Creek about a quarter of a mile west of Camp Creek northward for a distance of 10 miles. The fault has a sinuous course and near its southern end, just south of the Garden of the Gods, the relations appear to be those of a thrust fault dipping westward at an angle of about 50°. The uppermost layers of the Fountain here dip eastward at an angle of 60° and override the vertical beds of younger formations, so that the Fountain formation comes into contact with the Graneros shale at the reservoir in the NW. ¼ NE. ¼ sec. 3, T. 14 S., R. 67 W. This apparent overthrust relation may be due to compression and forward movement of the granite mass after it was uplifted and faulted by normal displacement, whereby the fault plane, formerly vertical, was tilted, as shown in figure 7.

North of the reservoir the fault turns to the northwest and cuts across the ends of the Purgatoire, Morrison, Lykins, and Lyons formations successively. It runs between the Lyons and Fountain formations west of the southernmost of the great outcrops of sandstone in the Garden of the Gods, and a branch of the fault crosses the Garden diagonally along the northwestern edge of this sandstone mass and caused the disappearance of the Lytle sandstone member of the Purgatoire formation and the Morrison formation northeast of the Gateway. The main fault continues northward west of the Gateway, and beyond Glen Eyrie, on Camp Creek, it causes the disappearance of the Fountain formation. The throw of the fault at this locality amounts to many hundred feet.

At several places smaller faults branch from the main fault in curving lines, as shown on the geologic maps, and along the zone of hogback ridges there are still smaller faults, which offset the vertical beds for a few feet or strike with the sedimentary rocks. To these minor faults are due the disappearance for short distances along the line of outcrop of parts of one or another of the formations.

In the valley of West Monument Creek, at the northern border of the quadrangle, the contact between the granite and the steeply upturned Fountain formation is a fault line, which extends southward as far as Monument Park. Parallel to and east of this fault, in the same valley, there is a lesser fault which has caused the disappearance of the Lyons and Lykins formations along their strike and brought the limestones of the Morrison formation against the arkosic sediments of the Fountain.

Minor faults that have produced small dislocations of the granite mass occur in the southern part of the quadrangle, about Deadman Canyon and along upper Red Creek.

Other small dislocations occur within the sedimentary beds near the mountains, but over the larger part of the quadrangle the folding is gentle and no faults have been observed.

GEOLOGIC HISTORY.

PRE-CAMBRIAN TIME.

The earliest geologic events recorded in the Colorado Springs quadrangle are those indicated by the presence of small areas of gneiss and schist in the midst of the Pikes Peak granite. The record of these events is fragmentary, but it covers a long period of time and a complicated history. Some of the schists are undoubtedly of sedimentary origin, but the source of the sediment composing them is not known. They were deeply involved in movements that produced folding, and the metamorphism they show must be attributed largely to dynamic agencies, although some of the metamorphic rocks appear to be due to later igneous intrusion. All these rocks underwent great erosion, and the erosion was followed by a considerable uplift, as is plainly indicated by the plutonic crystalline masses with which the metamorphic rocks are intimately associated.

Into these oldest rocks, the gneisses and schists above referred to, was intruded the mass of Pikes Peak granite, now covering many thousand square miles. Pegmatitic offshoots of this granite occur at many places.

Later in pre-Cambrian time finer-grained granites—the Cripple Creek, Windy Point, and Mount Rosa—were intruded into the complex. The time covered by these intrusions was probably not long, and the relations of the granites do not make clear the order of their intrusion. None are older than the Pikes Peak granite, but they are so far separated areally that they nowhere show intrusive relations among themselves. The latest manifestation of pre-Cambrian igneous activity in the region is found in the syenitic dike rocks. The wide distribution of these rocks points to igneous activity over much of the area of the granitic mountain block. The last events preceding Cambrian time were uplift and profound erosion. This erosion removed much of the surface rocks, exposed the granitic rocks, and reduced the land nearly to a plain.

PALEOZOIC ERA.

CAMBRIAN PERIOD.

Sawatch deposition.—At the beginning of the Cambrian period the land was nearly level and lay very low, but as the fossils thus far collected from the earliest Paleozoic rocks in the Pikes Peak region show that these rocks are later than Lower Cambrian, the Colorado Springs district was probably not under water in early Cambrian time. The land had been worn down to a surface of low relief, and the remnants of the old peneplain cut on the surface of the crystalline rocks below the Cambrian are a striking feature of the physiography of the quadrangle. These remnants are not large, but they are sufficient to show that the work of planation was completed.

The shores of the Cambrian sea were not stationary, and the record of sedimentation points to continued slow subsidence of the land along the coast line. The quartz sand first deposited in this sea was well washed, and much of it was probably brought from a distance by strong currents. Changing conditions in the Cambrian seas are indicated by the deposition of calcareous sandstones upon the basal sandstones and, toward the end of the Cambrian period, of glauconitic, coarser sandstone. Sedimentation was not interrupted during the Cambrian period, and no uplift occurred at its end, so that probably no land masses existed in the quadrangle at the end of Cambrian time.

ORDOVICIAN PERIOD.

Manitou deposition.—The deposition of limestone that began after the close of the Cambrian period continued uninterruptedly throughout Ordovician time. The Manitou limestone, which constitutes the record of this sedimentation, includes coarsely crystalline fossiliferous beds near its base, indicating possibly a greater abundance of life forms in the immediate neighborhood at the beginning of the period than later. A slight change in conditions is marked by the deposition of finer grained limestones later in the Ordovician period. The water of the early Ordovician seas appears to have been free from sand and mud, for the limestone beds are remarkably pure. Toward the close of the Ordovician period sands were deposited, but only a very thin representative of these deposits, the Harding sandstone, now remains in the southern part of the quadrangle.

After the material that formed the Manitou limestone and Harding sandstone had been laid down, there was a period of uplift and erosion, during which much of the quadrangle was land. The record shows a well-marked unconformity between the Ordovician and the succeeding beds, of Pennsylvanian age. This period of erosion was long enough to permit the removal of all the Ordovician and Cambrian beds at many places in the quadrangle.

SILURIAN AND DEVONIAN PERIODS.

It is inferred that the Colorado Springs region was a land area during most of the long period between the close of the Ordovician and the beginning of the Carboniferous, for no sediments referable to the Silurian or the Devonian are found either in the Colorado Springs quadrangle or along the Rocky Mountain Front Range in other parts of Colorado and the adjoining States. During at least the later part of the Devonian and the early part of the Carboniferous certain other parts of Colorado were covered by a sea, but no sediments like those appearing in the southwestern part of the State have been found within the quadrangle, which was therefore probably a land area until the close of the Devonian. That it was low-lying, well-eroded land at this time is inferred from the fact that in the succeeding Carboniferous period marine conditions prevailed along the Front Range immediately north of the Colorado Springs region and a few miles southwest of it.

CARBONIFEROUS PERIOD.

MISSISSIPPIAN EPOCH.

The Colorado Springs area probably underwent subsidence before the Mississippian epoch and was uplifted and eroded before the Pennsylvanian epoch. The evidence for this subsidence and uplift is found in the adjoining Castle Rock and Canon City quadrangles. No Mississippian beds are known in the Colorado Springs quadrangle, but beds of that age have been found a few miles north of it. They are known as the Millsap limestone. In Garden Park, north of Canon City, this formation appears only a few miles west of the Colorado Springs quadrangle. There the Millsap is limited below and above by unconformities, and the record of erosion seen in the unconformity between the Millsap and the overlying Pennsylvanian warrants the assumption that such Millsap sediments as may have been deposited in the Colorado Springs quadrangle were later removed by erosion, for the Millsap beds where they do occur are thin.

PENNSYLVANIAN AND PERMIAN EPOCHS.

Fountain deposition.—The record of the earliest events of Pennsylvanian time is found in the basal beds (Glen Eyrie shale member) of the Fountain formation in the Manitou embayment. These basal beds are fine-grained sandstones, which contain small lenses of coal and are overlain by shales. They indicate that the land then stood near sea level and was swampy. The record of plant life preserved in the remains of ferns and other vegetal forms, which have been found rather abundantly in association with the small lenses of coal, indicates that marine conditions did not prevail at the beginning of the Pennsylvanian epoch. Widespread sedimentation followed, leading to the deposition of the thick series of "Red

Beds" that form so marked a feature of the Colorado Springs region. The bright-red colors of these beds indicate that the sediments were derived from rock disintegrated on an arid upland, where the iron it contained was highly oxidized. The detritus was washed down to the lowlands by streams and rivers and accumulated in large part as a terrestrial deposit, though a portion of it was doubtless laid down in standing water. The large subangular cobbles in much of the conglomerates of these beds did not travel far, and all the material was manifestly derived from the mountain masses just west of the deposits. The occurrence of thin beds of shaly, fine-grained sandstone containing species of Lingulidiscina indicates a change of conditions. Near the end of the period of deposition of the Fountain formation the sea seems to have advanced over the Colorado Springs region, but the waters rose gradually, for no sharp break marks the close of Fountain deposition.

Lyons deposition.—The marine conditions under which the Lyons sediments were deposited seem to have varied but little from time to time. Strong currents brought well-washed quartz sands into the sea and laid them down in cross-bedded deposits. No variation occurred in the nature of sediments until the middle of the period of deposition, when coarse, bowldery beds were locally deposited. The material in these beds was derived from near-by land, for it includes fragments of the earlier sediments as well as of the older crystalline rocks. This change in the nature of the Lyons strata undoubtedly marks only a short time and was due to local conditions, for the later deposits are altogether similar to those first laid down in the beds that are regarded as probably Permian. To account for the marked cross-bedding in the upper sandstones of the Lyons, Fenneman has suggested that the sediments indicate deposition on the landward side of offshore sand bars, for the reason that the planes of cross-bedding dip very generally toward the old land, at angles approaching 30°.

Lykins deposition.—Shallow, shifting bodies of water, consequent upon the gradual withdrawal of the sea, marked the time when the thin sediments of the Lykins formation were deposited conformably upon the coarser beds of the Lyons. Alternating deposits of shale and fine-grained sandstone and small amounts of limestone accumulated in lakes which gradually diminished in volume. Many of them were so much reduced by evaporation at the close of the Lykins stage that their dissolved salts were at least in part precipitated. Deposits of gypsum, in places 90 feet thick, were formed in this way.

MESOZOIC ERA.

TRIASSIC AND JURASSIC PERIODS.

The lack of any beds of known Triassic age within the quadrangle, taken in connection with the events that occurred near the close of Lykins sedimentation, seems to indicate that the uplift which landlocked the bodies of water in which the Lykins sediments were deposited, near the end of the Paleozoic era, was pronounced and that it at last made a land area of the region. This land probably lay rather low and it remained low throughout the Triassic and Jurassic periods and well into the Cretaceous.

Fluviatile and lacustrine sediments probably accumulated during Triassic time, but so far as known they have all been removed by erosion. There is no indication that the sea transgressed over the region. Furthermore, it is not known that much erosion took place before the deposition of the clays and limestones of the Morrison formation, which in this area succeeds the Lykins sediments without such recognizable unconformity as is elsewhere indicated between the two.

LATE JURASSIC OR EARLY CRETACEOUS TIME.

Morrison deposition. — No marine Jurassic sediments are found in the Colorado Springs quadrangle. The shales, sandstones, and local limestones, about 250 feet thick, composing the Morrison formation, were laid down in fresh water as fluviatile and lacustrine sediments, and the sand and clay were continually shifted from point to point. The earliest beds deposited near Colorado Springs formed fresh-water limestone and were succeeded by deposits that formed friable sandstones and calcareous marls. Dinosaurian remains are found in these beds in the Denver Basin and in other parts of Colorado. The bodies of water in which the Morrison sediments accumulated were shallow, and near the end of the epoch deposition was interrupted by uplift.

CRETACEOUS PERIOD.

LOWER CRETACEOUS EPOCH.

Purgatoire deposition.—The beginning of marine conditions near the close of the Lower Cretaceous marks a great change. After the fresh-water limestones and sands of the Morrison formation were deposited the sea spread over the Great Plains region, and in it were laid down sediments strikingly different from those which had just before been deposited. Fairly coarse quartzose sand was abundantly supplied to the waters, together with a variable admixture of well-worn small pebbles. This signifies renewed activity of the streams. After the deposition of the Lytle sediments, when the land had been worn low, fine muds were brought into the sea, and in the Colorado Springs region an amount of shale (Glencairn member) equal in thickness to the sands of the Lytle member was spread over the sea floor.

UPPER CRETACEOUS EPOCH.

Dakota deposition.—The conditions of sedimentation during the Purgatoire epoch were greatly modified at the beginning of the Upper Cretaceous. The Dakota sediments, consisting of clean-washed quartz sand, were supplied by rivers that attacked newly uplifted land masses. The sands were distributed rather uniformly over a sea floor that occupied the whole of the Great Plains province, though the quantity of material deposited at any one place was not great. Remains of plants that were much broken up by the wash of the waters are found at many places in these quartz sandstones. Some were brought down by streams from near-by land; others are in place along an old shore line in areas that were occupied by shallow water. The most plausible view of Dakota sedimentation is that the deposits were laid down along the shores of an open sea. At times thin beds of carbonaceous shale and of coal were deposited. At the end of the Dakota epoch marine conditions prevailed.

Colorado and Montana deposition.—The earliest beds laid down in the sea waters of the Colorado epoch were shales, limy shales, and thin limestones, deposited in alternation. Upon the beds that accumulated in early Colorado time—the Graneros shale and Greenhorn limestone—was laid down the mud that formed the Carlile shale. Near the close of Carlile deposition a limy sand, nowhere thicker than 10 feet in the Colorado Springs quadrangle, was deposited over the whole area. The deposition of this limy sand was followed by the last extensive deposition of limestone-making material in the region, forming the Niobrara. After the pure calcareous beds of the Niobrara formation had been laid down muds were brought in by the rivers and spread broadcast over the sea floor, producing sediments that are among the thickest in the stratified series, the Pierre shale. They mark the very extensive wearing down of the supplying land areas. At the close of this period of continuous sedimentation brackish waters occupied the region and several hundred feet of sand (the Fox Hills sandstone) was deposited. After this the region was uplifted and has since remained land.

Laramie deposition.—By gentle oscillations the land, which had been so long under water in the Cretaceous period, was brought to a stand near sea level. The supply of sand which had marked the closing stages of Montana deposition was continued during the period of Laramie sedimentation. The materials that made up the Laramie were very much like those of the underlying Fox Hills formation. Grains of quartz make up by far the greater part of both formations. Among them, however, in the Laramie, small black grains of chert are prominent. At this time there were large swamps in which beds of coal accumulated, and the discontinuity of the coal beds in the Colorado Springs quadrangle may signify the existence of detached or discontinuous swamps. Fine quartz sand was then again deposited upon the vegetal matter that formed the larger coal measures in the basal portion of the beds, but a number of small coal seams alternating with these sandy measures indicate frequent changes in the conditions. Before the close of Laramie time fine clays and muds were deposited.

Post-Laramie deformation.—The close of the Cretaceous epoch in the Colorado Springs region was a time of uplift and active stream erosion. A large part of the Laramie, probably the greater part, was removed. Similar events are recorded from New Mexico to Montana, indicating that the post-Laramie uplift and erosion were widespread. In the Colorado Springs area the rocks were not disturbed by folding, and the succeeding beds were laid down upon the eroded surface of the Laramie sediments with apparent conformity.

CENOZOIC ERA.

TERTIARY PERIOD.

EOCENE EPOCH.

Dawson deposition.—Early in the Tertiary period, in the Eocene epoch, fluviatile deposits were spread widely over the land, extending eastward from the mountains for 40 or 50 miles, and deposits were also formed in shallow bodies of fresh water. The earliest of these beds in the Colorado Springs region consisted of finely comminuted andesitic sands. At some places coarser pebbly layers are found in this thin series of fragmental andesitic material. These beds do not occur in the Castle Rock quadrangle, on the north, and their source is not known. Here and there they were covered by much coarser pebbly layers, of a kind indicating that the streams which deposited the materials brought them from a wide area, for they contain fragments of almost all the older rocks of the quadrangle. The chief gathering ground for these materials, however, was the granite mountain region to the west. The fragments in the Colorado Springs quadrangle were reduced to fine gravel and sand, slightly coarser and in thicker beds near the mountains.

The succeeding Eocene history of the region is supplied by the sedimentary record in the Castle Rock quadrangle, a few miles to the north, where events were recorded that now have no expression in the Colorado Springs quadrangle. Rhyolitic beds that cap many mesas north of the Arkansas-Platte divide were laid down near the close of Dawson deposition. The source of this volcanic material is not known, but the beds probably once extended much farther south than their present distribution indicates, and the Colorado Springs region was doubtless covered to a slight depth by these rhyolitic beds, which have been entirely eroded away. The rhyolitic beds in the Castle Rock quadrangle were covered by a thin deposit of gravel of varying thickness.

OLIGOCENE EPOCH.

Castle Rock deposition.—The Castle Rock conglomerate in the quadrangle just north of the Colorado Springs quadrangle was deposited in Oligocene time, in much the same manner as the Dawson arkose beds. The Oligocene history of the Colorado Springs region probably included a similar record of fluviatile deposition. The Castle Rock conglomerate doubtless once extended southward beyond the areas in which it is now found and covered at least a part of the Colorado Springs quadrangle but was later entirely removed.

Early Tertiary erosion.—The Tertiary streams wore away the rocks at the surface to such an extent that the granite area in the western part of the quadrangle was reduced to a rolling plain by the end of Oligocene time. The region extending from Blodgett Peak to Blue Mountain, together with a much larger area on the north, west, and south, was worn down to a surface of slight relief during this long period of erosion, which was not interrupted by orogenic movements. The granite area was not so greatly elevated at that time and stood not much higher than the plains area. A remnant of this surface is shown in the mountain tops at the right in Plate I. The detrital materials were carried eastward by streams and contributed to the deposits making up the Dawson arkose and the Castle Rock conglomerate.

MIOCENE EPOCH.

Volcanic activity.—In Miocene time a small volcano was built up by a series of eruptions in the Cripple Creek region, which adjoins the Colorado Springs quadrangle on the west. This volcano at several times poured out phonolitic lavas and fragmental material. The phonolite in the Manitou quadrangle consists of masses of lava that lay on the periphery of the igneous rocks ejected from the Cripple Creek volcano. The molten rock was poured out at a number of places and flowed over the irregular surface of the granite for a distance of several miles from the craters. Small masses of phonolite were intruded into the Pikes Peak granite in the form of dikes. The larger part of the lava flows which once existed in the Colorado Springs region has been eroded away since the volcano was active, and the accompanying fragmental beds were also removed.

PLIOCENE EPOCH.

Mountain-making movements.—During the Pliocene epoch there were notable orogenic movements in the region. The granite block that lies west of the plains was uplifted and formed the Front Range of the Rocky Mountains, which now stands thousands of feet above the eastern part of the quadrangle. Much of it is a somewhat dissected gently rolling plateau, which still exhibits the marks of peneplanation of early Tertiary time, as shown at the right in Plate I. The uplift was accompanied by profound dislocations between the crystalline rocks and the sedimentary beds flanking them, as well as within the strata along the foothills. Not less marked was the differential movement within the granite block itself, for the part of the Pikes Peak mass south of the Ute Pass fault was uplifted thousands of feet above the granite adjoining it to the north. The dissected plateau, which stands at an elevation of about 9,500 feet north of the fault, has an elevation of over 12,000 feet south of the fault, as shown in figure 8.

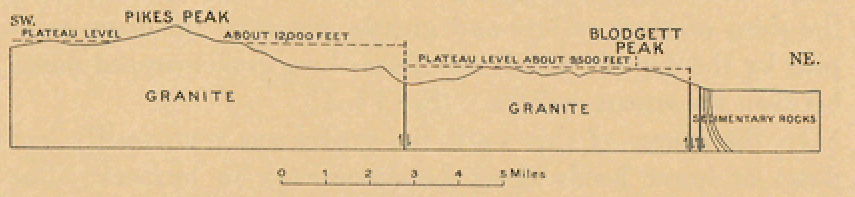


FIGURE 8.—Section through Pikes Peak showing dissected plateau representing the Tertiary peneplain displaced by the Ute Pass fault, the area about Pikes Peak having been relatively uplifted about 2,500 feet.

The granite block south of Ute Pass was at the same time thrust forward along the fault toward the southeast, and the series of sedimentary beds in the Manitou embayment, from the Sawatch sandstone to the Niobrara formation, was transected and offset about 4 miles, as shown in figure 6. The limestones and shales of the Cretaceous were flexed and dragged toward the southeast in a notable way.

The sedimentary beds and the crystalline basement on which they rest were at many places uplifted bodily. At other places they were tilted steeply. In the southwestern part of the quadrangle, along Red Creek, the gentle southward-plunging fold of the mountain uplift caused the sedimentary beds to dip radially away from the mountain front. The sandstone dikes were probably formed at this time in open fissures from imperfectly consolidated material of the Sawatch sandstone, which lies at the base of the sedimentary series. These dikes were formed along the line of the Ute Pass fault and in fissures near it and more or less parallel with it, possibly as indicated in figure 3 (p. 10). Some of the dikes, however, may have been formed much earlier, in connection with faulting movements along the same general line.

The pronounced uplift during Pliocene time renewed the activity of the streams, which began to cut canyons along the mountain front, to dissect the higher areas of the crystalline block, and to transport detrital materials to lower levels. This activity continued during the rest of the Pliocene epoch.

QUATERNARY PERIOD.

PLEISTOCENE EPOCH.

Glaciation.—During Pleistocene time glaciers formed in the valleys leading away from the summit of Pikes Peak at an altitude of 12,750 feet and at lower levels and moved downstream, some of them for 3 or 4 miles. The lower limit of ice work in the region is at an elevation of about 9,500 feet. The ice reached a maximum thickness of nearly 350 feet in some of the valleys.

The ice greatly changed the stream valleys, deepening them, lessening their grades, and making their cross sections U-shaped by steepening their sides. Their original step and tread form, due to unreduced ledges that interrupted their courses, was accentuated. Along the northeastern face of Pikes Peak cirques were formed, bounded by precipitous walls of rock 2,000 feet high. On the floors of the valleys and along their sides the bare rock was abraded, smoothed, and striated.

At the lower ends of the valleys, where their sides tend to flare away, glacial deposits accumulated in the form of lateral and terminal moraines. Rock in pieces of many sizes, the largest several feet in diameter, was spread out in long, gentle sloping lines along the valley sides or heaped together at the foot of the ice in irregular accumulations. Almost the whole of this material consists of fragments of the Pikes Peak granite.

The higher slopes of Pikes Peak were covered with snow, but the summit was not glaciated, and the ice sculpturing of the mountain did not proceed far enough to reduce its mass greatly. With a change of climate, which probably involved a reduction in precipitation, the streams of glacial ice diminished in volume. In the Pikes Peak region they did not persist until the Recent epoch, although in northern Colorado small masses of glacial ice still exist.

Deposition of gravel.—Along the eastern front of the mountains a widely extended, gently sloping plain of gravel was laid down in Pleistocene time. This gravel consists almost entirely of fragments of granite and is the product of stream work in the canyons within the mountains and along the steep face of the granitic mountain front. The formations in the foothills made only a small contribution to this gravel. At one time or another during early Pleistocene time the streams were at work at every point along the plain. They deposited the gravels very evenly, making a gently undulating eastward-sloping surface, which at one time bordered the mountains without a break from the northern line of the quadrangle to its southern boundary and extended eastward in places for 10 miles beyond the foothills. Additions in the form of talus were made along the steep mountain front at many points.

Later, when the major streams flowing out from the mountains were eroding their canyons in the granitic rocks still more deeply, they dissected the gravel plain where they crossed it and eroded valleys in the underlying soft shale and other sedimentary rocks after they had removed the gravel. The streams also worked laterally, cutting away the outwash gravel along the sides of their valleys and greatly reducing the areas occupied by the deposit, which now forms long gravel-capped mesas between the stream valleys. (See Pl. I.)

In the course of this work the gravel was temporarily laid down at lower levels along the streamways in terraces. The gently sloping bench of fine gravel on which the city of Colorado Springs is built is such a terrace. Almost all these terraces have been removed by the streams that formed them.

RECENT EPOCH.

Deposition of alluvium.—Stream work has not been accelerated since the Pleistocene epoch, and at present the precipitation is smaller. During most of the year the streams and rivers are sluggish and form small flood plains, to which contributions of gravel and fine sand are made by the flood waters from melting snows and occasional torrential rains. Only when the streams are thus flooded is their erosive work now of much effect, for during the greater part of the year they do not even cover their beds, and for months many of them disappear entirely and leave dry sandy washes along their courses.

ECONOMIC GEOLOGY.

The mineral resources of the area comprise coal, building stone (including sandstone, limestone, and arkose), shale and clay, cement materials, limestone for other uses than building, gypsum, semiprecious stones, sand, and gravel. The water resources comprise supplies of both surface and underground water. The soil is a resource of great importance. Small metalliferous deposits, although unproductive, have been prospected at many points in the mountains.

COAL.

Occurrence.—The workable coal is confined to the Laramie formation, the outcrop of which extends from Popes Bluffs southeastward beyond the quadrangle. The Colorado Springs coal field is structurally a part of the basin-like area which is defined by the outcrops of the Laramie formation and the overlying Dawson arkose and Castle Rock conglomerate. The coal-bearing strata within the quadrangle have an average dip of 5° or 6° in a direction slightly east of north. The coal crops out at several places northeast of Colorado Springs and may be very generally distributed through the Laramie formation beneath the surface in the synclinal basin that lies between Colorado Springs and Denver.

There is a general similarity in the succession of coal beds in the Colorado Springs region and in the Denver Basin. It is not unusual to find in a single section as many as five beds of coal. Only the lowest, however, is at present of economic value, though along Popes Bluffs coal is mined in small quantities at a higher horizon. In much of the field the lowest bed, which lies about 50 feet above the base of the Laramie, is not more than 4 feet thick. Its maximum thickness—about 14 feet—occurs in the Curtis mine, northeast of Colorado Springs, and for a mile northwest of the mine the bed, though thinner, is of workable thickness. Southeast of the Curtis mine the bed thins rapidly. A thickness somewhat less than 6 feet is found in the Keystone mine, southeast of which its thickness diminishes greatly along the strike. Near Burial Rocks, in the Cell and Davies mines, it is about 4 feet thick. West of Monument Creek there is apparently a local thickening of the main bed in the Carlton mine. The bed appears to be a lens that reaches its maximum thickness in the Curtis mine and thins away on each side, notably in the valley of Monument Creek, though it thickens locally for a short distance near the Carlton mine. In all the mines more or less bone is encountered, and here and there along the strike of the seam the coal probably gives place to shale. Many borings along the outcrops of the Laramie have not encountered coal, and the workable deposits are apparently in relatively small basins that lie close together. Many small beds or showings of coal at different horizons are discontinuous, the coal being replaced a short distance away by carbonaceous shale.

Character.—The coal in the quadrangle is of importance chiefly on account of its nearness to Colorado Springs, and the mines that are the heaviest producers are within a few miles of the city. The product, which is subbituminous, can not compete successfully with the coal from the Raton Mesa region, at the Colorado-New Mexico line. A large quantity of it is, however, consumed for domestic uses, and it is employed almost exclusively by the local power plants and by the mills near Colorado Springs and Colorado City that treat Cripple Creek ores. Most of it carries a large amount of moisture and a high percentage of ash. The ratio of fixed carbon to volatile hydrocarbons is greater than 1, although none of the coal is far from the border line between lignite and subbituminous coal.

The beds include layers of black lustrous coal, ranging in thickness from a fraction of an inch to several inches, interbedded with layers of black porous nonlustrous coal. On exposure to the air the coal breaks up and weathers rapidly. The sections of the coal in the principal mines (see fig. 9) were measured by M. I. Goldman.[1] Samples collected by Mr. Goldman were analyzed at the Pittsburgh laboratory of the United States Geological Survey, and the results are given below.

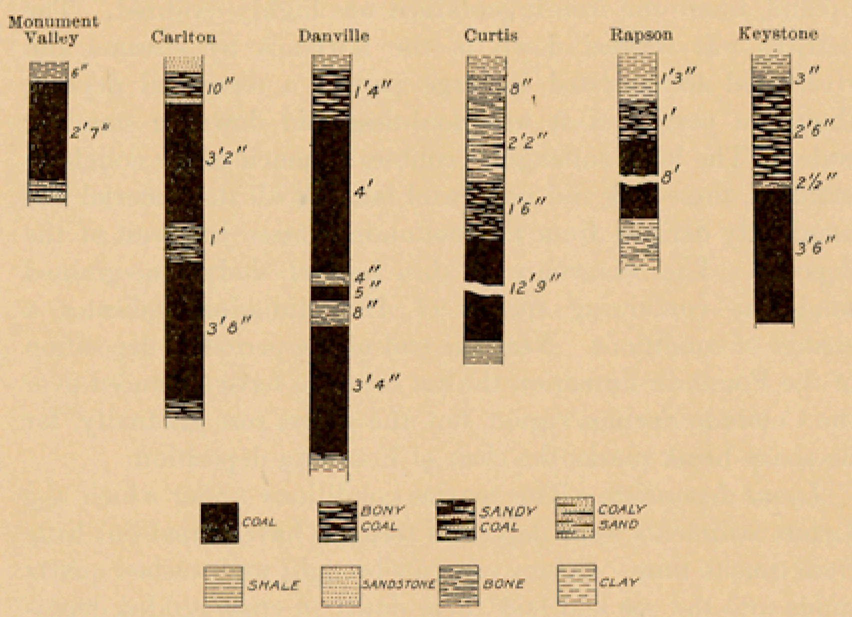


FIGURE 9.—Sections of coal bed in Laramie formation at six mines near Colorado Springs.

Analyses of coal samples from the Colorado Springs coal field, Colo.

[F. M. Stanton, chemist in charge.]

Mine.	Laboratory No.	Location.				Thickness.		Air-drying loss.	Form of analysis.	Proximate.				Ultimate.					Heat value.	
		Quarter.	Sec.	T. S.	R. W.	Coal bed.	Part sampled.			Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.	Calories.	British thermal units.
						Ft. in.	*Ft. in.*													
Monument Valley	6545	SW. ¼	11	13	67	2 7	2 7	11.4	As received	20.2	35.1	37.6	7.09	1.03	5.74	51.64	0.58	33.92	4,857	8,743
									Air dried	9.9	39.6	42.6	8.06	1.16	5.04	58.29	.65	26.86	5,482	9,868
									Dry coal		44.0	47.1	8.88	1.29	4.38	64.66	.73	20.06	6,082	10,948
									Pure coal[a]		48.3	51.7		1.42	4.81	70.96	.80	22.01	6,675	12,015
Carlton	6443		18	13	66	8 7	6 10	15.3	As received	25.5	31.6	38.1	4.8	.25					4,614	8,305
									Air dried	12.1	37.3	44.9	5.7	.30					5,448	9,806
									Dry coal		42.4	51.1	6.5	.34					6,195	11,151
									Pure coal		45.3	54.7		.36					6,626	11,927
Danville	6442		29	13	66	8 10	6 5	15.4	As received	21.8	33.6	37.9	6.7	.40					4,735	8,523
									Air dried	7.6	39.7	44.8	7.9	.47					5,597	10,075
									Dry coal		43.0	48.5	8.5	.51					6,055	10,899
									Pure coal		47.0	53.0		.56					6,620	11,916
Curtis	6440		29	13	66	12 9	6 10	15.6	As received	20.9	33.7	39.9	5.53	.39	6.05	52.25	.69	35.09	4,951	8,912
									Air dried	6.3	39.9	47.2	6.55	.46	5.12	61.91	.82	25.14	5,866	10,559
									Dry coal		42.6	50.4	6.99	.49	4.72	66.07	.87	20.86	6,261	11,270
									Pure coal		45.8	54.2		.53	5.07	71.04	.94	22.42	6,732	12,118
Rapson	6441		33	13	66	8	5 9	14.6	As received	19.9	34.3	38.3	7.5	.37					4,802	8,643
									Air dried	6.2	40.1	44.9	8.8	.43					5,623	10,121
									Dry coal		42.8	47.9	9.3	.46					5,995	10,791
									Pure coal		47.2	52.8		.51					6,613	11,903
Keystone	6546	NE. ¼	4	14	66	5 7	5 7	16.9	As received	25.6	30.2	38.6	5.57	.42	6.32	51.69	.71	35.29	4,848	8,726
									Air dried	10.5	36.3	46.5	6.70	.50	5.34	62.21	.85	24.40	5,834	10,501
									Dry coal		40.6	51.9	7.49	.56	4.67	69.51	.95	16.82	6,520	11,736
									Pure coal		43.9	56.1		.61	5.05	75.14	1.03	18.17	7,048	12,686

[a] "Pure coal" is used to indicate the hypothetical condition of the coal when all its moisture and ash are removed.

STRUCTURAL MATERIALS.

BUILDING STONE.

Granite.—Granite occurs in great abundance in the quadrangle but has not been quarried, as there is no market for it. Fine-grained bluish-gray stone of excellent grade is obtainable at a number of places near Mount Rosa, along the line of the Colorado Springs & Cripple Creek District Railway. Quarrying was started several years ago at St. Peters Dome, but owing to the dull greenish-drab colors of the rock at this point it did not meet with favor.

Sandstone.—The Sawatch sandstone is quarried in Ute Pass, west of Manitou. Some of the layers that furnish the best building stone lie about midway in the formation. The rock as quarried is red or red mottled with green. It breaks easily parallel to the bedding and yields blocks a foot thick and several feet long. It is strong and durable and has been much used for foundation work and in the walls of buildings. The outcrop of the Sawatch extends northward from Manitou for several miles, but only in the vicinity of Ute Pass is it easily accessible.

Quarries have been started in Quarry Canyon to take out layers of the even-grained sandstone of the Fountain formation. The rock is a coarse gritty sandstone cemented together by a fairly firm calcareous bond. Some layers are nearly white, but most of them are red, in pleasing tones. The rock is fairly strong and durable and will doubtless be much employed.

The bright brick-red sandstone near the top of the lower half of the Lyons sandstone—the rock which appears in the "Gateway" of the Garden of the Gods (Pl. VII)—was once extensively quarried in Redrock Canyon, near Colorado City. It can be obtained in large blocks without joints, flaws, or irregularities of any kind, but it is soft. The bond between the grains is chiefly ferric iron, a cement so weak that in places the rock is almost friable.

Some beds of the Dakota sandstone rank very high as building stone in the Colorado Springs region. The rock is gener-

[1] Goldman, M. I., The Colorado Springs coal field, Colo.: U. S. Geol. Survey Bull. 381, p. 334, 1910.

ally of even texture, and it has a durable bond between the grains of quartz. The cement may be calcareous, but more commonly it is siliceous. The colors of the rock at different places are white, creamy, yellowish, and reddish. That quarried on Turkey Creek, outside the quadrangle, is bluish gray. It is in a few places friable, but the better grades are thoroughly strong. The rock works well under tools, although it is somewhat brittle for elaborate carving. Blocks as much as 20 feet long and 6 feet thick are obtainable. The best grades are those with bluish tones and with faint lines like the venation in certain marbles, probably due to the presence of manganese dioxide. The veinlike markings add greatly to the beauty of the stone. After three or four years of exposure the rock is likely to grow dingy, but it is none the less a stone of high grade. Weathered moss-covered surfaces have been much sought for rustic effects. The creamy or yellowish layers are stained by limonite and generally contain specks or larger ball-shaped concretions of iron oxide which may make the stone unsuitable for use as building material. Quarries have been opened along the ridge south of Colorado City. No stone has been taken out at the south edge of the quadrangle, but the same rock is extensively quarried near Turkey Creek, a few miles farther south.

Arkose.—The Dawson arkose is often used for foundation and outside work. Layers in which the constituent pebbles and smaller grains are bound together by limonite form a strong conglomeratic rock. The natural surface is taken, and rough pieces are preferred. The rock occurs in thin layers at a number of horizons along the outcrops northeast of Colorado Springs.

Limestone.—The Niobrara formation affords the best limestone that is easily obtainable in the quadrangle for use as building stone, but it is not of very good grade. The single courses of the rock are 12 to 18 inches thick and are separated by shaly layers. The color is a good bluish gray or brownish gray but the stone has two very serious defects—it contains small iron concretions like those in the Dakota sandstone and it has a strong tendency to break irregularly. It is much cut by small cracks and is not so strong as it appears to be on casual examination.

CEMENT MATERIALS.

The quadrangle is abundantly supplied with materials for making Portland cement. The limestones and shales of the Niobrara formation are available for this use, though in the vicinity of Colorado Springs, owing to the nearly vertical dips, the cost of taking out the stone would be somewhat greater than at Portland and Cement, on Arkansas River between Pueblo and Canon City, where the horizontal beds are readily accessible. The area of the Niobrara formation at Colorado City within reach of the railroad is not so great as that in the Deadman Canyon region, but there the cost of transportation would prohibit quarrying, for the locality is many miles from railroad lines.

SHALE AND CLAY.

Building bricks are manufactured near Colorado City at a point about a mile north of Fountain Creek and along the railroad just south of Colorado Springs. The soft shales of the Pierre formation are used, and the supplies of this material are inexhaustible. There has been little demand for the better grades of pressed brick, and the output of ordinary brick is largely consumed in the neighborhood.

The clays of the Dakota sandstone are available for making fire brick. They have been mined near Colorado City and farther north within the quadrangle, but for several years the output of the plant at Colorado City has been small. At the southern edge of the quadrangle, where the Dakota sandstone occurs in extensive beds, there is considerable clay, but owing to its distance from railroad lines it has not yet been mined.

SAND AND GRAVEL.

The quadrangle is well supplied with sand and gravel in the deposits which cover the Pierre shales and which have been mapped as mesa gravels. The Mesa, west of Colorado Springs, has yielded within the city limits large amounts of this material in different degrees of fineness. Sand adapted to structural needs is obtainable at many places, and large amounts of gravel are employed in road work in the western part of the quadrangle, where at slight cost bedrock shale can be covered with gravel close at hand.

LIME AND LIMESTONE.

Limestone has been burned to obtain lime for local needs at kilns established between Manitou and Colorado City. Limestone of the Niobrara formation was once burned at a few places northwest of Colorado Springs and in Limekiln Valley, south of it. The Manitou limestone has been quarried for making lime near Manitou and still more profitably for refining beet sugar. The principal quarries were on the ridge above Williams Canyon, at a point about a mile north of Manitou and a mile and a half southwest of Glen Eyrie.

GYPSUM.

Near Colorado City, north of Fountain Creek, a bed of gypsum about 20 feet thick was long ago worked to a slight extent, but the most valuable deposits of gypsum in the quadrangle are at its south side, in the valley of Red Creek. Here, at the top of the Lykins formation, they attain a thickness of 90 feet. The beds are almost horizontal and are readily accessible. The material is largely impure, but many layers are free from any impurity. The usual color is pinkish white or clear white. The supply for structural uses and for application to the land as a fertilizer is so large as to warrant long continuance of the industry at this point.

SEMIPRECIOUS MINERALS.

The Pikes Peak region has long been famous among collectors of minerals. The microcline (amazon stone), smoky quartz, and topaz occurring in cavities in the granite within a few miles of the summit of Pikes Peak have supplied many beautiful specimens. Near St. Peters Dome pegmatitic veins have yielded zircon, astrophyllite, cryolite, arfvedsonite, thomsenolite, and prosopite, as well as the rare minerals gearksutite, ralstonite, elpasolite, tysonite, and fayalite. On the flanks of Cameron Cone in Crystal Park topaz and phenacite have often been found.

METALLIFEROUS DEPOSITS.

Small metalliferous deposits, although unproductive, have been prospected at many places in the mountains. The St. Peters Dome region has been searched systematically for gold, and for years serious prospecting for gold and for copper were carried on at Pecks Camp, about 4 miles south of Saderlind on the Colorado Springs & Cripple Creek District Railway.

WATER RESOURCES.

STREAMS AND WELLS.

The small streams that issue from the mountains are utilized for irrigating land in the valley of Camp Creek and at many other places near Colorado Springs. Several projects involving dam sites in the southern part of the quadrangle have been favorably considered, but only a small quantity of water has yet been used, and the supply available is not large.

A few miles south of the quadrangle small quantities of artesian water are obtained at relatively shallow depths, but the search for artesian water within the quadrangle has been unsuccessful, though several wells, one of them 2,800 feet deep, have been sunk near Colorado City. The Dakota sandstone and the Lytle sandstone member of the Purgatoire formation generally contain water, but as they dip so steeply that they afford only a comparatively small gathering ground and as the average annual rainfall on the gathering ground is only 14 to 17 inches it is doubtful whether their supply is sufficient to produce flows within the quadrangle. In the central part of the quadrangle these sandstones lie so deep that the cost of reaching them has prohibited their use as a source of water.

MINERAL SPRINGS.

Much of the prosperity of Manitou rests on the occurrence of a number of mineral springs that are strongly charged with carbon dioxide. They are in Ute Pass near the Ute Pass fault, where the Pikes Peak granite and the Manitou limestone are faulted together. The springs are genetically related to the Ute Pass fault, and though they are not thermal waters they probably rise from considerable depths. They have no known connection with such igneous rocks as lie about the Cripple Creek volcanic center. The waters are palatable and are among the most widely sold table waters of the West. The Manitou or Soda Spring is the best known. An analysis of the Manitou table water is given below. Navajo, Shoshone, and Cheyenne springs are on the same property, and Ute, Ute Chief, Ouray, and Little Chief lie within a short distance. Horn Mineral Springs are at Colorado Springs, a few miles away.

Analysis of Manitou table water.[1]

[Parts per million.]

Silica (SiO_2)	47.2
Iron and aluminum (Fe+Al)	1.8
Manganese (Mn)	1.7
Calcium (Ca)	457.9
Magnesium (Mg)	79.2
Sodium (Na)	551.0
Potassium (K)	71.3
Lithium (Li)	.23
Ammonium (NH_4)	.05
Carbonate radicle (CO_3)	----------
Bicarbonate radicle (HCO_3)	2,664.6
Sulphate radicle (SO_4)	219.2
Chlorine (Cl)	250
Bromine (Br)	Small amount.
Metaborate radicle (BO_2)	Faint trace.
Nitrate radicle (NO_3)	None.
Nitrite radicle (NO_2)	None.
Phosphate radicle (PO_4)	None.
Arsenate radicle (AsO_4)	None.
Iodine (I)	None.
Total anhydrous residue	2,992

Water is supersaturated with carbon dioxide (CO_2).

SOILS.

The alluvial soils in the bottoms of the valleys are the only soils in the quadrangle that have been much used for agriculture. Some of the residual adobe soils, produced by the weathering of shales in place, are notably infertile. Relatively little land—probably only 1 or 2 per cent of the area—is devoted to crop growing in the Colorado Springs quadrangle, for the quantity of water available for irrigation is small. Crops have been cultivated successfully in the valley of Camp Creek, the water being drawn from Queens Canyon. Small areas along Rock Creek and Little Fountain Creek have been similarly brought under cultivation. In the valley of Red Creek by the same amount of labor only a third of the crop can be raised by dry farming that can be raised with irrigation. The bottom lands along Fountain Creek, however, have yielded considerable amounts of forage. Nearly all the agricultural products of the region are consumed locally by ranchmen.

June, 1914.

[1] U. S. Dept. Agr. Bur. Chemistry Bull. 91, p. 70, 1905.

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

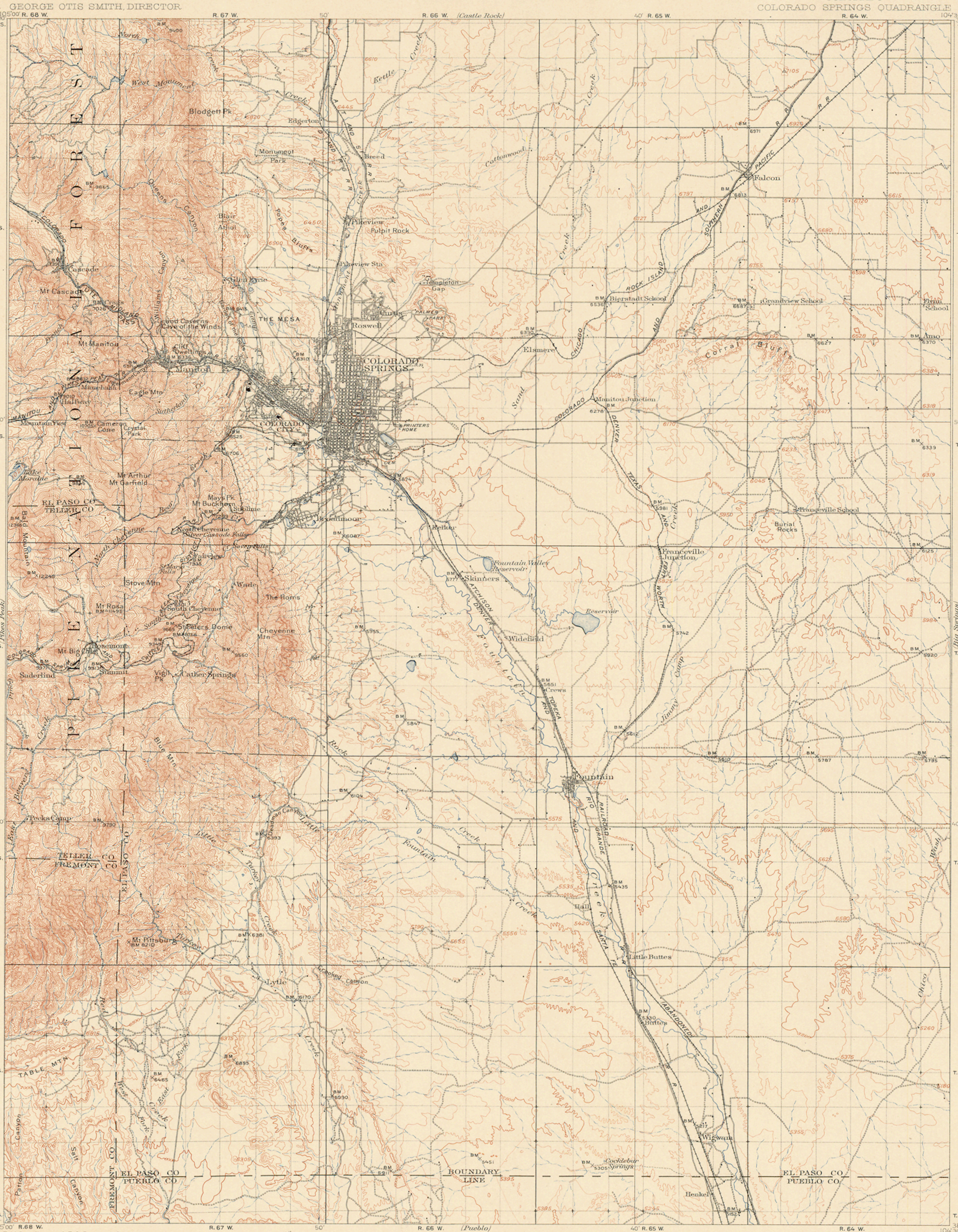
System.	Series.	Finlay (1916).[a]	Richardson (1915).[b]	Stose (1912).[c]	Henderson (1909).[d]	Darton (1905).[e]	Fenneman (1905).[f]	Gilbert (1897).[g]	Emmons, Cross, and Eldridge (1896).[h]	Cross (1894).[i]	Hayden Survey (1869–1876).
Tertiary.	Oligocene.	(Absent.)	Castle Rock conglomerate.						Monument Creek formation (Neocene). ["Monument Creek formation" as revealed by recent studies in the Denver Basin.]		Lignitic group: Monument Creek group (Miocene).
Tertiary.	Eocene.	Dawson arkose.	Dawson arkose.			Denver formation (Tertiary).			Denver formation (Cretaceous). ["Monument Creek formation" as revealed by recent studies in the Denver Basin.]		Lignitic group: Laramie formation. / Monument Creek group (Miocene).
Tertiary.	Eocene.	Dawson arkose.	Dawson arkose.			Arapahoe formation (Tertiary).			Arapahoe formation (Cretaceous). ["Monument Creek formation" as revealed by recent studies in the Denver Basin.]		Lignitic group: Laramie formation. / Monument Creek group (Miocene).
Cretaceous.	Upper Cretaceous.	Laramie formation.	Laramie formation.		Laramie formation.	Laramie formation.	Laramie formation.		Laramie formation.		Lignitic group: Laramie formation. / Laramie.
Cretaceous.	Upper Cretaceous.	Montana group: Fox Hills sandstone.	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.
Cretaceous.	Upper Cretaceous.	Montana group: Pierre shale.	Montana group: Fox Hills sandstone and Pierre shale.		Montana group: Pierre formation.	Pierre shale.	Pierre formation.	Pierre shale.	Montana group: Pierre formation.	Montana formation.	Fort Pierre.
Cretaceous.	Upper Cretaceous.	Colorado group: Niobrara formation.	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.
Cretaceous.	Upper Cretaceous.	Colorado group: Niobrara formation.	Colorado group: Niobrara and Benton formations.	Niobrara group: Timpas limestone.	Colorado group: Niobrara formation.	Niobrara formation.	Niobrara formation.	Niobrara formation.	Colorado group: Niobrara formation.	Colorado formation.	Niobrara.
Cretaceous.	Upper Cretaceous.	Colorado group: Carlile shale.	Colorado group: Niobrara and Benton formations.	Benton group: Carlile shale.	Colorado group: Benton formation.	Benton group: Carlile shale.	Benton formation.	Benton group: Carlile shale.	Colorado group: Benton formation.	Colorado formation.	Fort Benton.
Cretaceous.	Upper Cretaceous.	Colorado group: Greenhorn limestone.	Colorado group: Niobrara and Benton formations.	Benton group: Greenhorn limestone.	Colorado group: Benton formation.	Benton group: Greenhorn limestone.	Benton formation.	Benton group: Greenhorn limestone.	Colorado group: Benton formation.	Colorado formation.	Fort Benton.
Cretaceous.	Upper Cretaceous.	Colorado group: Graneros shale.	Colorado group: Niobrara and Benton formations.	Benton group: Graneros shale.	Colorado group: Benton formation.	Benton group: Graneros shale.	Benton formation.	Benton group: Graneros shale.	Colorado group: Benton formation.	Colorado formation.	Fort Benton.
Cretaceous.	Upper Cretaceous.	Dakota sandstone.	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.
Cretaceous.	Lower Cretaceous.	Purgatoire formation: Glencairn shale member.	Purgatoire formation.	Purgatoire formation.	"Dakota?" formation (probably in part Comanche).	"Dakota" sandstone (probably includes some Lower Cretaceous).	Dakota formation.	Dakota sandstone.	Dakota formation.	Dakota formation.	Dakota.
Cretaceous.	Lower Cretaceous.	Purgatoire formation: Lytle sandstone member.	Purgatoire formation.	Purgatoire formation.	"Dakota?" formation (probably in part Comanche).	"Dakota" sandstone (probably includes some Lower Cretaceous).	Dakota formation.	Dakota sandstone.	Dakota formation.	Dakota formation.	Dakota.
Cretaceous or Jurassic.	Lower Cretaceous or Upper Jurassic.	Morrison formation.	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.	(Absent.)	(Absent.)		Sundance marine beds.						
Carboniferous.	Permian (?).	Lykins formation.	Lykins formation.		Lykins formation (upper part Triassic?).	Upper Wyoming formation (Chugwater) (Triassic? or Permian).	(Triassic?): Lykins formation.		Wyoming formation (Juratrias).		Red Beds (Triassic).
Carboniferous.	Pennsylvanian.	Lyons sandstone.	Lyons sandstone.		Lyons formation.	Lower Wyoming formation (Fountain) (Pennsylvanian).	(Triassic?): Lyons sandstone.		Wyoming formation (Juratrias).		Red Beds (Triassic).
Carboniferous.	Pennsylvanian.	Fountain formation: Glen Eyrie shale member.	Fountain formation.		Fountain formation.	Lower Wyoming formation (Fountain) (Pennsylvanian).	(Triassic?): Fountain sandstone.	Fountain formation (Juratrias?).[j]	Wyoming formation (Juratrias).	Fountain formation (Carboniferous and Juratriassic?).[k]	Red Beds (Triassic).
Carboniferous.	Mississippian.		Millsap limestone.		Mississippian.	Millsap limestone.		Millsap limestone.		Millsap limestone.	
Ordovician.	Upper and Middle Ordovician.	(Absent.)	(Absent.)			Fremont limestone.				Fremont limestone.	
Ordovician.	Upper and Middle Ordovician.	Harding sandstone (included with Manitou limestone).	(Absent.)			Harding sandstone.		Harding sandstone.		Harding sandstone.	
Ordovician.	Lower Ordovician.	Manitou limestone.	Manitou limestone.			Manitou limestone.				Manitou limestone.	
Cambrian.	Upper Cambrian.	Sawatch sandstone.	Sawatch sandstone.			Reddish sandstone.					
Pre-Cambrian.		Pikes Peak granite.	Pikes Peak granite.		Algonkian.		Algonkian quartzite.	Archean schist and granite.	Archean gneiss, granite, and schist.	Algonkian quartzite, granite, including Pikes Peak granite, and gneiss.	
Pre-Cambrian.		Pikes Peak granite.	Pikes Peak granite.		Archean.		Archean granite and gneiss.	Archean schist and granite.	Archean gneiss, granite, and schist.	Algonkian quartzite, granite, including Pikes Peak granite, and gneiss.	

[a] Finlay, G. F., U. S. Geol. Survey Geol. Atlas, Colorado Springs folio (No. 203), 1916.
[b] Richardson, G. B., U. S. Geol. Survey Geol. Atlas, Castle Rock folio (No. 198), 1915.
[c] Stose, G. W., U. S. Geol. Survey Geol. Atlas, Apishapa folio (No. 186), 1912.
[d] Henderson, Junius, The foothills formations of north-central Colorado: Colorado Geol. Survey First Rept., pp. 145–188, 1909.
[e] 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.
[f] Fenneman, N. M., Geology of the Boulder district, Colo.: U. S. Geol. Survey Bull. 265, 1905.
[g] Gilbert, G. K., U. S. Geol. Survey Geol. Atlas, Pueblo folio (No. 36), 1897.
[h] Emmons, S. F., Cross, Whitman, and Eldridge, G. H., Geology of the Denver Basin in Colorado: U. S. Geol. Survey Mon. 27, 1896.
[i] Cross, Whitman, U. S. Geol. Survey Geol. Atlas, Pikes Peak folio (No. 7), 1894.
[j] May include Lyons sandstone and Lykins formation.
[k] As mapped in southeastern part of Pikes Peak quadrangle it included Lyons sandstone and Lykins formation.

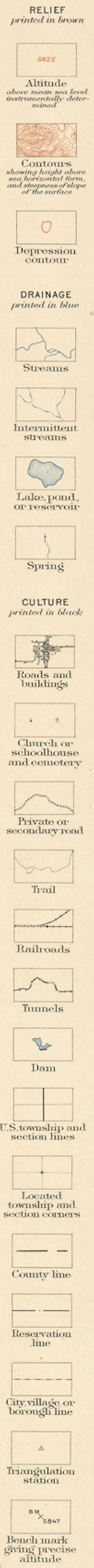
U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

TOPOGRAPHY

COLORADO
COLORADO SPRINGS QUADRANGLE



LEGEND



E. M. Douglas and E. C. Barnard, Geographers in charge.
Topography by R. T. Evans and H. R. Elliott.
Control by Coast and Geodetic Survey.
Surveyed in 1906-1907.

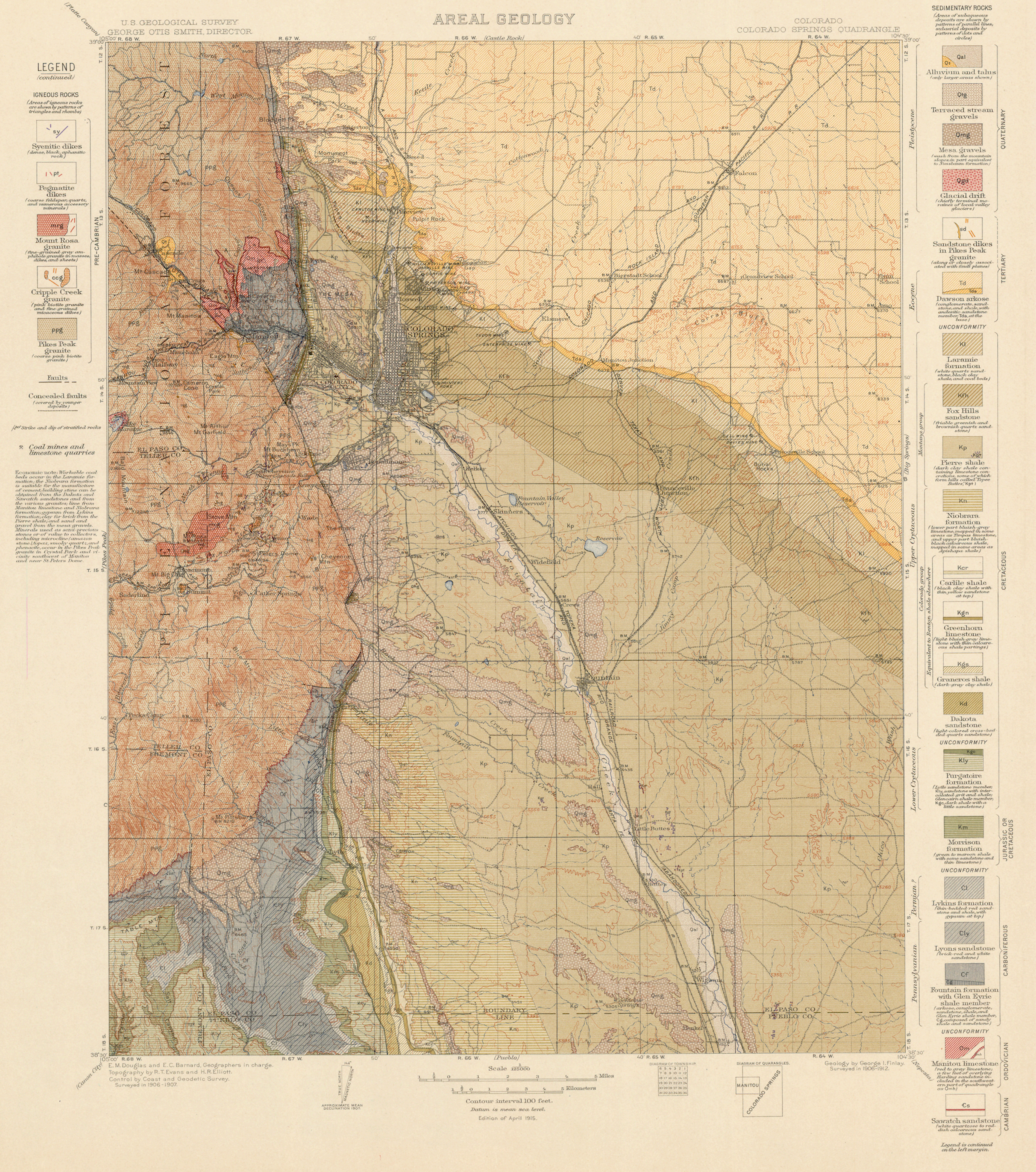
APPROXIMATE MEAN DECLINATION 1907.

Scale $\frac{1}{125000}$

Contour interval 100 feet.
Datum is mean sea level.

DIAGRAM OF TOWNSHIP

Edition of July 1909, reprinted Dec. 1914.



AREAL GEOLOGY
U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR
COLORADO
COLORADO SPRINGS QUADRANGLE
LEGEND
(continued)
IGNEOUS ROCKS
(Areas of igneous rocks are shown by patterns of triangles and rhombs)
Syenitic dikes
(dense, black, aphanitic rock)
Pegmatite dikes
(coarse feldspar, quartz, and numerous accessory minerals)
Mount Rosa granite
(fine-grained gray amphibole granite in masses, dikes, and sheets)
Cripple Creek granite
(pink biotite granite and fine-grained micaceous dikes)
Pikes Peak granite
(coarse pink biotite granite)
PRE-CAMBRIAN
Faults
Concealed faults
(covered by younger deposits)
20° Strike and dip of stratified rocks
Coal mines and limestone quarries
Economic note: Workable coal beds occur in the Laramie formation; the Niobrara formation is suitable for the manufacture of cement; building stone can be obtained from the Dakota and Sawatch sandstones and from the various granites; lime from Manitou limestone and Niobrara formation; gypsum from Lykins formation; clay for brick from the Pierre shale; and sand and gravel from the mesa gravels. Minerals used as semi-precious stones or of value to collectors, including microcline (amazon stone), topaz, smoky quartz, and phenacite, occur in the Pikes Peak granite in Crystal Park and vicinity southwest of Manitou and near St. Peters Dome.
LEGEND
SEDIMENTARY ROCKS
(Areas of subaqueous deposits are shown by patterns of parallel lines, subaerial deposits by patterns of dots and circles)
Alluvium and talus
(only larger areas shown)
Terraced stream gravels
Mesa gravels
(wash from the mountain slopes; in part equivalent to Nussbaum formation)
Glacial drift
(chiefly terminal moraines of local valley glaciers)
Pleistocene
QUATERNARY
Sandstone dikes in Pikes Peak granite
(along or closely associated with fault planes)
Dawson arkose
(conglomerate, sandstone, and shale, with andesitic sandstone member, Tda, at the base)
Eocene
TERTIARY
UNCONFORMITY
Laramie formation
(white quartz sandstone, black clay shale, and coal beds)
Fox Hills sandstone
(friable greenish and brownish quartz sandstone)
Pierre shale
(dark clay shale containing limestone concretions, some of which form hills called "Tepee Buttes," Kpt)
Montana group
Niobrara formation
(lower part bluish-gray limestone, mapped in some areas as Timpas limestone, and upper part bluish-black calcareous shale, mapped in some areas as Apishapa shale)
Carlile shale
(black clay shale with thin yellow sandstone at top)
Greenhorn limestone
(light bluish-gray limestone with thin calcareous shale partings)
Graneros shale
(dark-gray clay shale)
Colorado group
Equivalent to Benton shale elsewhere
Upper Cretaceous
Dakota sandstone
(light-colored cross-bedded quartz sandstone)
CRETACEOUS
UNCONFORMITY
Purgatoire formation
(Lytle sandstone member; Kly, sandstone with intercalated grit and shale; Glencairn shale member; Kgc, dark shale with a little sandstone)
Lower Cretaceous
Morrison formation
(green to maroon shale with some sandstone and thin limestone)
JURASSIC OR CRETACEOUS
UNCONFORMITY
Lykins formation
(thin-bedded red sandstone and shale, with gypsum at top)
Permian ?
Lyons sandstone
(brick-red and white sandstone)
Fountain formation with Glen Eyrie shale member
(arkose, conglomerate, sandstone, shale, and Glen Eyrie shale member, Cg, composed of sandy shale and sandstone)
Pennsylvanian
CARBONIFEROUS
UNCONFORMITY
Manitou limestone
(red to gray limestone; a few feet of overlying Harding sandstone included in the southwestern part of quadrangle as Omh)
ORDOVICIAN
Sawatch sandstone
(white quartzose to reddish calcareous sandstone)
CAMBRIAN
Legend is continued on the left margin.
COLORADO SPRINGS
MANITOU
Falcon
Colorado City
EL PASO CO.
TELLER CO.
FREMONT CO.
PUEBLO CO.
Fountain
Widefield
Manitou Junction
E.M. Douglas and E.C. Barnard, Geographers in charge.
Topography by R.T. Evans and H.R. Elliott.
Control by Coast and Geodetic Survey.
Surveyed in 1906-1907.
APPROXIMATE MEAN DECLINATION 1907
Scale 1/125000
Contour interval 100 feet.
Datum is mean sea level.
Edition of April 1915.
DIAGRAM OF TOWNSHIP
DIAGRAM OF QUADRANGLES
Geology by George I. Finlay.
Surveyed in 1906-1912.

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

STRUCTURE SECTIONS

COLORADO
COLORADO SPRINGS QUADRANGLE

LEGEND
(continued)

IGNEOUS ROCKS

SHEET SYMBOL / SECTION SYMBOL

PRE-CAMBRIAN

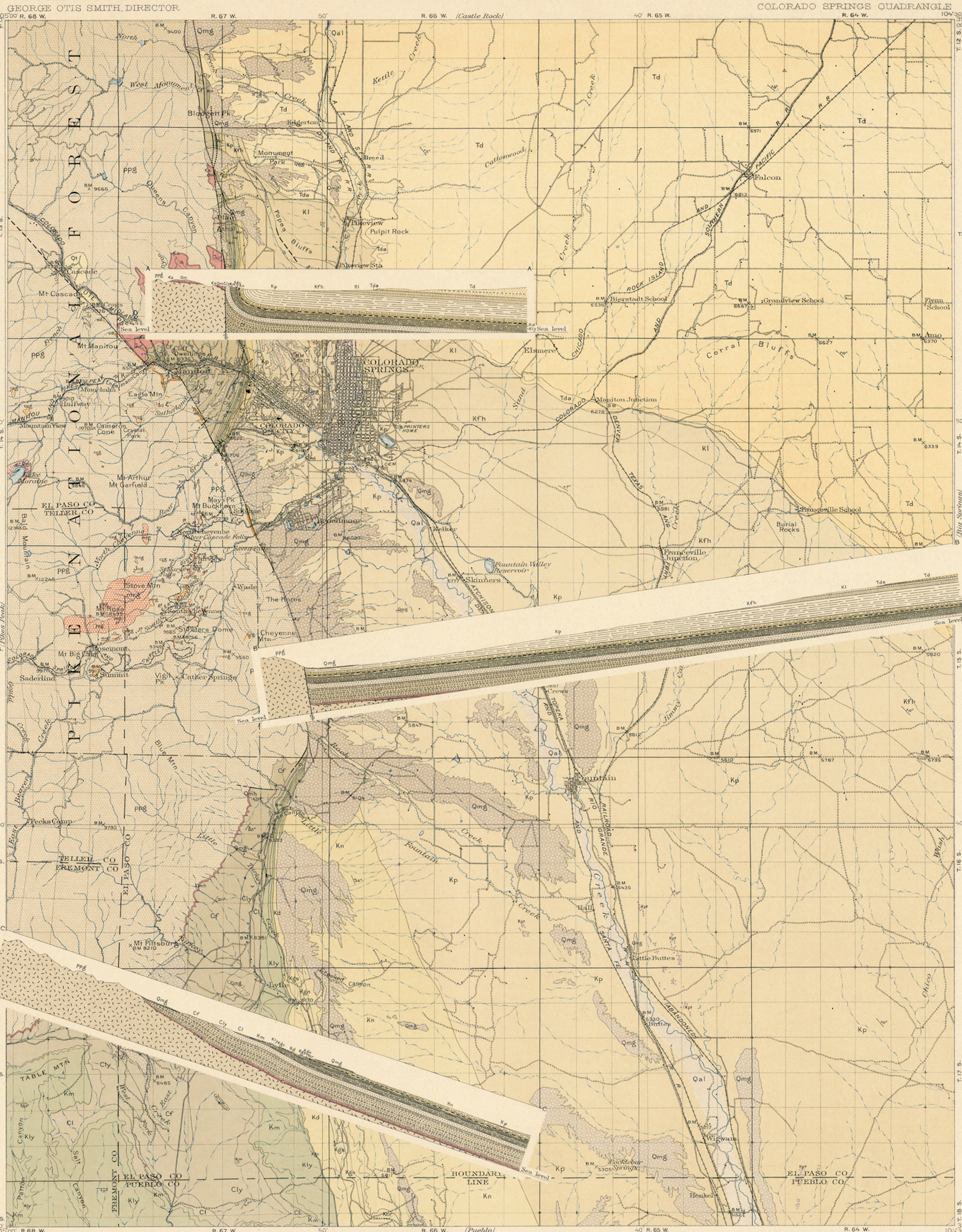
- sy — **Syenitic dikes** *(dense, black, aphanitic rock)*
- pt — **Pegmatite dikes** *(coarse feldspar, quartz, and numerous accessory minerals)*
- mrg — **Mount Rosa granite** *(fine-grained gray amphibole granite in masses, dikes, and sheets)*
- ccg — **Cripple Creek granite** *(pink biotite granite and fine-grained micaceous dikes)*
- PPg / PPg — **Pikes Peak granite** *(coarse pink biotite granite)*

Faults

Concealed faults *(covered by younger deposits)*

Strike and dip of stratified rocks

Note: Sections D-D and E-E are given in the text.



E. M. Douglas and E. C. Barnard, Geographers in charge.
Topography by R. T. Evans and H. R. Elliott.
Control by Coast and Geodetic Survey.
Surveyed in 1906-1907.

APPROXIMATE MEAN DECLINATION 1907.

Scale $\frac{1}{125000}$

Edition of June 1915

DIAGRAM OF TOWNSHIP.

DIAGRAM OF QUARANGLES.

Geology by George I. Finlay.
Surveyed in 1906-1912.

LEGEND

SEDIMENTARY ROCKS

SHEET SYMBOL / SECTION SYMBOL

QUATERNARY — *Pleistocene*

- Qal, Qt — **Alluvium and talus** *(only larger areas shown)*
- Qtg — **Terraced stream gravels**
- Qmg / Qmg — **Mesa gravels** *(wash from the mountain slopes, in part equivalent to Nussbaum formation)*
- Qgd — **Glacial drift** *(chiefly terminal moraines of local valley glaciers)*

TERTIARY

- sd — **Sandstone dikes in Pikes Peak granite** *(along or closely associated with fault planes)*
- *Eocene* — Td, Tda / Td, Tda — **Dawson arkose** *(conglomerate, sandstone, and shale, with andesitic sandstone member, Tda, at the base)*

UNCONFORMITY

CRETACEOUS

- Kl / Kl — **Laramie formation** *(white quartz sandstone, black clay shale, and coal beds)*
- *Montana group* — Kfh / Kfh — **Fox Hills sandstone** *(friable greenish and brownish quartz sandstone)*
- Kp, Kpt / Kp — **Pierre shale** *(dark clay shale containing limestone concretions, some of which form hills called "Tepee Buttes," Kpt)*
- *Upper Cretaceous — Colorado group* — Kn / Kn — **Niobrara formation** *(lower part bluish-gray limestone, mapped in some areas as Timpas limestone, and upper part bluish-black calcareous shale, mapped in some areas as Apishapa shale)*
- *Equivalent to Benton shale elsewhere* — Kcr / Kcr — **Carlile shale** *(black clay shale with thin yellow sandstone at top)*
- Kgn / Kgn — **Greenhorn limestone** *(light bluish-gray limestone with thin calcareous shale partings)*
- Kgs / Kgs — **Graneros shale** *(dark-gray clay shale)*
- Kd / Kd — **Dakota sandstone** *(light-colored cross-bedded quartz sandstone)*

UNCONFORMITY

- *Lower Cretaceous* — Kly, Kgc / Kgc, Kly — **Purgatoire formation** *(Lytle sandstone member; Kly, sandstone with intercalated grit and shale; Glencairn shale member; Kgc, dark shale with a little sandstone)*

JURASSIC OR CRETACEOUS

- Km / Km — **Morrison formation** *(green to maroon shale with some sandstone and thin limestone)*

UNCONFORMITY

CARBONIFEROUS

- *Permian ?* — Cl / Cl — **Lykins formation** *(thin-bedded red sandstone and shale, with gypsum at top)*
- *Pennsylvanian* — Cly / Cly — **Lyons sandstone** *(brick-red and white sandstone)*
- Cf, Cg / Cf — **Fountain formation with Glen Eyrie shale member** *(arkose, conglomerate, sandstone, shale, and Glen Eyrie shale member, Cg, composed of sandy shale and sandstone)*

UNCONFORMITY

ORDOVICIAN

- Om, Omh / Om — **Manitou limestone** *(red to gray limestone; a few feet of overlying Harding sandstone included in the southwestern part of quadrangle, as Omh)*

CAMBRIAN

- €s / €s — **Sawatch sandstone** *(white quartzose to reddish calcareous sandstone)*

Legend is continued on the left margin.

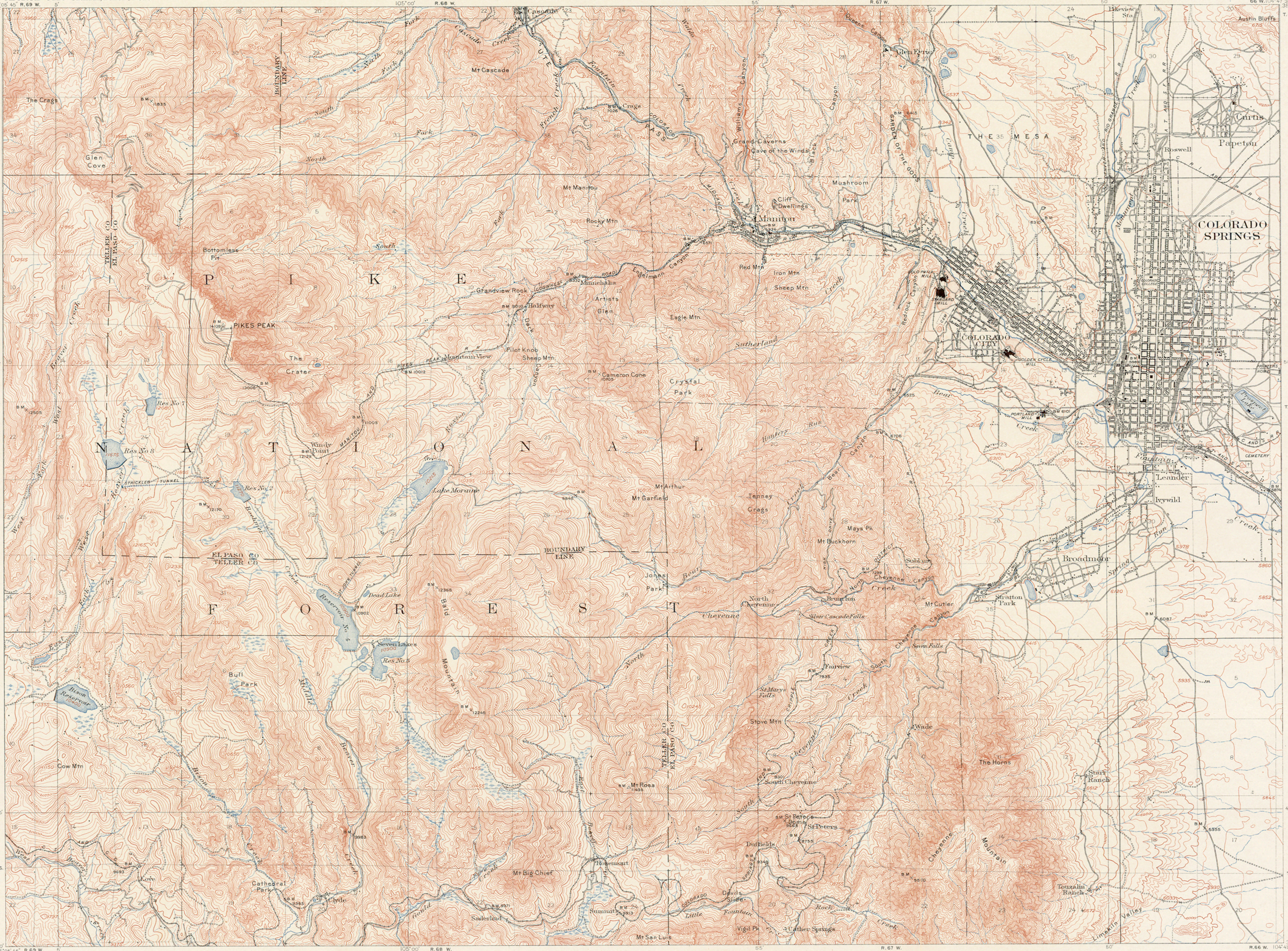
U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

TOPOGRAPHY

COLORADO
MANITOU QUADRANGLE

LEGEND
(continued)

- Tunnels
- Bridge
- Dam
- U.S. township and section lines
- Located township and section corners
- County line
- Reservation line
- City, village, or borough line
- Triangulation station
- Bench mark giving precise altitude



105°05'45" R.69 W. 105°00' R.68 W. 55' R.67 W. 50' R.66 W. 104°47'30"
38°52'30" T.13 S. T.14 S. T.15 S. 38°43'30"

E.M. Douglas and E.C. Barnard, Geographers in charge.
Topography by R.T. Evans, D.F.C. Moor, and H.R. Elliott.
Control by Coast and Geodetic Survey.
Surveyed in 1906-1907.

TRUE NORTH MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION 1907.

Scale $\frac{1}{48000}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 50 feet.
Datum is mean sea level.

Edition of May 1909, reprinted Feb. 1915.

LEGEND

RELIEF
printed in brown

- Altitude *above mean sea level instrumentally determined*
- Contours *showing height above sea, horizontal form, and steepness of slope of the surface*
- Depression contour
- Mine dump and wash

DRAINAGE
printed in blue

- Streams
- Intermittent streams
- Flume and pipe line
- Lake or reservoir
- Aqueduct tunnel
- Intermittent lake
- Marsh

CULTURE
printed in black

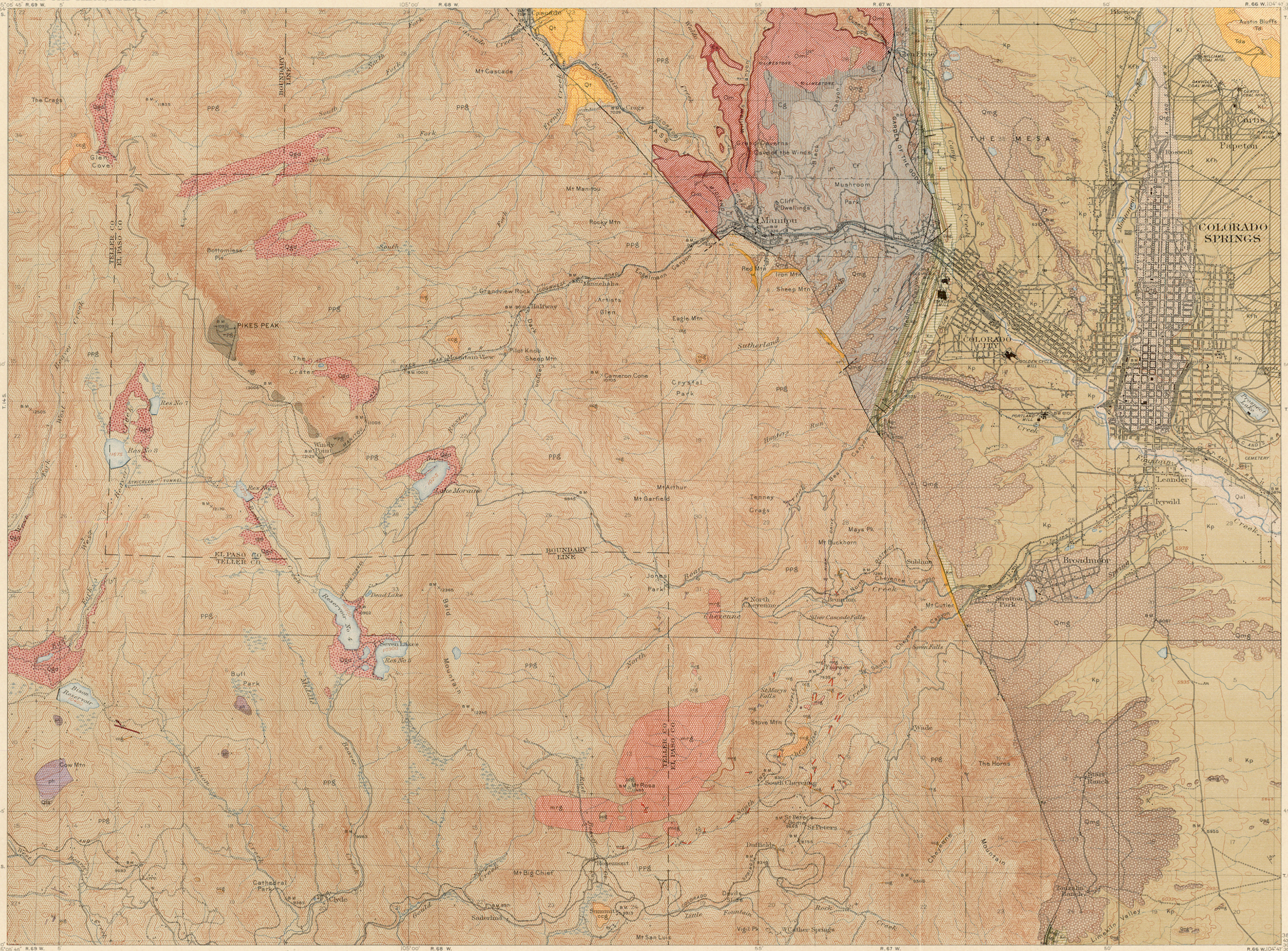
- Roads and buildings
- Church or schoolhouse and cemetery
- Private or secondary road
- Trail
- Railroads
- Electric railroad

Legend is continued on the left margin

U. S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

AREAL GEOLOGY

COLORADO
MANITOU QUADRANGLE



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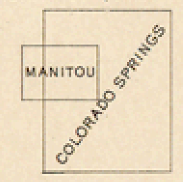
Topography by R. T. Evans, D. F. C. Moor, and H. R. Elliott.
Control by Coast and Geodetic Survey.
Surveyed in 1906-1907.

APPROXIMATE MEAN DECLINATION 1907.

Scale $\frac{1}{48000}$

Contour interval 50 feet.
Datum is mean sea level.
Edition of April 1915.

DIAGRAM OF QUADRANGLES.



Geology by George I. Finlay.
Surveyed in 1906-1912.

LEGEND

SEDIMENTARY ROCKS

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

QUATERNARY — *Pleistocene*

- Qal, Qr — Alluvium and talus *(only larger areas shown)*
- Qls — Landslide *(small mass on south slope of Cow Mountain)*
- Qtg — Terraced stream gravels
- Qmg — Mesa gravels *(wash from the mountain slopes, in part equivalent to Nussbaum formation)*
- Qgd — Glacial drift *(chiefly terminal moraines of local valley glaciers)*

TERTIARY

- sd — Sandstone dikes in Pikes Peak granite *(along or closely associated with fault planes)*
- *Eocene* — Td, Tda — Dawson arkose *(conglomerate, sandstone, and shale, with andesitic sandstone member; Tda, at the base)*

UNCONFORMITY

CRETACEOUS — *Upper Cretaceous*

- Kl — Laramie formation *(white quartz sandstone, black clay shale, and coal beds)*
- *Montana group*
  - Kfh — Fox Hills sandstone *(friable greenish and brownish quartz sandstone)*
  - Kp — Pierre shale *(dark clay shale containing limestone concretions)*
- *Colorado group*
  - Kn — Niobrara formation *(lower part bluish-gray limestone, mapped in some areas as Timpas limestone, and upper part bluish-black calcareous shale, mapped in some areas as Apishapa shale)*
  - *Equivalent to Benton shale elsewhere*
    - Kcr — Carlile shale *(black clay shale with thin, yellow sandstone at top)*
    - Kgn — Greenhorn limestone *(light bluish-gray limestone with thin calcareous shale partings)*
    - Kgs — Graneros shale *(dark-gray clay shale)*
- Kd — Dakota sandstone *(light-colored cross-bedded quartz sandstone)*

UNCONFORMITY

Lower Cretaceous

- Kly, Kgc — Purgatoire formation *(Lytle sandstone member; Kly, sandstone with intercalated grit and shale; Glencairn shale member, Kgc, dark shale with a little sandstone)*

JURASSIC OR CRETACEOUS

- Km — Morrison formation *(green to maroon shale with some sandstone and thin limestone)*

UNCONFORMITY

CARBONIFEROUS

- *Permian?* — Cl — Lykins formation *(thin-bedded red sandstone and shale, with gypsum at top)*
- *Pennsylvanian*
  - Cly — Lyons sandstone *(brick-red and white sandstone)*
  - Cf, Cg — Fountain formation with Glen Eyrie shale member *(arkose, conglomerate, sandstone, shale, and Glen Eyrie shale member, Cg, composed of sandy shale and sandstone)*

UNCONFORMITY

Legend is continued on the left margin.

LEGEND

SEDIMENTARY ROCKS
(continued)

ORDOVICIAN

- Om — Manitou limestone *(red to gray limestone)*

CAMBRIAN

- €s — Sawatch sandstone *(white quartzose to reddish calcareous sandstone)*

IGNEOUS ROCKS

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

TERTIARY

- ph — Phonolite *(dense, fine-grained, dark-gray to brownish-gray rock)*

PRE-CAMBRIAN

- sy — Syenitic dikes *(dense, black, aphanitic rock)*
- pt — Pegmatite dikes *(coarse feldspar, quartz, and numerous accessory minerals)*
- mrg — Mount Rosa granite *(fine-grained gray amphibole granite in masses, dikes, and sheets)*
- wpg — Windy Point granite *(brownish-red biotite granite)*
- ccg — Cripple Creek granite *(pink biotite granite and fine-grained micaceous dikes)*
- ppg — Pikes Peak granite *(coarse pink biotite granite)*

Faults

Concealed faults *(covered by younger deposits)*

20° Strike and dip of stratified rocks

Coal mines and limestone quarries

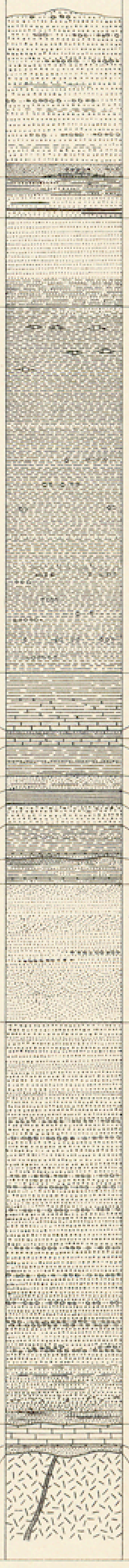
Metalliferous prospects, unproductive

Economic note: *Workable coal beds occur in the Laramie formation; the Niobrara formation is suitable for the manufacture of cement; building stone can be obtained from the Dakota and Sawatch sandstones and from the various granites; lime from Manitou limestone and Niobrara formation; gypsum from Lykins formation; clay for brick from the Pierre shale; and sand and gravel from the mesa gravels. Minerals used as semi-precious stones or of value to collectors, including microcline (amazon stone), topaz, smoky quartz, and phenacite, occur in the Pikes Peak granite in Crystal Park and vicinity, southwest of Manitou.*

COLUMNAR SECTION

GENERALIZED SECTION OF THE ROCKS EXPOSED IN THE COLORADO SPRINGS QUADRANGLE, COLO.

SCALE: 1 INCH=1,000 FEET.



System.	Formation.	Symbol.	Thickness in Feet.	Character of Rocks.	Character of Topography.
TERTIARY (EOCENE)	Dawson arkose.	Td	1,000±	White and gray arkose with conglomeratic layers and interbedded clays.	Undulating plains with prominent escarpments.
	Andesitic sandstone member.	(Tda)	(90)	Almost wholly fine-grained andesitic débris. Gray siliceous sandstone locally at base.	
	UNCONFORMITY				
CRETACEOUS — UPPER CRETACEOUS	Laramie formation.	Kl	250–300	Fine-grained white quartz sandstone and some black shale and thin seams of coal.	Slopes and low ridges.
	Fox Hills sandstone.	Kfh	600	Dark-gray and brownish-gray fine-grained sandstone, interbedded with shale in lower part.	Slopes and low ridges.
	Pierre shale.	Kp	2,500	Fine-grained dark-gray shale with columnar masses of limestone that here and there form "tepee buttes."	Small isolated conical hills called "tepee buttes."
				Fine-grained drab shale with ferruginous concretions of lime and iron carbonates.	Plains and slopes.
				Drab shale with disseminated gypsum, local sandy layers, and numerous limestone concretions.	
	Niobrara formation.	Kn	400–500	Upper part gray shale with disseminated gypsum; lower part light-gray calcareous shale with pale-gray limestone at base.	Plains, slopes, and low ridges
	Carlile shale.	Kcr	60	Black shale with brownish-gray calcareous sandstone at top.	Valley slopes.
	Greenhorn limestone.	Kgn	50	Light bluish-gray limestone and thin gray interbedded shales.	Terraces on valley slopes.
	Graneros shale.	Kgs	175–220	Gray to drab shale.	Valleys and outer slopes of hogback ridges.
	Dakota sandstone.	Kd	100	Whitish-gray and buff fine-grained sandstones; upper part cross-bedded.	High hogback ridges with cliffs.
	UNCONFORMITY				
CRETACEOUS — LOWER CRET.	Purgatoire formation. Glencairn shale member.	Kgc	50-150	Bluish-black and drab shales.	Slopes.
	Purgatoire formation. Lytle sandstone member.	Kly	145	Coarse porous pebbly sandstone.	Low hogback ridges and slopes.
CRETACEOUS OR JURASSIC	Morrison formation.	Km	225±	Maroon and olive-green clay shales with thin limestone and sandstone near base.	Slopes and low hills.
	UNCONFORMITY				
PERMIAN ?	Lykins formation.	Cl	180	Thin red sandy shales with gypsum layers near top and thin limestone near base.	Low slopes and ridges.
CARBONIFEROUS — PENNSYLVANIAN	Lyons sandstone.	Cly	800–850	White to pink fine-grained homogeneous sandstone in upper part; cross-bedded brick-red fine-grained homogeneous sandstone in lower part.	Ridges and prominent rock pinnacles in the Garden of the Gods and elsewhere in the foothills.
	Fountain formation.	Cf	800–4,500	Red, maroon, and white sandstone, arkose, and conglomerate, with small amounts of interbedded red and green shale.	Rugged valleys with picturesque monuments and other erosion forms in the Garden of the Gods, Monument Park, and elsewhere in the foothills.
	Glen Eyrie shale member.	(Cg)	(100)	Fine-grained thin-bedded buff and gray sandstones and black and drab shale.	
	UNCONFORMITY				
ORDOVICIAN	Manitou limestone.	Om	50–250	Red to gray limestone and massive blue-gray limestone. A few feet of overlying Harding sandstone of Silurian age present in the southwestern part of the quadrangle.	Slopes of mountain spurs and cliff walls.
CAMBRIAN	Sawatch sandstone.	Ꞓs	45	White fine-grained quartz sandstone with brownish-red glauconitic calcareous limestone at top.	
	UNCONFORMITY				
PRE-CAMBRIAN	Pikes Peak, Cripple Creek, and Mount Rosa granites.	ppg ccg mrg		Granite, mostly pink, intersected by syenitic and other dikes.	High ridges and mountain summits.

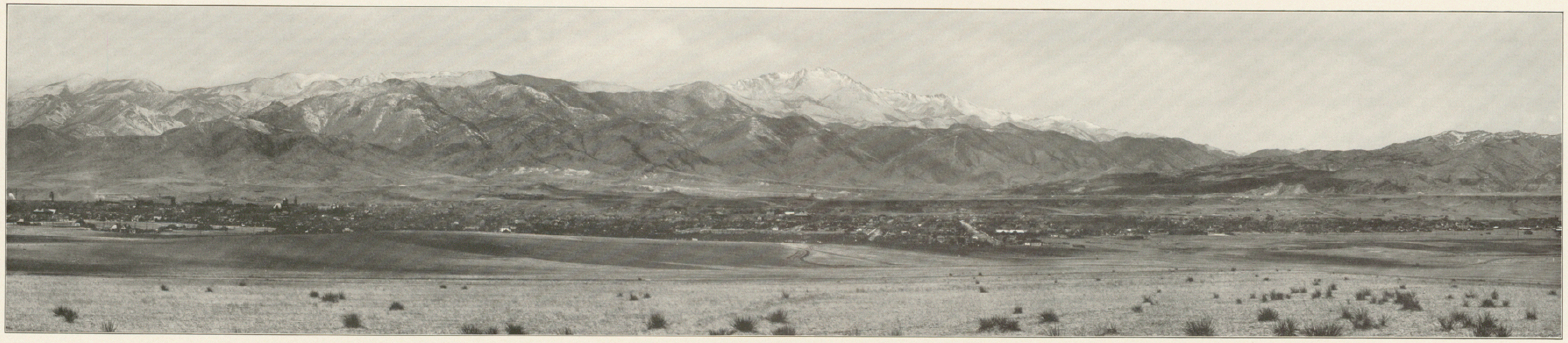


PLATE I.—FRONT RANGE FROM THE PLAINS EAST OF COLORADO SPRINGS.
Highest peak near center of mountain group is Pikes Peak; small round knob to left is Cameron Cone; large mass to left is Mount Garfield; sharp peak at extreme left is Mount Rosa. Mountain tops at right of Ute Pass and valley of Fountain Creek are part of a high plateau. Back of Colorado Springs is a gravel-capped terrace, which merges into The Mesa at right. Beyond The Mesa are the sedimentary rock ridges of the Garden of the Gods. The Ute Pass fault, which comes out of mountains along Fountain Creek, follows foot of range to left.

PLATE II.—PIKES PEAK SUMMIT FROM THE NORTHEAST SPUR.
Large granite masses like those shown in foreground cover much of the top of the mountain. Mountain tops at left are part of an elevated plateau. Sharp peak at extreme left is Mount Rosa.

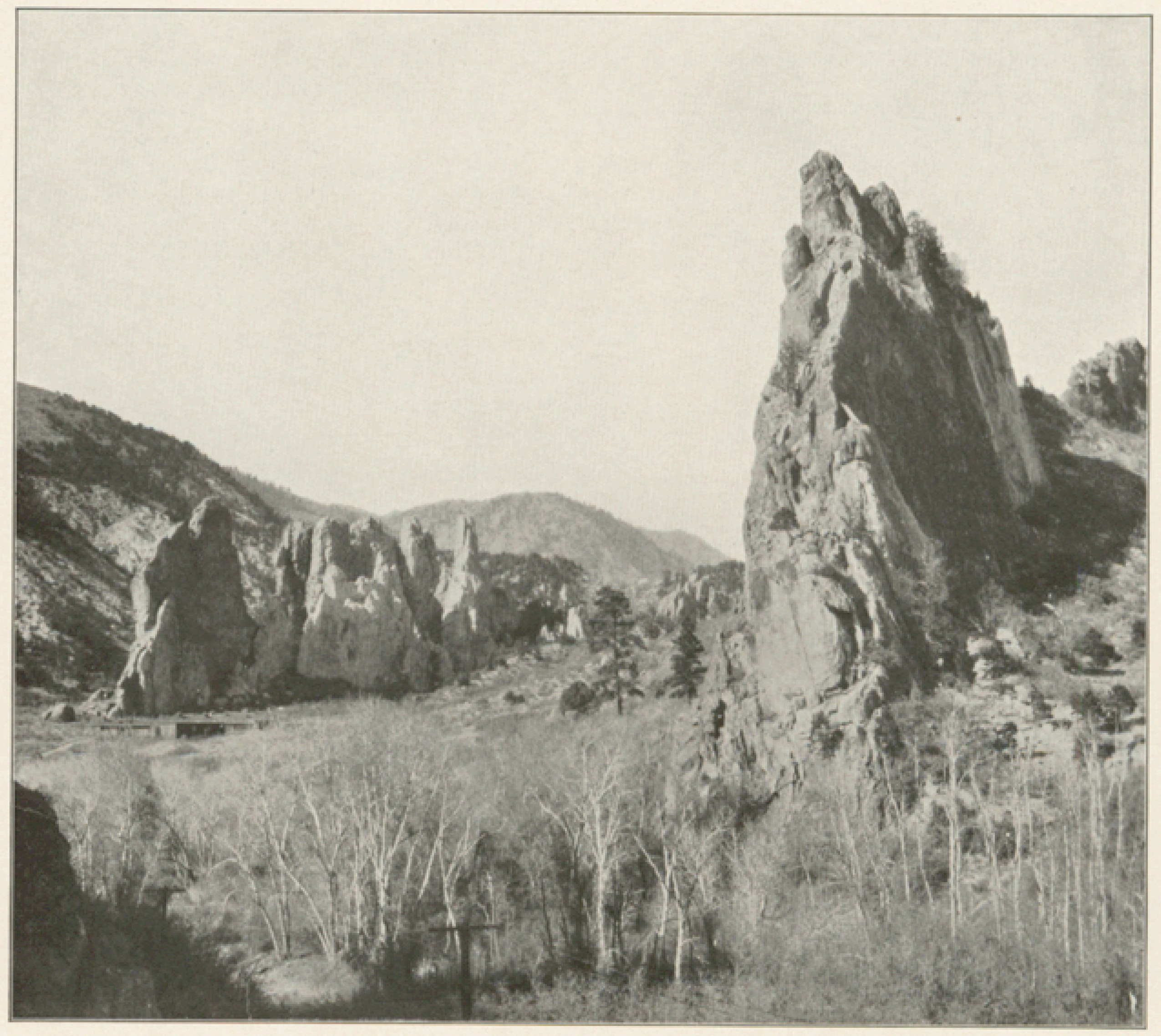


PLATE III.—HOGBACK RIDGE OF DAKOTA SANDSTONE IN GLEN EYRIE.
View looking northwest. Dakota sandstone in foreground dips steeply to the east. High ledges of vertical red and white sandstones of Lyons formation in middle distance. Manitou limestone on lower slopes of Front Range in left distance.

PLATE IV.—RIDGE OF BASAL LIMESTONE BEDS OF NIOBRARA FORMATION IN FOOTHILLS NORTH OF FOUNTAIN CREEK, COLORADO CITY.
View looking north. Vertical beds of lower formations form pinnacled ledges in left middle distance. Front Range in left background. The Mesa, capped by gravel, in right distance.

PLATE V.—MANITOU LIMESTONE AND SAWATCH SANDSTONE IN WILLIAMS CANYON NEAR THE NARROWS, MANITOU.
Manitou limestone forms upper white cliffs on left. Lower cliffs are composed of Sawatch sandstone.

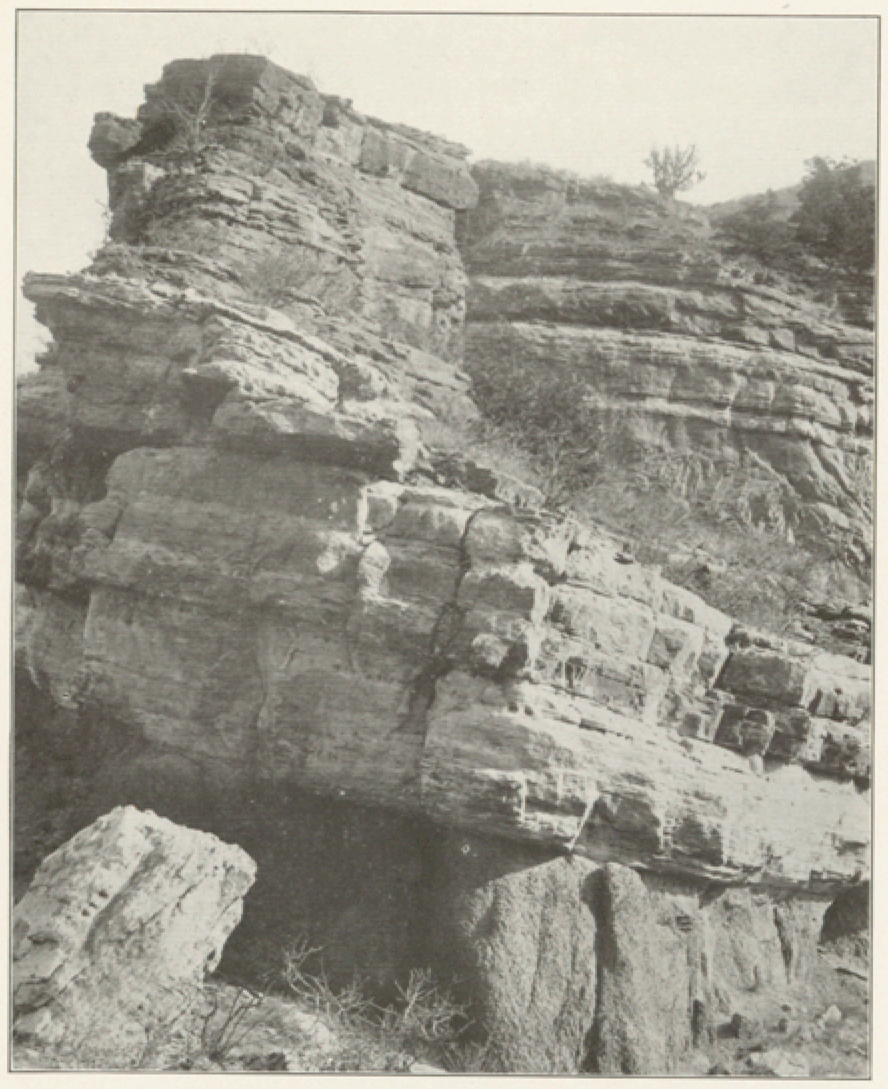


PLATE VI.—SAWATCH SANDSTONE RESTING ON EVEN SURFACE OF PIKES PEAK GRANITE.
Ute Pass, near Manitou.

PLATE VII.—GATEWAY OF GARDEN OF THE GODS.
View looking west to Pikes Peak in the distance. The gateway is formed by vertical beds of red sandstone of Lyons formation. High white ledge in front of the red sandstone is the top sandstone of the Lyons, and lower white ledge in foreground is gypsum at top of Lykins formation.

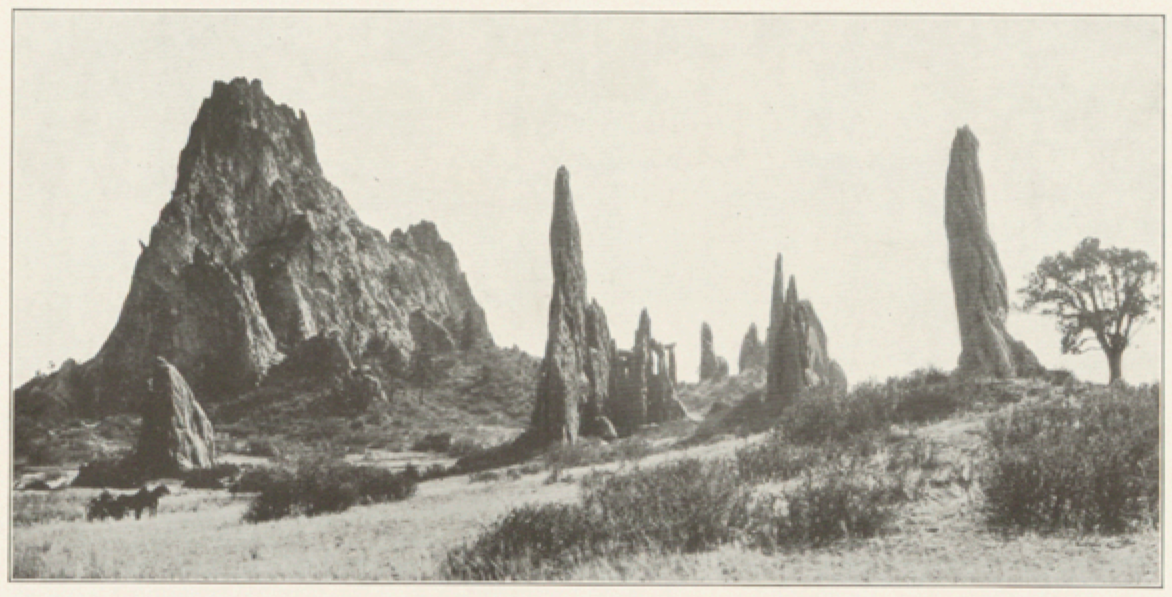


PLATE VIII.—ROCK PINNACLES FORMED BY EROSION IN GARDEN OF THE GODS.
View looking east. Pinnacles of vertical thin-bedded red sandstone of Fountain formation. More massive forms of thicker sandstones of Lyons formation on left.

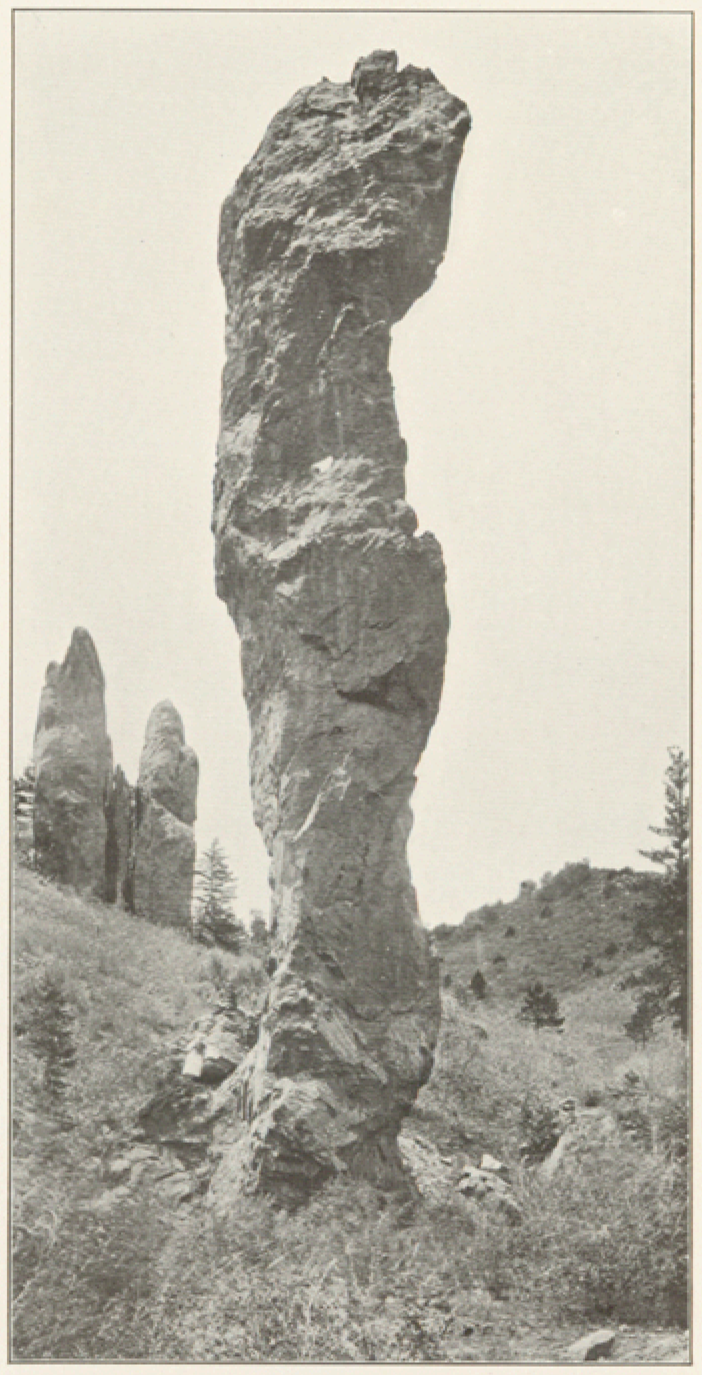


PLATE IX.—THE "MAJOR-DOMO," IN GLEN EYRIE.
A monument formed by erosion of vertical beds of red sandstone of Fountain formation.

PLATE X.—"HOODOOS" IN SOUTHERN PART OF GARDEN OF THE GODS.
View looking west. These curious-shaped masses are formed by erosion of red conglomeratic sandstone of Fountain formation.

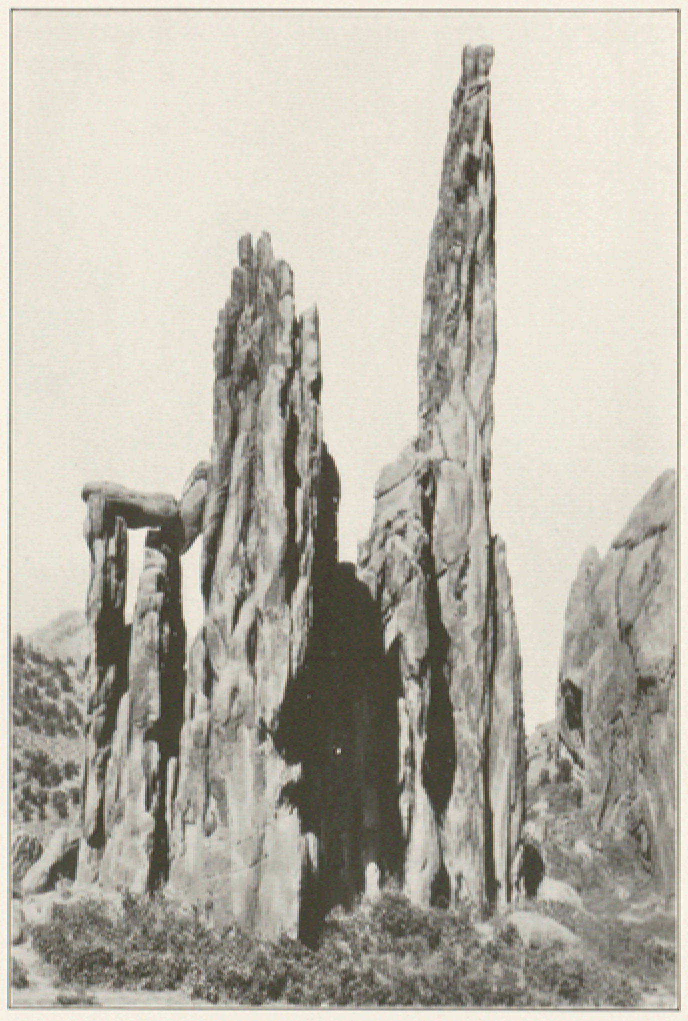


PLATE XI.—"CATHEDRAL SPIRES" IN GARDEN OF THE GODS.
Near view looking west of pinnacled forms shown in Plate VIII.

PLATE XII.—NATURAL MONUMENTS FORMED BY EROSION IN MONUMENT PARK.
The monuments are formed of Dawson arkose, layers of which have been hardened by a cement of iron oxide and have resisted weathering, thus forming a cap that has protected the softer rocks beneath. Two of these hard layers are shown in monument at left.

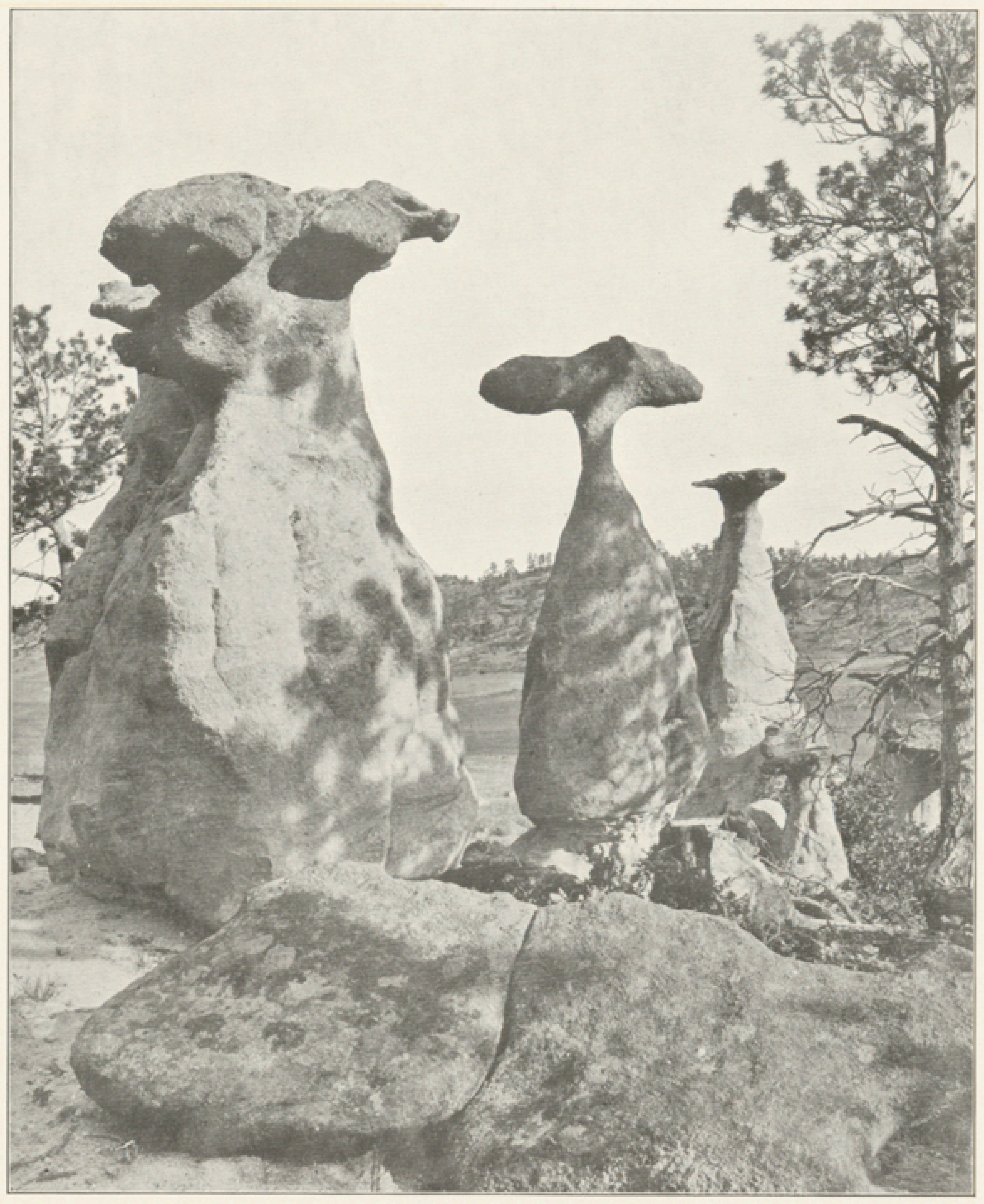


PLATE XIII.—BOTTLE-SHAPED MASSES FORMED BY EROSION OF DAWSON ARKOSE IN MONUMENT PARK.
Capping layer is brownish conglomeratic material hardened by iron oxide.

PLATE XIV.—NATURAL MONUMENTS FORMED BY EROSION OF DAWSON ARKOSE IN MONUMENT PARK.
Shows wide extent of capping of hard layer of brown sandstone.

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		Ꞓ	Peacock-blue.
Paleozoic	Carboniferous	Permian; Pennsylvanian; Mississippian	C	Blue.
	Devonian		D	Blue-gray.
	Silurian		S	Blue-purple.
	Ordovician		O	Red-purple.
	Cambrian		Ꞓ	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.

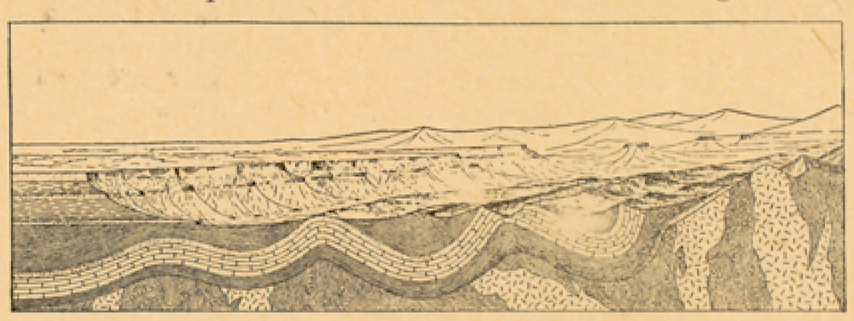


FIGURE 2.—Sketch showing a vertical section at the front and a landscape beyond.

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.

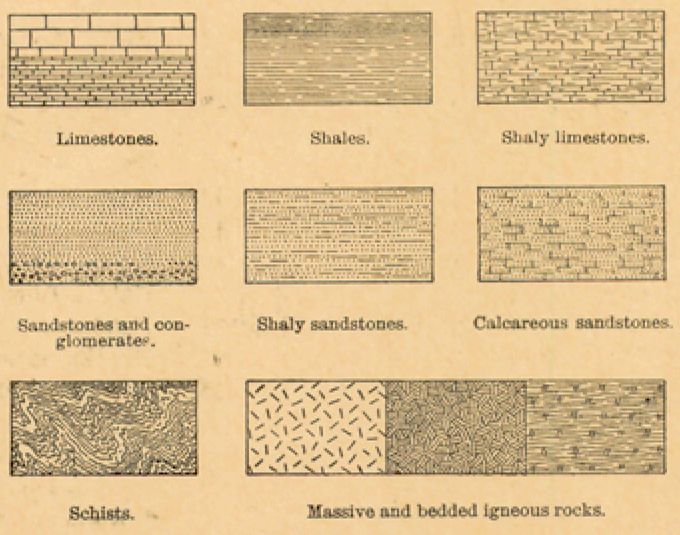
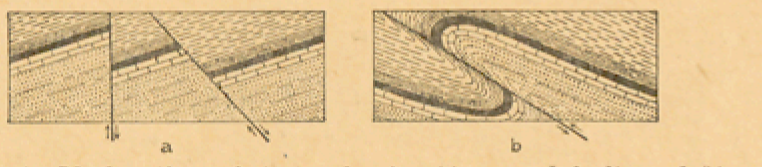


FIGURE 3.—Symbols used in sections to represent different kinds of rocks.

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.



a b

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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