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

GEOLOGIC ATLAS
OF THE
UNITED STATES

ENGINEER MOUNTAIN FOLIO

COLORADO

BY

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WASHINGTON, D. C.
ENGRAVED AND PRINTED BY THE U. S. GEOLOGICAL SURVEY
GEORGE W. STOSE, EDITOR OF GEOLOGIC MAPS   S. J. KUBEL, CHIEF ENGRAVER
1910

GEOLOGIC ATLAS OF THE UNITED STATES.

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

THE TOPOGRAPHIC MAP.

The features represented on the topographic map are of three distinct kinds—(1) inequalities of surface, called *relief*, as plains, plateaus, valleys, hills, and mountains; (2) distribution of water, called *drainage*, as streams, lakes, and swamps; (3) the works of man, called *culture*, as roads, railroads, boundaries, villages, and cities.

Relief.—All elevations are measured from mean sea level. The heights of many points are accurately determined, and those of the most important ones are given on the map in figures. It is desirable, however, to give the elevation of all parts of the area mapped, to delineate the outline or form of all slopes, and to indicate their grade or steepness. This is done by lines each of which is drawn through points of equal elevation above mean sea level, the vertical interval represented by each space between lines being the same throughout each map. These lines are called *contour lines* or, more briefly, *contours*, and the uniform vertical distance between each two contours is called the *contour interval*. Contour lines and elevations are printed in brown. The manner in which contour lines express altitude, form, and grade is shown in figure 1.

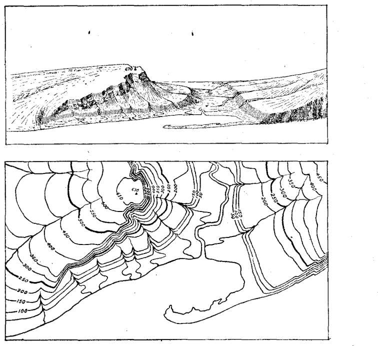


FIGURE 1.—Ideal view and corresponding contour map.

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

1. A contour line represents a certain height above sea level. In this illustration the contour interval is 50 feet; therefore the contour lines are drawn at 50, 100, 150, and 200 feet, and so on, above mean sea level. Along the contour at 250 feet lie all points of the surface that are 250 feet above the sea—that is, this contour would be the shore line if the sea were to rise 250 feet; along the contour at 200 feet are all points that are 200 feet above the sea; and so on. In the space between any two contours are all points whose elevations are above the lower and below the higher contour. Thus the contour at 150 feet falls just below the edge of the terrace, and that at 200 feet lies above the terrace; therefore all points on the terrace are shown to be more than 150 but less than 200 feet above the sea. The summit of the higher hill is marked 670 (feet above sea level); accordingly the contour at 650 feet surrounds it. In this illustration all the contour lines are numbered, and those for 250 and 500 feet are accentuated by being made heavier. Usually it is not desirable to number all the contour lines. The accentuating and numbering of certain of them—say every fifth one—suffices and the heights of the others may be ascertained by counting up or down from these.

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

3. Contour lines show the approximate grade of any slope. The vertical interval between two contours is the same, whether they lie along a cliff or on a gentle slope; but to attain a given height on a gentle slope one must go farther than on a steep slope, and therefore contours are far apart on gentle slopes and near together on steep ones.

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

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

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

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

Three scales are used on the atlas sheets of the Geological Survey; they are $\frac{1}{250,000}$, $\frac{1}{125,000}$, and $\frac{1}{62,500}$, corresponding approximately to 4 miles, 2 miles, and 1 mile on the ground to an inch on the map. On the scale of $\frac{1}{62,500}$ a square inch of map surface represents about 1 square mile of earth surface; on the scale of $\frac{1}{125,000}$, about 4 square miles; and on the scale of $\frac{1}{250,000}$, about 16 square miles. At the bottom of each atlas sheet the scale is expressed in three ways—by a graduated line representing miles and parts of miles, by a similar line indicating distance in the metric system, and by a fraction.

Atlas sheets and quadrangles.—The map of the United States is being published in atlas sheets of convenient size, which represent areas bounded by parallels and meridians. These areas are called *quadrangles*. Each sheet on the scale of $\frac{1}{250,000}$ represents one square degree—that is, a degree of latitude by a degree of longitude; each sheet on the scale of $\frac{1}{125,000}$ represents one-fourth of a square degree, and each sheet on the scale of $\frac{1}{62,500}$ one-sixteenth of a square degree. The areas of the corresponding quadrangles are about 4000, 1000, and 250 square miles, though they vary with the latitude.

The atlas sheets, being only parts of one map of the United States, are not limited by political boundary lines, such as those of States, counties, and townships. Many of the maps represent areas lying in two or even three States. To each sheet, and to the quadrangle it represents, is given the name of some well-known town or natural feature within its limits, and at the sides and corners of each sheet are printed the names of adjacent quadrangles, if the maps are published.

THE GEOLOGIC MAPS.

The maps representing the geology show, by colors and conventional signs printed on the topographic base map, the distribution of rock masses on the surface of the land and, by means of structure sections, their underground relations, so far as known and in such detail as the scale permits.

KINDS OF ROCKS.

Rocks are of many kinds. On the geologic map they are distinguished as igneous, sedimentary, and metamorphic.

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

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

The chief agent in the transportation of rock débris is water in motion, including rain, streams, and the water of lakes and of the sea. The materials are in large part carried as solid particles, and the deposits are then said to be mechanical. Such are gravel, sand, and clay, which are later consolidated into conglomerate, sandstone, and shale. Some of the materials are carried in solution, and deposits of these are called organic if formed with the aid of life, or chemical if formed without the aid of life. The more important rocks of chemical and organic origin are limestone, chert, gypsum, salt, iron ore, peat, lignite, and coal. Any one of the kinds of deposit named may be separately formed, or the different materials may be intermingled in many ways, producing a great variety of rocks.

Another transporting agent is air in motion, or wind, and a third is ice in motion, or glaciers. The most characteristic of the wind-borne or eolian deposits is loess, a fine-grained earth; the most characteristic of glacial deposits is till, a heterogeneous mixture of bowlders and pebbles with clay or sand.

Sedimentary rocks are usually made up of layers or beds which can be easily separated. These layers are called *strata*, and rocks deposited in such layers are said to be stratified.

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

Rocks exposed at the surface of the land are acted on by air, water, ice, animals, and plants, especially the low organisms known as bacteria. They gradually disintegrate and the more soluble parts are leached out, the less soluble material being left as a *residual* layer. Water washes this material down the slopes, and it is eventually carried by rivers to the ocean or other bodies of water. Usually its journey is not continuous, but it is temporarily built into river bars and flood plains, where it forms *alluvium*. Alluvial deposits, glacial deposits (collectively known as *drift*), and eolian deposits belong to the *surficial* class, and the residual layer is commonly included with them. Their upper parts, occupied by the roots of plants, constitute soils and subsoils, the soils being usually distinguished by a notable admixture of organic matter.

Metamorphic rocks.—In the course of time, and by various processes, rocks may become greatly changed in composition and in texture. If the new characteristics are more pronounced than the old such rocks are called *metamorphic*. In the process of metamorphism the constituents of a chemical rock may enter into new combinations and certain substances may be lost or new ones added. A complete gradation from the primary to the metamorphic form may exist within a single rock mass. Such changes transform sandstone into quartzite and limestone into marble and modify other rocks in various ways.

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

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

FORMATIONS.

For purposes of geologic mapping rocks of all the kinds above described are divided into *formations*. A sedimentary formation contains between its upper and lower limits either rocks of uniform character or rocks more or less uniformly varied in character, as, for example, an alternation of shale and limestone. Where the passage from one kind of rocks to another is gradual it may be necessary to separate two contiguous formations by an arbitrary line, and in some cases the distinction depends almost entirely on the contained fossils. An igneous formation contains one or more bodies of one kind, of similar occurrence, or of like origin. A metamorphic formation may consist of rock of uniform character or of several rocks having common characteristics or origin.

When for scientific or economic reasons it is desirable to recognize and map one or more specially developed parts of a varied formation, such parts are called *members*, or by some other appropriate term, as *lentils*.

AGES OF ROCKS.

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

The sedimentary formations deposited during a period are grouped together into a *system*. The principal divisions of a system are called *series*. Any aggregate of formations less than a series is called a *group*.

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

Many stratified rocks contain *fossils*, the remains or imprints of plants and animals which, at the time the strata were deposited, lived in bodies of water or were washed into them, or were buried in surficial deposits on the land. Such rocks are called fossiliferous. By studying fossils it has been found that the life of each period of the earth's history was to a great extent different from that of other periods. Only the simpler kinds of marine life existed when the oldest fossiliferous rocks were deposited. From time to time more complex kinds developed, and as the simpler ones lived on in modified forms life became more varied. But during each period there lived peculiar forms, which did not exist in earlier times and have not existed since; these are *characteristic types*, and they define the age of any bed of rock in which they are found. Other types passed on from period to period, and thus linked the systems together, forming a chain of life from the time of the oldest fossiliferous rocks to the present. Where two sedimentary formations are remote from each other and it is impossible to observe their relative positions, the characteristic fossil types found in them may determine which was deposited first. Fossil remains in the strata of different areas, provinces, and continents afford the most important means for combining local histories into a general earth history.

It is many places difficult or impossible to determine the age of an igneous formation, but the relative age of such a formation can in general be ascertained by observing whether an associated sedimentary formation of known age is cut by the igneous mass or is deposited upon it. Similarly, the time at which metamorphic rocks were formed from the original masses may be shown by their relations to adjacent formations of known age; but the age recorded on the map is that of the original masses and not that of their metamorphism.

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

Patterns composed of parallel straight lines are used to represent sedimentary formations deposited in the sea, in lakes, or in other bodies of standing water. Patterns of dots and circles represent alluvial, glacial, and eolian formations. Patterns of triangles and rhombs are used for igneous formations. Metamorphic rocks of unknown origin are represented by short dashes irregularly placed; if the rock is schist the dashes may be arranged in wavy lines parallel to the structure planes. Suitable combination patterns are used for metamorphic formations known to be of sedimentary or of igneous origin. The patterns of each class are printed in various colors. With the patterns of parallel lines, colors are used to indicate age, a particular color being assigned to each system.

The symbols consist each of two or more letters. If the age of a formation is known the symbol includes the system symbol, which is a capital letter or monogram; otherwise the symbols are composed of small letters.

The names of the systems and of series that have been given distinctive names, in order from youngest to oldest, with the color and symbol assigned to each system, are given in the subjoined table.

Symbols and colors assigned to the rock systems.

	System.	Series.	Symbol.	Color for sedimentary rocks.
Cenozoic	Quaternary	Recent, Pleistocene	Q	Brownish yellow.
	Tertiary	Pliocene, Miocene, Oligocene, Eocene	T	Yellow ocher.
Mesozoic	Cretaceous		K	Olive-green.
	Jurassic		J	Blue-green.
	Triassic		TR	Peacock-blue.
Paleozoic	Carboniferous	Permian, Pennsylvanian, Mississippian	C	Blue.
	Devonian		D	Blue-gray.
	Silurian		S	Blue-purple.
	Ordovician		O	Red-purple.
	Cambrian		Є	Brick-red.
	Algonkian		A	Brownish red.
	Archean		AR	Gray-brown.

SURFACE FORMS.

Hills, valleys, and all other surface forms have been produced by geologic processes. For example, most valleys are the result of erosion by the streams that flow through them (see fig. 1), and the alluvial plains bordering many streams were built up by the streams; waves cut sea cliffs and, in cooperation with currents, build up sand spits and bars. Topographic forms thus constitute part of the record of the history of the earth.

Some forms are inseparably connected with deposition. The hooked spit shown in figure 1 is an illustration. To this class belong beaches, alluvial plains, lava streams, drumlins (smooth oval hills composed of till), and moraines (ridges of drift made at the edges of glaciers). Other forms are produced by erosion. The sea cliff is an illustration; it may be carved from any rock. To this class belong abandoned river channels, glacial furrows, and peneplains. In the making of a stream terrace an alluvial plain is first built and afterward partly eroded away. The shaping of a marine or lacustrine plain is usually a double process, hills being worn away (*degraded*) and valleys being filled up (*aggraded*).

All parts of the land surface are subject to the action of air, water, and ice, which slowly wear them down, and streams carry the waste material to the sea. As the process depends on the flow of water to the sea, it can not be carried below sea level, and the sea is therefore called the *base-level* of erosion. Lakes or large rivers may determine local base-levels for certain regions. When a large tract is for a long time undisturbed by uplift or subsidence it is degraded nearly to base-level, and the fairly even surface thus produced is called a *peneplain*. If the tract is afterward uplifted, the elevated peneplain becomes a record of the former close relation of the tract to base-level.

THE VARIOUS GEOLOGIC SHEETS.

Areal geology map.—The map showing the areas occupied by the various formations is called an *areal geology map*. On the margin is a *legend*, which is the key to the map. To ascertain the meaning of any color or pattern and its letter symbol the reader should look for that color, pattern, and symbol in the legend, where he will find the name and description of the formation. If it is desired to find any particular formation, its name should be sought in the legend and its color and pattern noted; then the areas on the map corresponding in color and pattern may be traced out. The legend is also a partial statement of the geologic history. In it the names of formations are arranged in columnar form, grouped primarily according to origin—sedimentary, igneous, and crystalline of unknown origin—and within each group they are placed in the order of age, so far as known, the youngest at the top.

Economic geology map.—The map representing the distribution of useful minerals and rocks and showing their relations to the topographic features and to the geologic formations is termed the *economic geology map*. The formations that appear on the areal geology map are usually shown on this map by fainter color patterns and the areas of productive formations are emphasized by strong colors. A mine symbol shows the location of each mine or quarry and is accompanied by the name of the principal mineral mined or stone quarried. If there are important mining industries or artesian basins in the area special maps to show these additional economic features are included in the folio.

Structure-section sheet.—In cliffs, canyons, shafts, and other natural and artificial cuttings the relations of different beds to one another may be seen. Any cutting that exhibits those relations is called a *section*, and the same term is applied to a diagram representing the relations. The arrangement of rocks in the earth is the earth's *structure*, and a section exhibiting this arrangement is called a *structure section*.

The geologist is not limited, however, to natural and artificial cuttings for his information concerning the earth's structure. Knowing the manner of formation of rocks and having traced out the relations among the beds on the surface, he can infer their relative positions after they pass beneath the surface and can draw sections representing the structure to a considerable depth. Such a section is illustrated in figure 2.

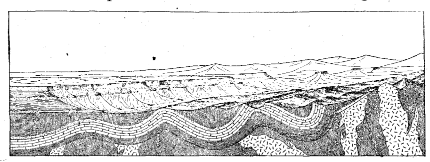


FIGURE 2.—Sketch showing a vertical section at the front and a landscape beyond.

The figure represents a landscape which is cut off sharply in the foreground on a vertical plane, so as to show the underground relations of the rocks. The kinds of rock are indicated by appropriate patterns of lines, dots, and dashes. These patterns admit of much variation, but those shown in figure 3 are used to represent the commoner kinds of rock.

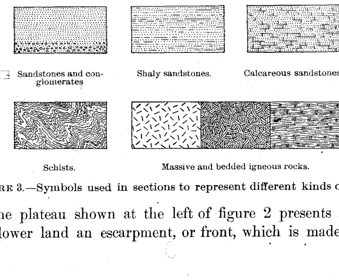


FIGURE 3.—Symbols used in sections to represent different kinds of rocks.

The plateau shown at the left of figure 2 presents toward the lower land an escarpment, or front, which is made up of sandstones, forming the cliffs, and shales, constituting the slopes. The broad belt of lower land is traversed by several ridges, which are seen in the section to correspond to the outcrops of a bed of sandstone that rises to the surface. The upturned edges of this bed form the ridges, and the intermediate valleys follow the outcrops of limestone and calcareous shale.

Where the edges of the strata appear at the surface their thickness can be measured and the angles at which they dip below the surface can be observed. Thus their positions underground can be inferred. The direction of the intersection of a bed with a horizontal plane is called the *strike*. The inclination of the bed to the horizontal plane, measured at right angles to the strike, is called the *dip*.

In many regions the strata are bent into troughs and arches, such as are seen in figure 2. The arches are called *anticlines* and the troughs *synclines*. As the sandstones, shales, and limestones were deposited beneath the sea in nearly flat sheets, the fact that they are now bent and folded is proof that forces have from time to time caused the earth's surface to wrinkle along certain zones. In places the strata are broken across and the parts have slipped past each other. Such breaks are termed *faults*. Two kinds of faults are shown in figure 4.

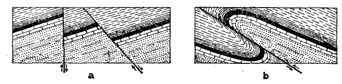


FIGURE 4.—Ideal sections of strata, showing (a) *normal* faults and (b) a *thrust* or *reverse* fault.

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

The section also shows three sets of formations, distinguished by their underground relations. The uppermost set, seen at the left, is made up of sandstones and shales, which lie in a horizontal position. These strata were laid down under water but are now high above the sea, forming a plateau, and their change of elevation shows that a portion of the earth's mass has been uplifted. The strata of this set are parallel, a relation which is called *conformable*.

The second set of formations consists of strata that have been folded into arches and troughs. These strata were once continuous, but the crests of the arches have been removed by erosion. The beds, like those of the first set, are conformable.

The horizontal strata of the plateau rest upon the upturned, eroded edges of the beds of the second set shown at the left of the section. The overlying deposits are, from their position, evidently younger than the underlying deposits, and the bending and eroding of the older beds must have occurred between their deposition and the accumulation of the younger beds. The younger rocks are *unconformable* to the older, and the surface of contact is an *unconformity*.

The third set of formations consists of crystalline schists and igneous rocks. At some period of their history the schists were folded or plicated by pressure and traversed by eruptions of molten rock. But the pressure and intrusion of igneous rocks have not affected the overlying strata of the second set. Thus it is evident that a considerable interval elapsed between the formation of the schists and the beginning of deposition of the strata of the second set. During this interval the schists were metamorphosed, they were disturbed by eruptive activity, and they were deeply eroded. The contact between the second and third sets is another unconformity; it marks a time interval between two periods of rock formation.

The section and landscape in figure 2 are ideal, but they illustrate actual relations. The sections on the structure-section sheet are related to the maps as the section in the figure is related to the landscape. The profile of the surface in the section corresponds to the actual slopes of the ground along the section line, and the depth from the surface of any mineral-producing or water-bearing stratum that appears in the section may be measured by using the scale of the map.

Columnar section.—The geologic maps are usually accompanied by a *columnar section*, which contains a concise description of the sedimentary formations that occur in the quadrangle. It presents a summary of the facts relating to the character of the rocks, the thickness of the formations, and the order of accumulation of successive deposits.

The rocks are briefly described, and their characters are indicated in the columnar diagram. The thicknesses of formations are given in figures that state the least and greatest measurements, and the average thickness of each formation is shown in the column, which is drawn to scale. The order of accumulation of the sediments is shown in the columnar arrangement—the oldest being at the bottom, the youngest at the top.

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

GEORGE OTIS SMITH,
Director.

May, 1909.

DESCRIPTION OF THE ENGINEER MOUNTAIN QUADRANGLE.

By Whitman Cross.

INTRODUCTION.

POSITION AND EXTENT OF THE QUADRANGLE.

The Engineer Mountain quadrangle is in southwestern Colorado, about 60 miles east of the Utah boundary and 34 miles north of New Mexico. It lies between the Needle Mountains on the east and the Rico Mountains on the west and includes some of the outer summits of each group. Immediately adjacent on the north is the very rugged western arm of the San Juan Mountains. The quadrangle is included between meridians 107° 45′ and 108° and parallels 37° 30′ and 37° 45′, embracing about 236 square miles.

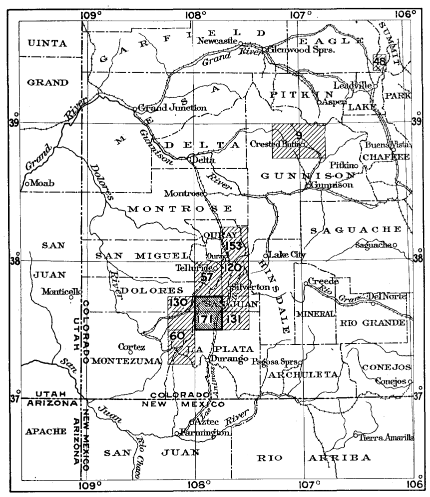


FIGURE 1.—Index map of the vicinity of the Engineer Mountain quadrangle.

The dark shaded rectangle represents the Engineer Mountain quadrangle. Other published folios covering parts of the area are as follows: Nos. 9, Anthracite-Crested Butte; 48, Tenmile District Special; 57, Telluride; 60, La Plata; 120, Silverton; 130, Rico; 131, Needle Mountains; 153, Ouray.

A little more than the southern half of the quadrangle lies in La Plata County and the greater part of the remainder in San Juan County; smaller portions are in Dolores and Montezuma counties. The relation of the quadrangle to others which have been surveyed is shown by the index map (fig. 1) and the list of published folios printed herewith.

GENERAL FEATURES AND RELATIONS OF THE QUADRANGLE.

The Engineer Mountain quadrangle presents a variety of striking topographic features, including broad valleys and deep canyons, wooded uplands of moderate relief, and, in marked contrast with these, sharp peaks and mountain ridges rising high above the timber line. This diversity of physical character is in many respects due to the position which the quadrangle occupies in relation to the mountain groups on three sides.

The geology of the area is as diversified as the topography and owes that diversity also to the relation of this area to the adjacent mountains. Pre-Cambrian formations are represented by a mass of gneiss and schist penetrated by granitic and other intrusions, and by a large series of ancient quartzites and slates which are steeply upturned and much metamorphosed. Paleozoic and Mesozoic sedimentary beds occur in a great section extending from the Upper Cambrian into the Cretaceous. Igneous rocks are present in both large and small masses and form some of the higher mountains.

The sedimentary formations are those common to a large territory, but their extensive exposure here is due to the structure existing about certain centers and the enormous denudation that has taken place in the San Juan Mountains. The appearance of the pre-Cambrian formations is due to the same causes. The igneous rocks are intimately related to those of neighboring centers of eruption.

On account of the various relations of the Engineer Mountain quadrangle to the surrounding country it is advisable to precede the detailed description of the area with an outline of the geology of the San Juan district.

GEOLOGY OF THE SAN JUAN REGION IN RELATION TO THAT OF THE ENGINEER MOUNTAIN QUADRANGLE.

The geological history of the mountainous portion of southwestern Colorado is very complex. From pre-Cambrian to late Tertiary time this region has been the scene of recurring earth disturbances of various kinds. Much of the district has now been studied in detail and maps of several quadrangles have been published. In the Telluride, Silverton, and Ouray folios a general review of San Juan geology has been given, but as the Engineer Mountain area does not illustrate many geologic features its discussion may properly be less extensive.

The volcanic San Juan Mountains.—The central portion of the San Juan area is a group of rugged peaks, of which many exceed 13,000 feet in elevation and a few exceed 14,000 feet. Timber line occurs at about 12,000 feet. This mountainous area extends from San Luis Park 80 miles westward, to the center of the Telluride quadrangle, with a varying width north and south of 25 to 40 miles. The mountain area thus embraces about 3000 square miles.

With the exception of the outlying Needle Mountains and a few other isolated summits the mountains of the area thus indicated are formed of igneous rocks, either volcanic or intrusive. Beginning early in Tertiary time, volcanic activity was intense during several epochs, in each of which there was emitted an enormous amount of lava and of fragmental material, covering many square miles. In the alternating quiet intervals erosion removed a great deal of the volcanic material, but on the whole accumulation exceeded denudation, so that toward the close of the Tertiary period there existed a volcanic plateau several thousand square miles in extent. This was built up by 5000 feet or more of lava, tuff, and agglomerate, penetrated in many places by large and small intrusive bodies of various shapes and relations. The lavas range in composition from rhyolite to basalt.

Since the cessation of eruptive activity erosion has been rapid and the volcanic pile has been reduced in area and its central portion carved into a group of rugged mountains separated by deep valleys. The work has been done by streams that attacked the mass on all sides. On the east the Rio Grande, on the north the Gunnison, on the west the Dolores, and on the south the San Juan, each with several large branches, have penetrated to the heart of the volcanic area. The Rio Grande flows to the Gulf of Mexico; the other three are all indirectly tributary to the Gulf of California, through Colorado River.

The result of this denudation has been to reduce the area of the volcanic rocks by means of their complete removal on the southern, western, and northern borders of the district, and to lay bare the foundation of sedimentary and metamorphic rocks upon which the volcanics were deposited. Outlying remnants of the lavas and tuffs give some evidence of their former extension, but there is nothing to indicate the earlier limits on the south or west. On the north the former continuity of the San Juan volcanic mass with that of the West Elk Mountains, across the stretch now traversed by Gunnison Canyon, is shown by remnants of the lower tuffs on certain ridges.

The present southwestern border of the volcanic rocks of the San Juan Mountains is in the Telluride quadrangle, approaching at some points within one-half mile of the north line of the Engineer Mountain quadrangle. No actual remnant of the surface volcanic rocks occurs in the latter area, but the former extension of at least the lower beds is indicated by a small patch of a definitely recognizable conglomerate which caps the hill of 12,750 feet elevation east of Cascade Creek close to the quadrangle line, as shown by the map. That deposit, named the Telluride conglomerate, is probably of Eocene age. It underlies the lowest tuff conformably over wide areas in the San Juan Mountains and occurs in that position in the immediately adjacent portion of the Telluride quadrangle.

The absence of the volcanic rocks of the San Juan Mountains in the Engineer Mountain quadrangle is due chiefly to the fact that the base of these rocks was probably higher there than anywhere else. In the nearest exposures in the Telluride quadrangle the elevation of the base varies from 12,500 to nearly 13,000 feet. It descends to about the level of 11,000 feet on the north and northeast, near Telluride and Silverton, respectively. This northeasterly dip of the base of the San Juan tuff is probably due to changes of level since its deposition.

The intrusive igneous rocks of the San Juan Mountains are represented in the Engineer Mountain quadrangle by a small portion of a large monzonite stock in which the canyon of Cascade Creek is excavated, on the northern border of the area. This mass cuts only sedimentary beds along the contact seen in the Engineer Mountain quadrangle but penetrates the volcanic rocks in the Telluride area.

Figure 6 shows the character of the southwestern front of the San Juan Mountains and of the lower country adjoining, most of which, seen in the view, lies in the Engineer Mountain quadrangle. A glance at the geological map in the Telluride folio will assist in making the relations plain.

Substructure of the San Juan Mountains.—The volcanic rocks of the San Juan Mountains rest on a foundation of Mesozoic and Paleozoic beds, together with a complex of pre-Cambrian sediments, schists, gneisses, and intrusive masses. This superposition is shown by the relations on the border of the volcanic area and in many places in deep valleys that penetrate the mountain district.

In the Ouray quadrangle, on the north side of the San Juan, the general dip is to the north. The deep cutting of Uncompahgre River there reveals the section to the base of the Paleozoic rocks. The strata of the Telluride area dip westward, but the lowest beds exposed are Permian (?). On the south side of the San Juan Mountains the general dip is southerly, but the Needle Mountains appear to represent a local center of uplift exerting controlling influence on the structure for several miles around. As this center is immediately adjacent to the Engineer Mountain quadrangle its effect dominates to some extent the broader San Juan structure.

In addition to the broad quaquaversal structure which resulted from uplift in post-Cretaceous time, the sediments exhibit relations of unconformity at several horizons, and certain gaps in the section indicate epochs of nondeposition or of erosion. These features, however, are not all particularly characteristic of the San Juan region.

The Engineer Mountain quadrangle presents a nearly complete section of these Paleozoic and Mesozoic formations, which illustrates the structure of the broad San Juan dome and its modification by more local disturbances.

The pre-Cambrian geology of the San Juan Mountain area is probably marked by complexity comparable with that so clearly exhibited in the Needle Mountains. In that area occur apparently Archean schists and gneisses with subordinate intrusive rocks. Succeeding these is a greenstone series with scanty associated quartzites. These rocks, called the Irving greenstone, have been tentatively referred to the Algonkian system. Following them in age is a group of conglomerate, quartzite, and shale or slate, called the Needle Mountains group. These rocks have been greatly folded and faulted, as will be explained in some detail in considering the Uncompahgre formation, which belongs to this group.

Great masses of intrusive granite of several kinds and of gabbroid rocks have penetrated the gneisses and schists, and some of them, at least, are younger than the quartzites and slates of the Uncompahgre. Representatives of several of the pre-Cambrian formations occur prominently in the Engineer Mountain area.

Beneath the volcanic rocks of the central San Juan the pre-Cambrian formations are presumably extensive. At the head of the Lake Fork of the Gunnison in the Silverton and San Cristobal quadrangles occur massive granite and gneiss. Here and there inclusions of gneiss, schist, or granite in the volcanic rocks also give clues to the underlying rocks. The relations of the Algonkian and Archean bodies are not determinable.

GEOLOGICAL INVESTIGATIONS IN THE QUADRANGLE.

Work of the Hayden Survey.—The geological map of southwestern Colorado contained in the Atlas of Colorado prepared by the Hayden Survey possesses so great merit as a whole that it seems all the more necessary to refer to certain serious errors it contains respecting the Engineer Mountain quadrangle.

Potato Hill and a small area south of it are referred to the "metamorphic Paleozoic," as distinguished from the "metamorphic granite" of the Animas Valley to the south. No ground for this distinction exists.

An isolated area of "Silurian," unique in the San Juan, is shown by the Hayden map east of Potato Hill. A careful examination has revealed only granite gneiss and schist in this area. The "Devonian" of the map also covers ground chiefly occupied by granite and gneiss, and the representation of an ending to the Devonian at the mouth of Lime Creek is inexplicable, for the Ouray limestone is particularly well exposed to the south from that point, along the west side of the Animas Valley, and connects in normal manner with the exposures on the south slope of the Needle Mountains observed by Endlich.

The representation of an isolated patch of Triassic beds at the head of Lime Creek and the expression of a hiatus by showing Cretaceous shale resting on "Upper Carboniferous" at the head of Dolores River and the Dakota resting on the same strata north of Silver Creek are errors which it is difficult to explain.

The igneous masses of Graysill and Engineer mountains are represented as belonging to the main volcanic formation of the San Juan—"trachoreite"—the plain evidence of intrusive origin having escaped notice. The intrusive bodies of Flattop and Hermosa Peak are, however, correctly grouped with the porphyries of the La Plata and Rico mountains.

Work of the United States Geological Survey.—The Engineer Mountain quadrangle is surrounded by districts of economic importance, concerning which folios have already been published, namely, Telluride, Rico, La Plata, Needle Mountains, and Silverton. In connection with the study of each of these areas more or less work was done in the Engineer Mountain quadrangle, but the map was not completed until 1908. Special assistance in the field work has been rendered by A. C. Spencer, Ernest Howe, W. H. Emmons, A. Johannsen, and Howland Bancroft, all of whom have been regular assistants at various times. George W. Stose, George H. Girty, M. K. Shaler, and George I. Finlay have, in different seasons, rendered aid in particular directions. The glacial geology of the quadrangle was investigated by Allen D. Hole in 1908, and a special section of this folio, dealing with that subject, was prepared by him.

TOPOGRAPHY.

RELIEF.

General character.—The Engineer Mountain quadrangle is characterized by a great variety of topographic forms. These may be readily recognized by a practiced eye through the study of the contour map. Most of the features are clearly illustrated by the views reproduced in this folio, which should be studied in connection with the accompanying descriptions. As the illustrations show, the quadrangle has physical features of great beauty as well as bare and rugged summits and unscalable cliffs. The mountains are in fact easily ascended. In variety of picturesque and attractive scenery the Engineer Mountain quadrangle compares favorably with most others of the beautiful San Juan region. The topographic features of the area will be described under appropriate headings.

Northern portion of the quadrangle.—The general character of the northern and most diversified portion of the area is illustrated by figures 5 and 6. The first of these, taken near the summit of Blackhawk Peak (12,687 feet), the culminating point of the Rico Mountains, gives some idea of the relative elevation of that group and shows clearly the relation of these mountains to the high and extremely rugged San Juan Mountain front. The dominant and particularly characteristic summits of the area are the broad Graysill Mountain together with Hermosa Peak (12,574 feet) and Engineer Mountain (12,972 feet), which flank it on either side. All these owe their existence and special features to the great intrusive masses of quartz trachyte, occurring in soft sedimentary beds. The features of the interesting summit from which the quadrangle derives its name are shown in detail in figures 7, 8, and 9. The mountain appears in the distance in figure 6. The mass of Engineer Mountain must have been vastly bolder and more impressive before the central peak was so greatly reduced in volume by the landslides whose débris is seen in the views.

At the southeastern extremity of Graysill Mountain is a sharp point called Grayrock Peak, which, when seen from the south, in the valley, seems almost comparable to Engineer Mountain. It is in fact but a projection from the main mountain which has more the character of a broad ridge bounded by quartz trachyte cliffs. It illustrates, as does Flattop, a stage in the erosion of a laccolithic mass when the cover has not been wholly removed, exposing the massive rock to such sculpturing as Engineer Mountain has undergone.

The northern portion of the area contains, in Cascade Creek valley, a type of the canyons that are present on all sides of the San Juan. The extreme head of this canyon is within the monzonite stock, only 1 mile north of the quadrangle line. Between Engineer and Graysill mountains, 6 miles from its head, this valley is 3600 feet deep and its slopes are very steep, yet generally forested. Less striking, but by no means insignificant mountain valleys, are those of Dolores River, Barlow and Silver creeks, and a north fork of the Hermosa. Figure 6 shows the valley of Barlow Creek.

The details of mountain and valley sculpture in the northern part of the quadrangle are such as are common in regions of intrusive rocks where massive sandstone ledges alternate with softer strata. About the Rico Mountains there are several sharp little summits, due to remnants of gray porphyry, with strongly contrasting red slopes below. Whitecap Mountain is a type of these porphyry-capped peaks. On the valley sides and mountain slopes there are many ledges, cliffs, benches, and sharp projecting shoulders, due either to massive porphyry or to sandstone. Such formations are illustrated in several of the views.

The mountain to which the trifling name Potato Hill (11,876 feet) was given by some irreverent early settler, whose occupation can be easily inferred, is the most prominent outlier of the West Needle Mountains. It has been cut off from that group by Lime Creek, the canyon of which, east of the mountain, is nearly 3000 feet in depth. In figure 13 the relations of this summit to Engineer Mountain and to the West Needles are shown, as well as the character of the glaciated ridges on either side of Lime Creek, which belong geographically and geologically with the pre-Cambrian area.

Animas Valley.—The southeastern section of the quadrangle belongs chiefly to Animas Valley, and its prominent topographic forms, though very different from those of the northern part of the area, are very striking. The valley has three particularly prominent features—the canyon, an old upper valley of gentle relief, and an imposing scarp (Hermosa Cliffs) that bounds it on the west.

Animas Canyon is a gorge whose steep, rough, and in places forbidding sides are carved in the dark pre-Cambrian schists. The canyon is not so imposing here, where the river is but 2500 feet below the highest adjacent summit, as it is in the Needle Mountains, only a few miles to the northeast, where the depth of the canyon is over 6000 feet. There are several deep side gorges, the most notable being those of Cascade and Canyon creeks. Although the walls come close together in some places there are several gravel-covered expanses, shown on the geological map.

The bench, 2 or 3 miles in width, between Animas Canyon and Hermosa Cliffs, now traversed by Elbert Creek, is one of the most interesting topographic features in the quadrangle. On it were formerly several beautiful lakes, most of which are now replaced by the Ignacio reservoir of the Animas Power and Water Company. Figure 4 represents one of the smallest of this group of lakes as it formerly appeared. On this old upper valley bottom are several alluvial flats, now occupied chiefly by hay ranches. There are also low hills and an irregular ledge of Devonian limestone, above which is a minor bench that slopes with the dip of the underlying strata toward the great bounding scarp.

Hermosa Cliffs, which rise 1500 feet or more above the bench just described, extend with but one break for 10 miles northward from the quadrangle boundary. They continue practically up the valley of Cascade Creek and to the south in the Durango quadrangle for 2 miles or more. In figure 14 the line of gray cliffs is very prominent and their relation to the lower bench is seen. Figure 4 gives a glimpse of the cliffs west of the reservoir and figure 2 shows the details of the upper part of the scarp, characteristic of the whole line of cliffs.

On the opposite side of the Animas Valley there appear the western extremities of sloping mesas of lower Paleozoic beds, which form a prominent feature of the southern slopes of the Needle Mountains.

Hermosa Basin.—The central and southwestern parts of the quadrangle belong to the basin of Hermosa Creek. It is an area of wooded uplands and ridges, chiefly in the territory of the red beds which constitute the Cutler formation. The ruddy tones of the sandstones may be seen in many exposures, surrounded by forests of spruce or aspen. At the junction of North and East forks of Hermosa Creek is Hermosa Park, a grassy opening of which the valley of the East Fork is practically an extension. Below the park the Hermosa cuts deeper and deeper into the Carboniferous formations and the stream flows in a rugged canyon in some places. There are no mountains of igneous rock in this portion of the quadrangle, which in this respect presents a marked contrast to the other districts described.

DRAINAGE.

Nearly all the drainage of the Engineer Mountain quadrangle is into Animas River, which is one of the principal tributaries of the San Juan. Through this stream the waters reach the Colorado and ultimately the Gulf of California. The remaining drainage is by way of Dolores River to Grand River and thus to the Colorado.

Animas River is a swift mountain stream having a never-failing source in the high mountains of the Silverton quadrangle. The descent of the river within the quadrangle is about 650 feet in a little more than 8 miles, its lowest point on the southern boundary having an elevation of about 7100 feet.

The chief tributary of the Animas in the Engineer Mountain quadrangle is Cascade Creek, which receives the waters of Lime Creek a short distance above its mouth. Cascade Creek has a fall of about 3250 feet from the northern boundary of the quadrangle to its mouth, a distance of about 13 miles. A large part of Cascade Creek is now diverted to unite with Elbert Creek in the Ignacio reservoir.

Tank and Canyon creeks are small eastern tributaries of the Animas, Canyon Creek being the more important. Hermosa Creek is also a tributary of the Animas, which it enters in the Durango quadrangle 6 miles south of the Engineer Mountain quadrangle line. The South Fork of Hermosa Creek derives its waters from the northeast slope of the La Plata Mountains.

DESCRIPTIVE GEOLOGY.

PRE-CAMBRIAN METAMORPHIC AND IGNEOUS ROCKS.

A great complex of sedimentary, igneous, and metamorphic rocks older than the Cambrian Ignacio quartzite is exhibited in the Needle Mountains and surrounding country. This complex is represented by several distinct elements in the eastern zone of the Engineer Mountain quadrangle traversed by Animas River and Lime Creek. The sedimentary portion of this complex is well defined and is treated as the basal unit of the stratigraphic column, but the gneisses, schists, and ancient intrusives are so intimately related in occurrence that they will be considered together, although some of the intrusives are younger than the sediments referred to the Algonkian system. The gneisses and schists are believed to be of Archean age.

METAMORPHIC ROCKS.

ARCHEAN GNEISS AND SCHIST.

General character.—The rocks referred to the Archean constitute a series of gneisses and schists of marked foliated texture, which are cut by the Twilight and Eolus granite masses and by a gabbro body, all of which are distinguished on the map, and by numerous lesser dikes and irregular masses of granite, aplite, pegmatite, diabase, and other rocks. These intrusives do not as a rule possess foliated texture and where such texture is present it is plainly to be differentiated from the schistosity of the Archean rocks.

The gneisses and schists appear to have been derived from igneous rocks of granitic, dioritic, or diabasic general character. The detailed original relations of these materials can not be determined, but clearly a complex of large bodies, penetrated by dikes of granite and diabase, was subjected to mashing or shearing with recrystallization and the resultant development of gneissic or schistose foliation.

The diverse characters of the original rocks are shown by their range from feldspathic quartzose gneisses to amphibolites and hornblende schists. In texture these rocks vary widely, ranging from rather coarse grained gneiss with distinct traces of the original rock to finely foliate mica or hornblende schist. Although the crushing to which the rocks have been subjected has greatly obscured the primary relations of various types, the hornblende schists in many places clearly represent dikes.

Distribution and structure.—The Animas Canyon section of gneiss and schist ends abruptly about 1½ miles south of the Engineer Mountain quadrangle, being covered by sediments or cut off by granite. The arm of schists shown on the map between the Twilight and Eolus granite masses extends several miles up the Animas Canyon into the heart of the Needle Mountains. Its relation to other pre-Cambrian formations is shown in the Needle Mountains folio.

The structure of the Archean gneisses and schists is well exhibited in the walls of Animas Canyon, which crosses obliquely the lines of schistosity. Near the southern line of the quadrangle the strike is nearly east-west. From this course it swings to northeast-southwest and then, on the north side of the gabbro intrusion, to north-south. The dips of the schistosity are variably steep to the south, southeast, or east, being in few localities less than 45° and at certain places reaching the vertical. Strike and dip symbols on the map show the structure at certain localities. There is some local crumpling of schists, but apparently there is no complex structure involving a duplication of parts of the section.

Derivation from igneous rocks.—A large part of the hornblendic gneisses and schists were derived from quartz diorite, which may have originally contained augite and hornblende or the former alone. The least-altered rocks of this series occur in the Durango quadrangle. In that area may be seen nearly massive rocks consisting of common hornblende, lime-soda feldspar (oligoclase or andesine), and quartz. In some places a paramorphic change of augite into hornblende has occurred. Where the mashing is least pronounced the feldspar and quartz plainly make up about half of the rock. In the more schistose forms secondary hornblende needles and biotite flakes obscure the white minerals, and hornblende seems to predominate more strongly than is actually the case.

Another considerable part of the schists is derived from ophitic diabase and in some of this a part of the primary augite remains, but usually uralitic or massive hornblende and newly formed needles of the same mineral, together with the crushed condition of the feldspar, render the determination of the original rock difficult except by means of the evidence of various stages represented in different places. Some but not all of the diabase rocks producing these schists were in the form of dikes.

A third and subordinate part of the schist and gneiss series was plainly derived from granite. Such rocks consist of quartz, orthoclase, microcline, plagioclase, hornblende, and biotite, the dark silicates being subordinate in amount.

In many places the alternation of hornblendic and feldspathic or quartzose material indicates impregnation of the schist series in connection with ancient intrusions of granite.

Relations to the Twilight granite.—The map represents Twilight granite as occupying the entire pre-Cambrian area lying north of the gabbro stock and east of the Ignacio quartzite line to the fault north of Potato Hill. The boundary between schists and granite is not sharply defined; the line on the map represents a zone within which the two rocks are most intimately mingled, as is stated under the heading "Twilight granite."

Not only along the boundary, in the zone mentioned, but also throughout the area mapped as Twilight granite, dark schists occur in minor bands or irregular bodies of different sizes, the mapping of which is practically impossible. No considerable area of the intrusive granite is entirely free from dark schist fragments.

Age.—The reference of the ancient gneisses and schists of the Animas Valley to the Archean is based principally on their general resemblance to rocks assigned to that system in other districts and on the fact that they are older than the Needle Mountains group of sediments, referred to the Algonkian, and also older than a series of intrusive granites and other rocks which are older than the Ignacio quartzite. These intrusives have suffered relatively little metamorphism, but the gneisses and schists have undergone extreme alteration of the kinds common to the rocks of the Archean crystalline complex.

PRE-CAMBRIAN IGNEOUS ROCKS.

The Archean gneisses and schists of the Needle Mountains and vicinity are penetrated by several large and many small masses of granite and other coarsely crystalline igneous rocks. The principal intrusive bodies occur in the Needle Mountains quadrangle and have been described in considerable detail in the folio (No. 131) covering that area. The two largest intrusive masses are the Eolus and Twilight granites, parts of which appear in the Engineer Mountain quadrangle. A third important mass, of gabbroic character, is apparently confined to the Engineer Mountain area.

TWILIGHT GRANITE.

Occurrence.—The Twilight granite, of more or less distinct gneissose texture, forms a large batholith whose complex relations to the Archean schists and gneisses have already been mentioned. This mass is the main element in the constitution of the West Needle Mountains, including their highest summit, Twilight Peak, which is about 2 miles due east of Potato Hill. The exposed portion of the batholith is irregularly oval in shape; its major axis is about 10 miles in length in a north-northeast to south-southwest direction, and its average width is about 4 miles.

From the crest of the West Needle Mountains the rock extends down their western slope, across Lime Creek into the Engineer Mountain quadrangle, and disappears beneath the Paleozoic sediments, as shown on the geological map. The northern limit of the exposed mass is a fault plane and the southwestern border is a line of contact with the later gabbro mass. The eastern boundary is therefore the only primary one now exposed and no reliable estimate of the former size and shape of the mass can be made.

The intrusion of this granite mass into the Archean schists was preceded or attended by tremendous shattering of the schists. The granite contains an enormous number of inclusions of the schists, and certain portions of the broad zone of contact exhibit what is practically a breccia of schist cemented by granite. In some places the shattering of the schist produced very irregular fragments; in others the schist was split into thin slabs parallel to its foliation and the granite injected between them, here in thin dikes and there in wide or variable arms.

The relations of the two rocks just described are graphically illustrated by figures 10, 11, and 12 of this folio and by figures 10 and 11 of the Needle Mountains folio. The complex mingling of the two rocks, such as is illustrated in the figures, characterizes the entire eastern contact zone of the mass.

In the central part of the body of the Twilight granite inclusions of dark schist and gneiss are much less abundant than in the contact zone, yet no very considerable area of the granite is wholly free from schist fragments. These inclusions are not uncommonly long, narrow strips, visible from a distance and resembling the diabasic dikes, which also occur in the granite.

At several places near the line of overlying quartzite on the west dark schists appear in greater abundance than in the central portion of the granite, suggesting proximity to the main contact of the granite on that side. One locality rich in schists lies between Columbine Lake and Purgatory and another at the western base of Potato Hill. Slightly gneissoid granite, almost free from inclusions, is, however, also present at many places near the quartzites, so that the extent of the granite can not safely be conjectured.

Almost the entire area of the Twilight granite in the Engineer Mountain quadrangle has been glaciated. In figure 13 is shown the gentle character of the granite slopes, with their typical roches moutonnées. Above the ice-sculptured surface rises only the nunatak summit known as Potato Hill, seen in the figure. Excellent exposures of the granite are numerous and the complex contact zone is particularly well shown in the walls of Animas Canyon and in the lesser gorges of Cascade and Little Cascade creeks.

Character.—The Twilight granite is as a rule gray in color, of medium grain, and of more or less clearly foliate or gneissose texture. Quartz and feldspar strongly predominate over biotite, the most common of the dark silicates, with which hornblende is frequently associated. In some places near the center of the mass the rock is pink or nearly white in color and of somewhat coarser grain than usual.

The prevalent foliation of the mass is of primary origin and is due to movement of the rock before its final solidification. Much of the mass, however, shows a later schistosity of dynamometamorphic origin, which in certain zones is pronounced. The primary texture is shown to be such by the curving and twisting of the foliation about sharp-angled inclusions of schist and by its parallelism with contact planes of various positions. Some of the quartz and feldspar grains are elongated parallel to the foliation shown by the mica and hornblende, but much of the rock is practically granular so far as the quartz and feldspar are concerned.

The secondary schistosity is readily distinguishable from the fluidal texture in many places because it involves both granite and amphibole schist fragments, and through the crushing and shearing the original contact relations become much obscured. In certain zones on the slope of the West Needle Mountains the two rocks are very well developed fissile schists. The relations are there so intricate as to illustrate finely one way in which Archean rocks of different origin may have become so confusedly mingled as to defy absolute determination of their primary character and relations, in the absence of transitions to less altered rocks, such as are found in this region.

The secondary schistosity just referred to is commonly developed parallel or nearly parallel to the earlier structure of the schists, and much of the fluidal gneissic foliation has the same direction, as the granite was injected parallel to great sheets of the invaded schists. It thus becomes difficult or impossible to determine exactly the amount of primary foliation in the main mass of the rock.

The textural facies sometimes called "pencil gneiss" is not uncommon in the Twilight granite mass. In this the micas in particular and other constituents to some extent are drawn out in one direction rather than in certain planes. This may be seen in localities where the foliate texture is apparently primary, but as it also occurs in places where the amphibole schists exhibit the same texture in parallel position the secondary origin of the pencil texture must be granted.

The mineral composition of the Twilight granite batholith varies principally in the character of the feldspars. In the central part of the mass the rock is richer in orthoclase and microcline than in the contact zone. In that zone lime-soda feldspars greatly predominate. These are variably rich in the soda feldspar molecule, approaching albite in many places but ranging to andesine in others. A specimen from Little Cascade Creek contains 4.83 per cent soda and 0.22 per cent potash, and a coarser-grained phase, rich in orthoclase and microcline, occurring near Purgatory Park in Cascade Creek valley, contains 3.62 per cent soda and 2.52 per cent potash. These extremes are connected by transition rocks. The term granite is thus applied to this mass in a general sense and much of the rock might with propriety be called quartz monzonite or quartz diorite. Quartz is very abundant throughout and in some places seems to exceed the feldspars in amount, but it varies greatly from place to place.

Variations also occur in the proportions of biotite and hornblende and to some extent in the total amount of these minerals as compared with quartz and feldspar. Muscovite is present in the greater part of the rock, being locally as abundant as biotite, but it is rarely visible to the naked eye. The minerals apatite, zircon, titanite, garnet, and magnetite are microscopic accessories of very subordinate importance and of common characteristics.

Associated pegmatite.—As has been stated, the gneissic texture of the contact zone rarely extends into the apophyses of the granite which penetrate the schist or into the narrower cross dikes or arms which connect the larger masses. In most of these places the granite is granular and does not vary markedly in grain from the adjacent gneissose rock. In numerous arms, however, the grain is coarser. Although the constituents are in some places as regularly distributed as in the main body of the rock, a tendency to segregation is common and many drusy miarolitic cavities occur. In some arms the entire mass is distinctly pegmatitic; in others it is partly so and the texture of some cross dikelets varies from place to place.

Bodies of typical pegmatitic character—exhibiting irregular distribution of constituents, coarse grain, and miarolitic cavities—are rarely more than a few inches wide and this phase of the granite does not as a rule project from the apophysis or arm into the larger mass. The transition from the common texture to the pegmatitic is abrupt in some places and gradual in others. Pegmatite of the type here referred to nowhere cuts the gneissose rock as if filling a fissure in it, although pegmatite of a different character traverses the schists and the Twilight granite in all its phases. This later pegmatite is rich in orthoclase and microcline and is usually pinkish in color.

The pegmatitic phase of the Twilight granite consists of the minerals of that rock, and the greater part of the feldspar is a white plagioclase, as a rule albite or oligoclase. No minerals foreign to the granite have been observed, such as those which are often found in independent dikes of pegmatite.

From the facts presented it appears that the magma of the Twilight granite occupying small apophyses and cross fissures of the contact zone has in many places consolidated into a pronounced pegmatitic phase. Apparently because of these conditions of occurrence the pegmatitic portions of the mass crystallized before the consolidation of the larger masses. There is no evidence that special factors, such as the so-called mineralizing agents, were more active in the formation of this pegmatite than in that of the granite itself. This pegmatite is regarded simply as a facies of the Twilight granite—an igneous rock.

EOLUS GRANITE.

Occurrence.—The Eolus granite occurs high on the east side of Animas Canyon beneath the Paleozoic beds. This body belongs to a mass that occupies about one-third of the area of the Needle Mountains quadrangle and extends an unknown distance to the south under the sedimentary rocks. Many of the highest summits of the Needle Mountains are within this granite mass, including Eolus Peak, from which the rock receives its local designation, a term useful in distinguishing it from other granite masses.

The Eolus granite cuts the Archean gneisses and schists and the quartzite of the Algonkian Uncompahgre formation. It is overlain by Upper Cambrian sediments, so that the time of intrusion is established as late Algonkian or early Cambrian.

In striking contrast to the Twilight granite and to other granites of the Needle Mountains the Eolus mass is characterized by sharply defined contacts and comparative freedom from inclusions of foreign rocks.

Character.—The main part of the Eolus mass is a very coarse grained biotite granite with a variable amount of hornblende. The feldspar is usually pink and tends to develop in large irregular crystals producing a rude porphyritic texture. As a rule potash feldspar (orthoclase) predominates over lime-soda feldspars (plagioclase); locally, however, the relations are reversed, as is the case near the western border of this mass, in the Engineer Mountain quadrangle, and the rock is then technically rather a quartz monzonite or quartz diorite than a granite. The quartz of this granite is usually of a distinct bluish color.

Hornblende and biotite are much more abundant in the rock of the Eolus type than in any other granitic variety of the Needle Mountains and make the rock appear dark in places where the texture is fine grained. The gradations in mineral composition and texture just referred to take place gradually.

GABBRO.

Occurrence.—The gabbro mass represented on the map as cutting Archean schists and Twilight granite in the zone of their contact is unique in petrographic character among the pre-Cambrian intrusive rocks of the Needle Mountains region. The part of the body now exposed is about 3 miles long from southeast to northwest, and as it is 2½ miles wide on the line of overlying sediments it presumably extends westward beneath them for a considerable distance.

Though of unusual composition, this mass represents a great intrusion resembling in physical features the granitic batholiths or stocks of the region. The contact with the Twilight granite and associated schists is irregular in detail, numerous small arms and tongues of the gabbro projecting for 20 feet or more. The southern contact is obscured in many places by glacial and other débris.

The gabbro is cut by many small dikes of reddish aplite, some of which extend into the surrounding granite or schist. These dikes are no doubt genetically connected with the gabbro.

Character.—The gabbro mass varies a great deal in composition and texture, but shows no sharp changes indicating intrusive relations of any of the varieties. Texturally the rock is granular, ranging from medium to very coarse grain. In some places the crystals of feldspar or diallage are from 1 to 2 inches in diameter. Such large individuals generally inclose many small grains of other minerals and the resulting poikilitic fabric is pronounced.

A primary banded or gneissic texture is present in certain parts of the contact zone and also in portions of the interior of the mass. A dark dense phase of the rock was observed near the contact in a few places but is by no means a characteristic of the border zone.

The portion of the mass east of the Ignacio reservoir is chiefly made up of lime-soda feldspar (labradorite), diallage, and hypersthene, with subordinate amounts of biotite, hornblende, quartz, and orthoclase, variably developed. In some places, especially where a banded texture appears, hypersthene replaces diallage almost entirely and the rock becomes a norite.

On the west side of the reservoir the mass is richest in quartz, hornblende, and biotite, and some specimens from this portion of the mass are nearly free from diallage and hypersthene.

Pegmatite and aplite associated with gabbro.—In intimate association with the gabbro occur many dikes or veins consisting mainly of microcline, orthoclase, and quartz. These are commonly only a few inches wide and a few yards long. They cut both gabbro and schist, with sharp contacts. Some dikes have the fine, even grain of typical aplite; others are pegmatitic; and some are partly of one and partly of the other character. Biotite is the only dark silicate observed. In many places quartz and feldspar occur in intricate micrographic intergrowth. The essential minerals of the gabbro are entirely absent from these associated aplite and pegmatite dikes, so far as they have been examined.

MINOR INTRUSIVE ROCKS.

The gneisses, schists, and larger intrusive masses described are cut by small dikes and irregular bodies of granite, granite porphyry, syenite, aplite, pegmatite, diabase, and several other rocks, which are not represented on the map. For the most part these rocks are like the minor intrusive bodies generally found in considerable number in a pre-Cambrian crystalline complex. Some of the granite, pegmatite, and aplite dikes are more recent than the large granite masses but are undoubtedly connected genetically with them. A few granite porphyry dikes occurring near the southern border of the quadrangle belong to a group of such dikes associated with the coarse granite cutting the schists about the town of Rockwood. A mica syenite dike outcropping only for a few yards on Little Cascade Creek cuts both gabbro and schist and is probably related to the gabbro in origin.

One of the most important of these lesser masses occurs in the cliffs north of Tank Creek at an elevation of about 8500 feet. It has extremely irregular form and is of very variable composition. It consists of hornblende-rich granite, with local phases characterized by abundant biotite, augite, and plagioclase. It seems probable that this body is related to the Eolus granite, which in its adjacent contact phase is abnormally rich in plagioclase and hornblende.

Another small and irregular intrusive occurs on the north side of Little Cascade Creek on the old wagon road leading down to the river. It is a dark gabbro porphyry but is not directly connected with the gabbro body near by.

SEDIMENTARY FORMATIONS.

The columnar section sheet of this folio gives a concise, comprehensive statement of the sedimentary section in the Engineer Mountain quadrangle. It embraces all the pre-Tertiary formations known in southwestern Colorado except the upper members of the Cretaceous system and the lower portion of the Algonkian Needle Mountains group. Nearly all of the formations have received names derived from localities adjacent to the San Juan Mountains and all have been fully described in other folios.

ALGONKIAN SYSTEM.

NEEDLE MOUNTAINS GROUP.

SUBDIVISIONS.

The term Needle Mountains group was proposed in the Needle Mountains folio for two apparently Algonkian formations. The lower of these is a conglomerate that occurs in the eastern part of the Needle Mountains and that was named the Vallecito conglomerate, after one of the main valleys of the quadrangle. The pebbles of this formation are chiefly schist, greenstone, and quartzite, but include minor amounts of vein quartz, jasper, and iron ore. The known thickness of the conglomerate is 1000 feet.

Above the Vallecito conglomerate there is a great series of quartzites and slates, unfossiliferous as far as known, which exhibits faulting and folding so complex that the thickness of the series can not be determined, although it certainly amounts to several thousand feet. These beds have been named the Uncompahgre formation, after Uncompahgre Canyon, on the north side of the San Juan, where they are exposed in an extensive section which has been described in the Silverton and Ouray folios.

The quartzites and slates of the Uncompahgre formation cross the northern part of the Needle Mountains in a broad belt within which stand some of the highest and most rugged peaks of the group. Owing to faulting and to the intrusion of the Eolus granite the Vallecito conglomerate is missing in this zone. The quartzites and slates extend westward into the Engineer Mountain quadrangle, where they appear in a much contracted band of nearly vertical strata bounded on the north and south by faults. They disappear on the west beneath the Paleozoic formations, as represented on the map.

UNCOMPAHGRE FORMATION.

Character.—The Uncompahgre formation consists of alternating quartzites and shales or slates in approximately equal development. For the most part, the two rocks occur in prominent members several hundred feet thick. One quartzite member is more than 1000 feet thick and includes very little or no shale. In some parts of the section the two rocks alternate in beds only a few feet in thickness. The map shows an alternation of quartzite and slate, which is well exhibited in the canyon of Lime Creek, just east of the quadrangle line, but, as is explained below, this section is not a normal one.

Quartzite is the predominant element in the Uncompahgre formation. It occurs in very hard, dense, massive strata, of varying grain, carrying small quartzite pebbles in many layers. The formation, however, includes no important actual conglomerate. White and gray are the common colors of the quartzites; pink, red, or purple are less frequently seen. The shale or slate strata of the formation were originally somewhat arenaceous clays. By metamorphism, connected either with intense folding or with the great granitic intrusion in the region, secondary minerals, such as muscovite (sericite), chlorite, garnet, chiastolite, etc., have been variably developed in these clay beds. The presence of secondary mica, combined with foliation due to folding and shearing, has changed much of the clay or shale into imperfectly schistose or slaty rocks. The degree of metamorphism varies so much from place to place that neither "shale" nor "slate" is everywhere applicable to these rocks. "Slate" is used as a general term corresponding best to "quartzite," which is applied to the arenaceous strata.

Occurrence and structure.—The quartzites and slates of the Uncompahgre formation in the Engineer Mountain quadrangle are limited to one small area in its northeastern part. They occur on end or dip very steeply, the quartzites tending to form projecting ribs, in the depressions between which lie the softer shales. The relief has been much modified by glacial scouring.

The apparently simple section is in fact complex in that it represents closely compressed folds with diagonal shear faulting, by which certain beds have been greatly decreased in thickness or cut out entirely. This structure is represented on the map by fault contacts that lie parallel or nearly parallel to the lines of stratification. As this zone of Uncompahgre beds widens eastward in the Needle Mountains quadrangle anticlines and synclines appear in the midst of the section. The southern boundary becomes an overthrust fault in the West Needle Mountains.

The northern limit of the Uncompahgre area in the Engineer Mountain quadrangle is a fault of post-Carboniferous or perhaps of Tertiary age and is presumably coincident in depth with one of the strike or shear faults of pre-Cambrian age. (See "Structure," p. 11.)

CAMBRIAN SYSTEM.

IGNACIO QUARTZITE.

Name and definition.—In the Silverton folio (No. 120) the basal formation of the Paleozoic section in the San Juan region was first described as the Ignacio quartzite, the name being that of the lakes that formerly occupied the site of the present Ignacio reservoir, in the Engineer Mountain quadrangle. The formation rests unconformably on various pre-Cambrian rocks, including granite, gabbro, gneiss, and the sediments of the Needle Mountains group. Its upper plane is one of erosion, the next succeeding deposits being of Devonian age. The name Ignacio is thus applied to a thin remnant of what may have been a much thicker deposit, which, from evidence to be stated, is believed to be of Upper Cambrian (Saratogan) age. The character and relations of the formation are well exhibited on and near the western border of the Ignacio reservoir.

Distribution and mode of occurrence.—On the west side of the Animas Valley a narrow zone of Ignacio quartzite borders the pre-Cambrian formations from the Durango quadrangle line northward for 14 miles, to the east-west fault at the summit of Coalbank Hill. A few isolated exposures lie north of that fault. On the east side of Animas Canyon the quartzite appears as the basal member of the Paleozoic section, capping granite and schist on both sides of Canyon Creek. Owing to its southwestern dip the formation crosses the river about 3 miles south of the quadrangle, connecting the exposures of different elevation in the Engineer Mountain quadrangle.

The Ignacio is very well exposed on the south slopes of the Needle Mountains, east of the Animas Valley. It occurs in much smaller areas in the Silverton and Ouray quadrangles, as shown in the folios concerning those areas.

The Ignacio quartzite outcrops in a characteristic and distinct ledge in a zone on the west side of the Animas Valley. Below the ledge is a glaciated surface of older rocks and above it in many places the softer Elbert formation has been scoured off by ice, so that the top of the ledge of white or gray quartzite forms a bench surface. Glacial markings on the quartzite are common. The formation is so thin that gravel, soil, and talus obscure it in places. The general position of the Ignacio ledge is shown in figure 14, for it lies near the base of the Ouray limestone, which is prominent in the view.

Character.—The Ignacio formation of the Engineer Mountain quadrangle consists of quartzite and of subordinate and variable amounts of sandy shale and conglomerate. Its variation in thickness is due chiefly to erosion. The maximum thickness of the section measured in the quadrangle is about 80 feet, but in certain localities the entire formation has been eroded away. There is much lateral variation in development of even the most persistent strata and therefore no section is typical of the formation as a whole.

The floor on which the deposits were laid down was somewhat undulating and in many places where hollows existed a basal conglomerate was first formed. In the Animas Valley this conglomerate consists mainly of well-rounded pebbles of the extremely hard bluish-gray quartzites of the Uncompahgre formation. These pebbles in most places have a maximum diameter of a few inches, but in the patch of coarse conglomerate $2\frac{1}{2}$ miles north of Potato Hill they reach a diameter of 2 or 3 feet. This isolated exposure of very coarse, hard, glaciated conglomerate rests directly on upturned quartzites of the Uncompahgre formation from which the rocks of the bowlders were evidently derived. Similar conglomerate occurs at the base of the Ignacio on Coalbank Hill, decreasing in coarseness southward, though not regularly.

Lying above the conglomerate or resting directly on older rocks is a quartzite of rather coarse grain, commonly containing a few pebbles of white, gray, or pink quartzite. This has thin shaly partings, which separate it into beds 1 to 5 feet thick. Above this quartzite comes, generally, a zone in which sandy shale beds are more prominent. Some of these finer-grained shales exhibit trail or burrow markings, mud cracks, or ripple marks and commonly contain the problematic forms called *Cruziana*, which are believed to be of vegetable origin.

Above this shaly zone is a fine or medium grained quartzite in well-defined beds, with marked cross-bedding. This is the uppermost member of the formation in the Engineer Mountain quadrangle.

Where the formation is from 50 to 80 feet thick the two quartzites and an intermediate more shaly member are commonly recognizable, as in the zone south of Little Cascade Creek, but in the canyon of Cascade Creek the Ignacio is represented by 44 feet of alternating quartzite and sandy shale, the lower member here being indistinguishable from the central one, while the upper one is missing through erosion. Between Cascade Creek and Coalbank Hill there is great variation in the relative amounts of conglomerate, quartzite, and shale in different sections.

The variations in the color of the Ignacio beds at different localities are also very striking. The lower quartzite is red in some places and white in others, and the upper member is almost equally variable in the same way.

Age.—The reference of the Ignacio quartzite to the Saratogan series of the Cambrian rests mainly on a small fossil shell found originally in the Needle Mountains quadrangle in a very well exposed section of the formation and obtained later in the Ouray quadrangle. This has been identified by C. D. Walcott as *Obolus* sp.?, related to forms occurring in the Middle or Upper Cambrian at various localities in the western United States. Minute fragments of other undeterminable shells were associated with this fossil. Careful search of many exposures since the first discovery of this important fossil has failed to reveal further specimens of it on the southern slopes of the San Juan.

The reference of the Ignacio quartzite to the Cambrian is in accord with the evidence that that system is represented in central Colorado by a thin quartzite.

DEVONIAN SYSTEM.

The Devonian sediments of southwestern Colorado are embraced within two formations, the Elbert and the Ouray. The former includes the lower beds, of variable lithologic character, which were deposited after a period represented by the great stratigraphic break separating them from the Ignacio quartzite. The Ouray limestone is a lithologic unit which transgresses the line between the Devonian and the Carboniferous systems.

ELBERT FORMATION.

Definition.—The Elbert formation was first described in 1904,[a] the name being derived from Elbert Creek, in the Engineer Mountain quadrangle, on and near which the beds are exposed in many places. The formation includes the Devonian section from the base to the Ouray limestone and consists as a rule of less than 100 feet of calcareous shales and earthy or sandy limestones, with subordinate quartzites in some places. These beds are further distinguished from the overlying Ouray by a faunal difference which seems to be persistent. Ganoid fish remains have been found in the Elbert beds at several localities, but they have not yet been detected in the Ouray. On the other hand, the invertebrate fauna of the Ouray formation has not been found in the Elbert.

At the base of the Elbert formation is an unconformity that marks a great hiatus. Although in most places the formation rests with singular uniformity on the Ignacio quartzite, without notable discordance, in some places it transgresses this thin Cambrian formation and rests on pre-Cambrian rocks of various characters.

Distribution and features of occurrence.—The position of the Elbert formation at or very near the base of the Paleozoic section determines its general distribution. Its outcrop is confined naturally to the narrow belt of four thin formations bordering the pre-Cambrian rocks. The main exposures in the Engineer Mountain quadrangle are on the west side of the Animas Valley, extending from the faulted area north of Potato Hill southward to the quadrangle line. About 3 miles below this, owing to their southwestern dip, the lower Paleozoic formations cross the valley of Animas River, and on the eastern side they rise to connect with the border exposures on the southern slopes of the Needle Mountains. The beds appear within the quadrangle to the east of Animas Canyon on both sides of Canyon Creek, these exposures being continuous with those shown on the map in the Needle Mountains folio.

The Elbert beds have but small exposures in the Silverton, Rico, and Ouray quadrangles. The only unsurveyed portion of the San Juan region in which they may occur at the surface lies east of Animas River, in the Ignacio and San Cristobal quadrangles.

The Elbert formation, being comparatively soft and lying between the massive Ouray limestone and the hard Ignacio quartzite, is commonly not well exposed. As the Animas Glacier moved parallel to the principal zone of its outcrop it scoured the soft Elbert strata away, leaving a bench of the underlying quartzite and a lateral cliff of the overlying limestone at the base of which the Elbert occurs. The Elbert beds are in many localities greatly obscured by the talus from this Ouray limestone cliff. The best exposures are where Elbert Creek and other streams cross the zone of the lower Paleozoic rocks.

Lithologic character.—The Elbert formation varies in thickness and in lithologic character from place to place. This variation may be best shown by describing the progressive changes exhibited between the northern and southern exposures within the quadrangle.

In the fault zone north of Potato Hill, where the Paleozoic beds rest on steeply upturned Algonkian quartzites and shales, the Elbert is believed to be represented by 15 feet or less of calcareous sandy strata. Where they rest on shale, flakes of this material are common in the lowest layers. The Ignacio is not present in this zone except near the bordering faults. The limestone above the sandy beds referred to contains crinoid stems and corresponds in other respects to the Ouray, though very thin in this vicinity.

At the crest of Coalbank Hill the conglomerate phase of the Ignacio formation and the Ouray limestone are typically developed. Between them there can be but about 10 feet of Elbert strata, and these are not exposed. Farther south, along the zone where the Elbert should be, small outcrops of sandy limestone of rusty brown color appear, within 200 yards of the top of the hill, in the middle of the Elbert zone. A little farther south evidences of shaly beds may be found above and below this limestone, which gradually becomes a rather persistent minor ledge between the Ouray and Ignacio. Here and there exposures show thin limestones and calcareous shales near the base of the Ouray.

The Elbert is well exposed in a ravine due west of Potato Hill, where G. W. Stose measured the following section:

[a] Cross, Whitman, A new Devonian formation in Colorado: Am. Jour. Sci., 4th ser., vol. 18, 1904, p. 245.

Section of Elbert formation in ravine west of Potato Hill.

Top.		Feet.
1.	Limestone, thin bedded	3
2.	Shale, calcareous	4
3.	Limestone in thin distinct beds	5
4.	Shale, calcareous, pink to gray, with a few thin limestone bands	15
5	Limestone, very thin bedded, wavy	4½
6.	Limestone, sandy, with irregular wavy bedding, and some intercalated sandstone layers	11½
		43

Massive Ouray limestone lies above this section, and 39 feet of normal Ignacio quartzite separates it from the pre-Cambrian rocks below. All the limestones are very fine grained, are gray in color, and have thus far yielded no fossils or salt casts.

The Elbert formation increases in thickness between the above section and the canyon of Cascade Creek, where it includes nearly 100 feet of strata which have the general character of the following section:

Section of Elbert formation in Cascade Creek canyon.

Top.		Feet.
1.	Limestone and shale, alternating in beds not more than 5 feet thick, in part very finely laminated; massive, dense in texture, buff or gray in color. The basal limestone (3 feet) contains chert	42
2.	Quartzite, limestone, and shale in alternating beds, quartzite predominating (23 feet); variegated in color—red, pink, gray, or white. Some limestone layers, cherty	31
3.	Limestone, very dense, hard, sandy in part, in several distinct beds; buff or gray in color	25
		98

About one-half mile south of Columbine Lake and 3 miles south of the section just given there is a somewhat different development of the formation.

Section of Elbert formation south of Columbine Lake.

Top.		Feet.
1.	Shale, reddish or gray, not well exposed	10
2.	Shale and limestone, alternating, limestone predominant, salt casts observed	20
3.	Limestone, in several beds separated by thin shale layers. Limestone dense, gray, hard, forming distinct ledge. Fish scales found in basal part of lowest stratum	30
4.	Quartzite and sandy shale in wavy layers, calcareous in part, gray or red in color. Trail marks and mud cracks in shales. Particles of fish bones and scales scattered all through this member	25
		85

From Columbine Lake southward the formation retains the general character shown in the last section. Salt casts become more and more prominent in the upper shales and the arenaceous character of the lower member is persistent, though most beds are notably calcareous.

About 1 mile south of the quadrangle line the Elbert and Ignacio formations are well but not continuously exposed.

In spite of the great variability of the Elbert formation, illustrated by the sections, it possesses characters making its identification easy in most localities. The lowest member is distinctly calcareous even where it is dominantly arenaceous; the middle portion is characterized by dense unfossiliferous limestones; the upper zone is largely calcareous shale and as a rule exhibits salt casts which are of diagnostic value.

These salt pseudomorphs were observed by Endlich on the south slopes of the Needle Mountains, where they are more common and more perfectly developed than elsewhere, and his explanation of their origin appears to be correct. He postulated that in some way shallow bodies of salt water became isolated and in time evaporated until the concentration permitted crystallization of salt cubes. "Subsequent inundations of the places that had scarcely been laid dry brought with them sand and silt, covering the newly formed crystals. By the gradual percolation of water through the cover the salt was dissolved, and a quantity of the material composing the cover found its way into the cavities thus produced."[a]

Age and correlation.—The Upper Devonian age of the Elbert formation appears to be beyond question. Its stratigraphic relations show that it embraces the earlier variable deposits that were laid down after a long period seemingly of nondeposition in this region. The succeeding deposits of more massive limestone contain an Upper Devonian invertebrate fauna and the upper part of that lithologic unit is of Mississippian age.

The fish remains of the Elbert formation, though scanty, are regarded as Upper Devonian by C. R. Eastman, who discussed them in connection with the original description of the formation.[b] He identified *Bathriolepis coloradensis* sp. nov. in remains from near Rockwood in the Durango quadrangle and specifically undeterminable fragments of the same genus and of *Holoptychius* from the Needle Mountains quadrangle. A plate from the section near Columbine Lake is regarded by Eastman as belonging to an *Anthrodice*.

Beds like those of the Elbert formation in lithologic character have not been noted in other districts, but Eastman regards the so-called "Parting" quartzite of central Colorado as of the same age, the correlation being suggested by fish remains obtained from that formation near Aspen by J. E. Spurr.[a] The variable character of the Elbert sediments, which locally contain much quartzite, tends to confirm this correlation. It is possible that an equivalent of the Elbert is present in the Kanab Valley of southern Utah, where "placoganoid fishes of a Devonian type" were noted by Walcott in 1880.

[a] Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1874, p. 212.

[b] Am. Jour. Sci., 4th ser., vol. 18, 1904, p. 253.

OURAY LIMESTONE.

Definition.—The Ouray limestone was named by Spencer in 1900 after the town of Ouray, where it is typically exposed. It has been described in detail in several folios on the San Juan region. The formation, which includes 100 to 300 feet of limestone and forms a striking lithologic unit, is underlain conformably by the Elbert formation and bounded above by an erosion plane separating it, in the San Juan region, from the peculiar Molas formation of the Pennsylvanian series. Its observed variation in thickness is due principally to this erosion. The lower part of the formation is Devonian and the upper part Mississippian, except where erosion was sufficient to remove the latter before the deposition of the Molas formation.

Character.—The lowest stratum referred to the Ouray is a distinctly crystalline limestone carrying crinoid stems and, in some places, a cup coral. This bed is easily distinguished from the denser, earthy, unfossiliferous limestones that occur at the top of the Elbert in some localities. The lower third of the Ouray in most places consists of limestone layers a few inches thick with shaly layers or, rarely, quartzite, between them. A wavy bedding is found in places and large unfossiliferous chert concretions are common at a horizon near the base.

The greater part of the formation is dense, massive limestone, some beds being saccharoidal. Toward the top the strata are commonly more and more coarsely crystalline, are sparingly fossiliferous, and contain fossil-bearing chert. The colors are white, straw-yellow, buff, or light pinkish. Owing to the massive character of the limestone and the conditions of its occurrence the characteristic topographic forms presented by the formation are low mesas, benches, and prominent cliffs.

Age.—Invertebrate fossils are common at numerous horizons in the Ouray, but they are inconspicuous in the saccharoidal layers. From the base to a horizon somewhat above the middle the fauna is clearly Upper Devonian, according to G. H. Girty, who has fully described 28 species or varieties of fossils. Among the more important species are—

Schizophoria striatula.	Schuchertella chemungensis.
Productella semiglobosa.	Productella subalata?
Athyris coloradoensis.	Athyris vittata var.
Spirifer coniculus.	Spirifer disjunctus var. animasensis.
Camarotœchia endlichi.	Naticopsis gigantea.
Paracyclas sp.	Straparollus clymenioides.
Naticopsis? (Isonema) humilis.	
Orthoceras (several species).	

This fauna is considered by Girty as more closely related to the faunas of the Devonian in Athabasca and Russia than to those of other districts in the United States.

The fossils of the Carboniferous portion of the Ouray will be referred to in a later section.

Occurrence and distribution.—In the Engineer Mountain quadrangle the Ouray limestone, like the Elbert and Ignacio formations, is limited in its occurrence to the zone bordering the pre-Cambrian rocks on the west and to small areas on the east side of the Animas Valley. The latter exposures continue into the Needle Mountains quadrangle, where the massive limestone beds form the surface of several broad sloping mesas. The Devonian fauna of the formation was first found by F. M. Endlich, of the Hayden Survey, on one of these mesas, now called in his honor Endlich Mesa.

Figure 14 shows the relations of the Ouray exposures to the schist surface and to Hermosa Cliffs. From the structural and topographic conditions illustrated in this view it will be readily understood that the Ouray limestone tends to form benches that slope gently toward the base of the cliffs and present ledge exposures on the east or main valley side. The Hayden map incorrectly represents Devonian beds as lacking south of Cascade Creek.

Correlation.—The Ouray limestone corresponds in some respects with the Leadville limestone of central Colorado, which was originally described as Carboniferous, its age having been determined from fossils in its upper part. Some of the Devonian forms of the Ouray have been reported from lower parts of the Leadville limestone, but studies warranting exact correlation have not yet been made.

CARBONIFEROUS SYSTEM.

MISSISSIPPIAN SERIES.

UPPER PART OF THE OURAY LIMESTONE.

As was stated in describing the Ouray limestone, it is known that a Mississippian fauna occurs in certain localities in the upper part of that formation, which is separated from the uppermost Devonian fossiliferous beds by about 50 or 75 feet of massive limestone in which no fossils have thus far been discovered. Post-Ouray erosion removed those upper fossil-bearing strata completely over large areas, and as neither the

[a] Mon. U. S. Geol. Survey, vol. 12, 1886, p. 61.

Upper Devonian nor the basal Carboniferous strata are everywhere fossiliferous, it is impossible to decide in many places whether the upper portion of the Ouray limestone ledge is Carboniferous or not.

From the great quantity of Carboniferous chert pebbles in the succeeding Molas formation it must be assumed that above the known horizons of the Ouray there once existed in this region a considerable thickness of chert-bearing limestone of Mississippian age. The invertebrate fossils obtained from the upper part of the Ouray limestone and from the pebbles of the Molas formation have been identified by G. H. Girty, who furnishes the following list of the more important and characteristic Mississippian forms:

Rhodocrinus sp.	Spirifer peculiaris?
Platycrinus sp.	Eumetria marcyi?
Rhipidomella pulchra.	Camarotœchia metallica.
Schuchertella inæqualis.	Myalina keokuk.
Productus semireticulatus var.	Phillipsia peroccidens.
Spirifer centronatus.	

One of the principal localities which has furnished Carboniferous fossils in the Ouray limestone is in the Engineer Mountain quadrangle on the southwest side of Cascade Creek, within half a mile of the stream.

PENNSYLVANIAN SERIES.

MOLAS FORMATION.

Definition.—The Molas formation was named in the Silverton folio from its good exposures about Molas Lake, which lies 4 miles east of the northeast corner of the Engineer Mountain quadrangle. The name applies to a thin formation of peculiar lithologic character, the first deposit after the interval of nondeposition and erosion which left its traces on the surface of the Ouray limestone. Where the Molas formation has been recognized in the region adjacent to the San Juan Mountains it rests almost universally on the Ouray limestone.

The surface of Ouray limestone on which the Molas was deposited was marked by deep solution crevices, some of which penetrated to depths of several feet. These were filled by the red mud of the Molas, whose coloring matter, ferric hydroxide, has spread into the massive limestone by numerous cracks. In some localities the zone between the Ouray and the Molas is practically a breccia of Ouray limestone blocks in a matrix of red shale or sand of the Molas formation.

Character.—The Molas may be generally described as a thin series of reddish calcareous shales and sandstones, variable beds or lenses of chert conglomerate, and, rarely, thin layers of fossiliferous limestone. Not more than 75 feet of strata have been referred to the Molas in any section, but its beds are so soft and friable that good exposures are rare. Its strong red color is very characteristic and its line of junction with the overlying Hermosa formation is in general sharply determinable by a change of color as well as by the more massive texture of the limestone or sandstone in the Hermosa.

Age.—The only fossils thus far found in the limestones of the Molas were obtained on Stag Mesa, in the Needle Mountains quadrangle. These were determined by G. H. Girty as *Echinocrinus triplex?*, *Rhombopora lepidodendroides*, *Rhipidomella pecosi*, *Spirifer boonensis?*, *Composita subtilita*, and *Myalina perniformis?*. These show close relationship with the fauna of the Hermosa formation and warrant the assumption that the Molas represents the early sedimentation of the Pennsylvanian epoch, distinguished by certain lithologic features.

Distribution.—The Molas formation accompanies the Ouray limestone but is as a rule not well exposed in this quadrangle. It occurs principally either at the base of Hermosa Cliffs, where it is commonly concealed by detritus or valley alluvium, or as a thin coating to benches of the Ouray limestone. On many slopes underlain by the Ouray, scattered chert pebbles or reddish sandy soil show the presence of the Molas in a thin remnant, at least. Where the Molas beds have been wholly removed the limestone may often be recognized as belonging to the uppermost zone of the Ouray through the reddish color penetrating it in the manner already described.

Characteristic exposures of the zone of transition between the Ouray and Molas occur at the point where the road crosses Cascade Creek.

HERMOSA FORMATION.

Definition.—The Hermosa formation was named in 1900 by Spencer, from Hermosa Creek, along which, in the Engineer Mountain and Durango quadrangles, it is well exposed. The term is applied to about 2000 feet of sandstones, shales, and limestones which occur conformably between the Molas and Rico formations. The basal stratum of the Hermosa is a notably persistent massive limestone, somewhat less than 15 feet in thickness as a rule, containing abundant fossil shells. It is normally dark in color but has been impregnated in some places by iron hydroxide derived from the underlying Molas beds. The upper limit of the Hermosa is determined by the appearance of the Rico fauna in a limestone of distinctive lithologic features

Character.—The Hermosa is a succession of alternating limestones, shales, sandstones, and grits, with conglomerates in some places. Each of these rocks occurs locally in massive and fairly homogeneous beds, which may exceed 50 feet in thickness. Each may also occur in very thin beds in rapid and irregular alternation with the others. The shaly members are usually not homogeneous. Some are dark calcareous shales; others are sandy.

Sections of the Hermosa formation a few miles apart can not be correlated as to individual beds owing to the great lateral variation of many or all of its strata. This variation extends not only to the thickness of particular beds, but also to the general quantitative distribution of different kinds of sediments in different parts of the formation. Thus the proportion of limestone to other sediments in the formation increases very materially between the southern portion of Hermosa Cliffs and the slopes northeast of Engineer Mountain. In the former locality limestone appears in but few ledge-making beds; in the latter it is almost as prominent as massive sandstone. The middle third of the formation is richest in limestone. As a rule the limestone beds are bluish gray, dense, and in many places bituminous, and nearly all carry fossils, at least sparingly. The sandstones are gray, pink, or green in color. Most of the more massive beds are feldspathic and pink. Green is the predominant color in the lower third and pink in the upper third. The shales are green, reddish, or dark gray.

Fossils and correlation.—Invertebrate fossils are numerous and well preserved in many limestones and calcareous shales of the Hermosa formation. By far the larger number are brachiopods, though gasteropods occur and also the characteristic foraminifer *Triticites secalicus*. Most of the species are identical with forms occurring in the Missouri group of the Carboniferous of the Mississippi Valley, which corresponds in point of age with what is commonly known as the "Upper Coal Measures." The same fauna is also found at various places in Colorado. In the Elk Mountains similar fossils are found in the Weber and Maroon formations, as described in the Anthracite-Crested Butte folio (No. 9), showing that the Hermosa may comprise the Weber and part of the Maroon formation. The following is a partial list, supplied by G. H. Girty, of the most characteristic Hermosa fossils:

Triticites secalicus.	Productus nebraskensis.
Chætetes milleporaceus.	Marginifera muricata.
Rhombopora lepidodendroides.	Marginifera wabashensis.
Derbya crassa.	Spirifer boonensis?
Chonetes mesolobus.	Spirifer cameratus.
Productus semireticulatus var. hermosanus.	Squamularia perplexa.
Productus gallatinensis.	Composita subtilita.
Productus cora.	Deltopecten occidentalis.
Productus punctatus.	Acanthopecten carboniferus.
	Myalina subquadrata.

Reference to the Hayden map of southwestern Colorado will show that the strata between the Devonian and the Jurassic sandstone (corresponding to the La Plata sandstone) were mapped as "Middle and Upper Carboniferous." The mapping of the former division corresponds in general with the occurrence of the Hermosa formation.

Occurrence and distribution.—The Hermosa formation is one of the most prominent in the quadrangle, as a glance at the map will show. Its most notable exposures face the Animas Valley in a great scarp that rises abruptly from the bench of the Ouray and Molas formations. To this scarp has been given the name of the formation so well exhibited in it. The general features of the cliff exposures are shown in figure 14; the details in the upper part in figure 2. The scarp between Engineer Mountain and Potato Hill, seen in figure 13, is also due to the Hermosa. Everywhere the massive limestones and sandstones tend to cause benches or ledges, which form a striking feature of the dip slope represented in figure 15.

Only the upper part of the formation appears in the Hermosa Valley in this quadrangle. The heavy grit beds of the upper 300 feet cause prominent terraces or benches about Hermosa Park and on both sides of the stream below it.

In the Needle Mountains, Durango, and Rico quadrangles the Hermosa formation is also very prominent. On the north side of the San Juan it is well shown in cliffs facing the town of Ouray.

RICO FORMATION.

Definition.—The Rico formation was first discriminated as such during the survey of the mountains from which it derives its name and was originally described in a report on the geology of the Rico Mountains by Cross and Spencer.[a] The name is applied to the lower portion, 250 to 325 feet thick, of the "Red Beds" section of the southwest side of the San Juan Mountains. The beds contain a marine fauna and are thus notably distinguished from the overlying unfossiliferous red strata, to which they bear a striking resemblance in lithologic character. The Rico strata are considered as transitional between marine and fresh-water deposits.

[a]Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 59.

The stratum at the upper limit of the Rico formation as it has been mapped is, except at one locality, mentioned below, the uppermost fossiliferous limestone, or its equivalent where that can be recognized. Discontinuity of exposures and lateral variation in the character of the formation prevent the identification of the equivalent of the highest known fossil-bearing stratum in widely separated sections where fossils can not be found at that apparent level. The discovery of a fossil-bearing limestone of Rico character in the midst of a section of typical red beds of the Cutler formation on the south face of Engineer Mountain makes it seem probable that the Rico fauna may locally appear considerably above the horizon hitherto supposed to be the top of the formation at its maximum thickness. Although the Rico is thus not a consistently founded formation as to its upper limit, it seems highly desirable to distinguish it as closely as possible from the overlying red beds of the Cutler.

Character.—The formation consists of sandstones and conglomerates with intercalated shales and usually sandy fossiliferous limestones. Lithologically the formation resembles the overlying red beds of the Cutler more than the grayish Hermosa strata below. The basal stratum in and near the Rico Mountains is commonly a sandy limestone or calcareous sandstone of pink color, strongly marked by the abundant shells it contains. These fossils are preserved in white calcite, which contrasts strongly with the pinkish matrix. The manner of occurrence of the Rico fossils is almost diagnostic of the formation near the Rico Mountains, for similar beds do not there appear in the Hermosa. It is much less characteristic in the Animas Valley. Although fossils also occur in thin dark-gray limestones, like those of the Hermosa, at several horizons within the Rico, the features of the lowest stratum are repeated at higher levels in many sections.

The greater part of the formation is made up of sandstones and sandy shales, most of which are highly feldspathic Many of the massive sandstone or grit beds are conglomeratic, containing pebbles of schist and quartzite. Cross-bedding is common. Some of the shaly beds are chocolate or purplish in color; the grits and sandstones are of lighter shades. The color of the formation as a whole is a much darker red than that of the overlying Cutler formation and where the exposures are good the Rico can be distinguished in a general way by this difference in color at a distance of several miles. The color line is not a sharp one, however, nor does it terminate persistently at a definite horizon.

Fossils and correlation.—The fossils of the Rico formation are almost all marine invertebrates. The known fauna embraces approximately 25 genera and 40 species. This material has been studied by G. H. Girty, whose judgments concerning the age and correlation of the formation are given in the succeeding paragraph.

The fauna was originally thought to suggest both Permian and Pennsylvanian affinities. It was therefore called Permo-Carboniferous and was correlated with the Neosho and Chase of the Kansas section. After more detailed and extended comparisons had been made it was referred to the Pennsylvanian without qualification and correlated with distinctly older formations in Kansas—the Deer Creek, Hartford, and Howard limestones.[a] One of the species which was regarded as especially important in the correlation of the Rico is *Chonetes mesolobus*. In Kansas *C. mesolobus* is confined to the lower formations of the Pennsylvanian. In the Rico quadrangle its known occurrence is restricted to a single locality on Dolores River, which has been referred somewhat questionably to the Rico formation. Three other species were found associated with it there, not one of the four being known elsewhere in the Rico. On the other hand, only one of them has been found in the Hermosa formation. The lithologic and stratigraphic evidence is therefore not conclusive in determining the horizon of these fossils as Rico and it is possible that this significant species may have to be left out of the evidence used in correlating the Rico fauna.

A nearly full list of fossils from the Rico formation may be found in the cited report by Cross and Spencer, and in Professional Paper 16 of the Geological Survey. Girty supplies the following partial list of characteristic forms:

Productus cora.	Allerisma terminale.
Composita subtilita.	Schizodus pandatus?
Deltopecten occidentalis.	Pleurophorus subcostatus.
Myalina wyomingensis.	Edmondia gibbosa.
Myalina subquadrata?	Zygopleura plicata.
Myalina perattenuata?	Naticopsis monilifera.
Pseudomonotis hawni.	Strophostylus remex.
Pseudomonotis equistriata.	Bulimorpha chrysalis.
Pseudomonotis kansasensis.	Euphemus nodicarinatus.
Aviculipinna nebraskensis.	

Distribution.—The Rico beds appear in a narrow band between the Hermosa and Cutler formations. Their most prominent exposures are on the sides of Hermosa Creek. The faulted area north of Hermosa Park exhibits several fossiliferous beds which are very useful in working out the structure.

[a]Girty, G. H., The Carboniferous formations and faunas of Colorado: Prof. Paper U. S. Geol. Survey No. 16, 1903, p. 267.

A well-exposed section of the formation occurs in a ravine on the south slope of Engineer Mountain, where the uppermost fossil-bearing stratum appears at a higher horizon than usual. The Rico beds occupy a large surface in the upland country between Hermosa Creek and Hermosa Cliffs, but in spite of the favorable topography good sections of the formation there are very rare, on account of the prevalence of a dense growth of aspen.

PERMIAN (?) SERIES.

CUTLER FORMATION.

Limits and character.—The Cutler formation was first distinguished as such in the Silverton folio (1905), the name being derived, however, from Cutler Creek, in the Ouray quadrangle, where a characteristic section is exposed. The formation includes a succession of red shales, sandstones, grits, and conglomerates, aggregating 2000 feet as a maximum observed thickness. These strata constitute the greater part of the "Red Beds" of southwestern Colorado. The formation normally overlies the Rico conformably, as may be seen on the south side of the San Juan Mountains, but in the Ouray quadrangle no beds containing the Rico fauna were detected and the Cutler was therefore mapped and described as resting without any visible break on the Hermosa. The base of the Cutler formation is in practice determined by the uppermost fossiliferous stratum assigned to the Rico, or its equivalent, but, as has been already noted, this results in much uncertainty as to the line between the formations in many localities.

The upper limit of the Cutler formation is a stratigraphic break which was first observed in the Ouray quadrangle and which, it seems reasonable to assume, is present in all known sections, since above this break comes the clearly recognizable Dolores formation, of Upper Triassic age.

The Cutler formation is composed principally of shallow-water or fluviatile deposits. They are mainly arenaceous but as a rule include a calcareous cement, and thin earthy or sandy limestones are distributed at intervals throughout. Many of these limestones are nodular and some of them form conglomerates of apparently intraformational character.

The fluviatile or continental character of the Cutler formation is suggested by its very abrupt and irregular changes in thickness and by the constitution of its sandstones, conglomerates, and shales. Ripple-marked surfaces and rain-drop impressions are seen on many of its shale layers, cross-bedding is a feature of its sandstones and grits, many of the grits are highly feldspathic, and its conglomerates contain chiefly pebbles of pre-Cambrian rocks.

The strong and bright-red color of the Cutler formation as a whole is very pronounced. The finer-grained beds have the strongest color; the grit and conglomerate strata are generally pinkish but include portions that are gray, white, or dark red.

Age and relations.—The Cutler formation was assumed to be Triassic until the discovery of a pronounced break, with local angular unconformity, by which it is now known to be separated from the Triassic beds above.

The absence of recognizable Rico strata below the Cutler on the northern side of the San Juan, already referred to, may be interpreted as indicating either a break or that beds which are fossiliferous in one district are barren in another. The latter explanation is thought to be correct because the Rico fauna occurs in red beds of lithologically pronounced Cutler facies on the south face of Engineer Mountain about 225 feet above the horizon which would otherwise be taken as the upper limit of the Rico. The intervening 225 feet of unfossiliferous beds are lithologically typical of the Cutler. This occurrence serves to confirm the view already expressed—that the Rico and Cutler formations constitute a series of transitional beds which range from marine to apparently continental deposits. The Rico formation contains the uppermost marine sediments, but it would seem that the change to continental deposition did not take place at absolutely the same horizon in all parts of the San Juan region.

From its broader stratigraphic relations the Cutler formation is now believed to be equivalent to the beds from which a Permian fauna has been reported in the Grand Canyon district of Utah and Arizona and western New Mexico. It is therefore provisionally referred to the Permian period, but owing to its close relationship with the Rico it may prove to belong in the Pennsylvanian.

Distribution.—The red beds of the Cutler occur in one continuous belt between the Rico and Dolores formations, occupying a larger area than any other formation of the quadrangle. Many partial sections, each comprising several hundred feet, have been found. The strong red color of its cliff exposures makes them recognizable for many miles. The formation is more perfectly exhibited in the Dolores Valley below Rico, a few miles west of the Engineer Mountain quadrangle. On the western slope of the San Juan the Cutler is concealed by younger formations except in the San Miguel Valley. It is well exposed in the Uncompahgre Valley, on the northern side of the mountains.

TRIASSIC SYSTEM.

DOLORES FORMATION.

Definition.—The Dolores formation, named from Dolores River, embraces all the Triassic beds of southwestern Colorado. It includes a few hundred feet, at most, of intensely red strata, the upper portion of the "Red Beds" of the region. The formation is sharply defined at its base by a peculiar fossiliferous conglomerate and at its summit by contact with the white sandstone of the Jurassic La Plata. Both the upper and the lower boundary of the Dolores are in fact planes of stratigraphic break, as shown by angular unconformity and overlap in certain districts, but on the southwest side of the San Juan evidence of the break is found at but few places.

Character.—Where the Dolores formation is best developed it exhibits a bipartite character. Its lower portion consists of an alternation of rather thin bedded sandstones, sandy shales, and limestone conglomerates, in some places 250 feet thick. This series of beds is characterized by the limestone conglomerates and by the fact that the strata are more commonly greenish or gray than distinctly red in color. All the known fossils of the formation occur in these beds.

Most of the limestone pebbles of the conglomerate are gray in color, fine grained, and so minute and so uniform in size as to suggest a pisolitic character, an impression which is, however, not confirmed by microscopical examination. In some places the pebbles are several inches in diameter. No fossil-bearing pebbles have been observed. A few pebbles of quartzite, granite, and other rocks occur locally in the conglomerate, and the matrix is variably sandy, with a calcareous cement.

These conglomerates characterize several bands in the lower 200 feet or more of the formation, and apparently they may appear at any horizon within this part of the section. The lateral variation is so great that a ledge 20 feet thick, consisting chiefly of conglomerate, may be replaced in a few yards by sandstone with numerous thin layers of conglomerate. Cross-bedding is common in both sandstones and conglomerates.

These peculiar conglomerates are as a rule interbedded with thin-bedded gray sandstone and greenish shale, the mass aggregating in thickness 50 to 75 feet. In many places these rocks exhibit ripple and trail markings and mud cracks. Carbonized plant stems occur in these beds, but no determinable leaves nor fossil wood.

The upper part of the formation consists of fine and even grained quartzose sandstone and sandy shale, in many places presenting no distinct subdivisions. It may be massive and resistant to erosion or friable and crumbling. Its color as a rule is bright vermilion and it thus stands in marked contrast to the white La Plata sandstone above.

Thickness.—The thickness of the Dolores formation varies greatly throughout the Engineer Mountain and adjacent quadrangles. This variation is due chiefly to pre-La Plata erosion. In the Durango and Rico quadrangles the formation reaches a thickness of nearly 800 feet. In the Engineer Mountain quadrangle it is in most places not more than 200 feet thick but in some localities exceeds 400 feet. The upper red sandstone is lacking in some sections.

Distribution.—The Dolores crosses the northern part of the quadrangle in a narrow band and caps a spur of the divide between Hermosa Creek and Dolores River, on the western border of the area. The limestone conglomerates and associated sandstones form prominent ledges in many places, as about Jura Knob, east of Cascade Creek, and at the head of North Fork of Hermosa Creek. A fine section of the formation is exposed in Section Point in the outcrops represented in figure 5. The formation is there 440 feet thick.

Age and correlation.—The Dolores formation is of Upper Triassic age, as shown by the scanty yet widely distributed vertebrate, invertebrate, and plant remains obtained from it. The limestone conglomerates usually contain fragmentary bones or fairly well preserved teeth of belodont crocodiles and megalosauroid dinosaurs of Triassic types. The limestone conglomerates are so generally characterized by these remains that careful search of a good exposure seldom fails to reveal fragments of bones or teeth.

Several species of *Unio* and a gasteropod, probably *Vivipara*, have been found in the limestone conglomerates at several localities. One Triassic plant, *Pachyphyllum münsteri*, has been obtained.

The meager fauna of the Dolores beds appears to be part of one also known in New Mexico, Arizona, Utah, and Wyoming. The identification of the conglomerate of the Dolores formation on Grand River, Utah, and the wide distribution of the vertebrate fauna make it seem probable that Dolores strata once extended over a large part of the Rocky Mountain and adjacent provinces. The correlation and distribution of the formation have been discussed in several publications.[a]

[a] Cross, Whitman, and Howe, Ernest, Red Beds of southwestern Colorado and their correlation: Bull. Geol. Soc. America, vol. 16, 1905, pp. 447-498 Cross, Whitman, Stratigraphic results of a reconnaissance in western Colorado and eastern Utah: Jour. Geology, vol. 15, 1907, pp. 634-679. The Triassic portion of the Shinarump group Powell: Jour. Geology, vol. 16, 1908, pp. 97-133.

JURASSIC SYSTEM.

LA PLATA SANDSTONE.

Limits and character.—The La Plata sandstone was first so named in the Telluride folio, from its prominence in the La Plata Mountains. It is defined as including a marked lithologic unit consisting principally of two massive white sandstones with a variable thin-bedded and more or less calcareous member between them. The formation lies at the base of the series of fresh-water strata commonly assigned to the Jurassic in western Colorado.

The base of the La Plata is a plane of unconformity at which the lower sandstone overlaps the Dolores and all older sedimentary beds to the Archean, as shown north of the San Juan Mountains and elsewhere. The variation in the thickness of the Dolores formation in the Engineer Mountain quadrangle is due to this unconformity.

The upper limit of the La Plata is drawn at the base of a clay shale of greenish or reddish color, the first stratum of this character in a section of alternating shales and sandstones in the McElmo formation. The thickness of the La Plata ranges from 250 to 400 feet in the Engineer Mountain quadrangle.

Both sandstone members of the formation are very white, massive, and of fine and even grained texture and consist chiefly of quartz grains. These sandstone beds form many steep cliffs or smooth and rounded faces of bare rock. The sandstone is normally very friable and is characterized by marked cross-bedding. Intricate and delicate veining of secondary white quartz appears locally in the more massive layers.

The lower sandstone is generally white but in some places is brilliantly colored in varying shades of orange and yellow. The coloration ordinarily extends irregularly from the base of the formation upward and as a rule is very distinct from the vermilion of the underlying sandstone of the Dolores formation.

The intermediate calcareous member of the formation consists of an alternation of thin-bedded sandstones, some red and some white, with sandy and calcareous shales which in many places grade into limestone. In Graysill Mountain, Jura Knob, and elsewhere the limestone is strongly developed. It is dark blue-gray and is very fine grained in texture. No fossils have been found in it in the San Juan region.

Distribution.—The white sandstones of the La Plata form a conspicuous portion of the sedimentary section. They contrast markedly with the bright-red Dolores formation below and the duller-toned McElmo above. The formation occurs principally in a band of outcrops that crosses the northern part of the quadrangle. It also appears in the bed of Dolores River and in a few isolated exposures.

The massive beds naturally produce cliffs, and some prominent ledge outcrops can be seen for long distances. The view given in figure 5 shows the white band of the La Plata sandstone in Section Point standing out sharply from the dark-red Dolores beds below.

Age and correlation.—The age of the La Plata sandstone is indicated chiefly by its stratigraphic position. It succeeds unconformably the Upper Triassic beds of the Dolores formation. A general correlation with the White Cliff sandstone of the plateau country has been established by continuity of exposures down the valleys of San Juan and Dolores rivers. Since the White Cliff sandstone lies below marine Jurassic beds described by Powell, the age of the La Plata seems determined as Lower Jurassic.

The La Plata is undoubtedly the equivalent of the lower sandstones of the Gunnison formation of the Elk Mountains, Colorado, described by Eldridge in the Anthracite-Crested Butte folio. A few minute fresh-water shells were found by Eldridge near the base of the Gunnison.

McELMO FORMATION.

Limits and character.—The name McElmo was proposed in the Telluride folio for the alternating shales and sandstones which lie between the La Plata and Dakota sandstones. This series is somewhat variable in thickness, ranging from 400 to 1000 feet in the part of southwestern Colorado that has been examined. The vertical limits of the McElmo formation are accurately determinable by means of the uniform character of the La Plata and Dakota sandstones, between which it lies.

In the Engineer Mountain quadrangle the McElmo has a thickness of 400 to 500 feet. It is here composed more largely of shale than in the Telluride quadrangle, where its thickness on San Miguel River is nearly 1000 feet and where sandstone forms its most important element. Shale and sandstone alternate in the formation in variable proportions. The beds of shale as a rule are colored some shade of green, but are locally pink or deep Indian red, and they include some variegated red and green bands. The shales are fine grained and sandy and occur in homogeneous bands, in places several feet thick, with little or no distinct lamination. The sandstones are fine and even grained and friable in texture; those of the lower portion resemble the La Plata sandstone, and at least one of the upper beds is very similar to the Dakota sandstone. The arenaceous layers are white or yellowish and locally grade horizontally and vertically into sandy shale and thence into clay shale. In the upper part of the section there is a fine-grained conglomerate which is practically identical in character with the lowest conglomerate of the Dakota. The large number of crumbling beds in the formation cause numerous gaps in all discovered exposures, and no detailed section can be given.

Distribution.—The McElmo formation is limited to the northern part of the Engineer Mountain quadrangle. It occurs in narrow bands except in the valleys of Dolores River and Barlow Creek, where its beds occupy broad slopes. On account of the generally soft and friable nature of the beds outcrops of notable extent are much less common than those of the more uniform sandstone formations above and below.

Age and correlation.—The age of the McElmo formation is assumed to be Jurassic from the opinion prevalent among paleontologists concerning the vertebrate fauna long known from the Morrison formation on the eastern flanks of the Front Range and in the equivalent "Como beds" of Wyoming. Representatives of this fauna have been found by E. S. Riggs in McElmo beds in the Grand River valley at the north end of the Uncompahgre Plateau.

The McElmo represents the upper part of the Gunnison formation of Eldridge. That the McElmo and Morrison formations embrace certain equivalent strata is scarcely open to question. That the formations are vertically coextensive and thus fully equivalent can not be considered as demonstrated by present knowledge.

CRETACEOUS SYSTEM.

DAKOTA SANDSTONE.

Character.—The Dakota sandstone of the Engineer Mountain quadrangle has the general character common to it in Colorado. It is composed of variable gray or brownish quartzose sandstones, much cross-bedded, with a peculiar conglomerate at or near the base and several shaly layers at different horizons. Its thickness in the Engineer Mountain quadrangle ranges from 100 to 150 feet. The basal conglomerate, carrying small chert pebbles of white, dark-gray, or reddish colors, which is so persistent over large areas adjacent to the Rocky Mountains, is here rather variable in development. Conglomerate of this character is not, moreover, strictly confined to the base of the section.

The thin-bedded sandstones occur in zones 30 to 40 feet thick. These zones are separated by variable sandy shales which as a rule are carbonaceous and carry thin seams of coal. The shale members are strongly developed near the middle and again near the top of the formation. They contain abundant indistinct plant remains.

The coal from the shaly layers of the Dakota was formerly mined in the valley of Barlow Creek just north of the quadrangle. It is at present of no economic importance, for the railroad brings in better coal from other formations.

Distribution.—The Dakota sandstone is restricted to the divides about the head of Dolores River and to the slopes adjacent to Cascade Creek. It occurs over a large area in Flattop through the erosion of the soft Mancos shale above it. In both Flattop and Sliderock ridges intrusions of monzonite porphyry or quartz trachyte are found at the horizon of the shale layers of the Dakota.

MANCOS SHALE.

Character.—In the Telluride folio (No. 57) the body of shale that lies above the Dakota sandstone and beneath the Mesaverde formation was named the Mancos shale, on account of its characteristic development in Mancos Valley, especially about the town of Mancos. In its typical development the formation is a series of dark clay-shale beds nearly 2000 feet thick, presenting no persistent lithologic or paleontologic horizon which can be used as a guide to subdivision. The shales are characteristically of a dark-gray or lead color and are nearly everywhere somewhat sandy. Near the base two calcareous layers become limestones in places and are locally rich in fossils. Thin sandstones also appear here and there in the basal part of the formation, but neither the limestone nor the sandstone layer is developed with sufficient uniformity to be traced for considerable distances. The invertebrate fossils occur chiefly at horizons about 125 and 225 feet above the Dakota sandstone.

Distribution.—The Mancos is more slightly developed in the Engineer Mountain quadrangle than any other of the Mesozoic formations. It forms a cap to the Dakota of Flattop and thin remnants of it have been preserved from erosion by the intruded sheets of trachyte in Sliderock Ridge and in the divide southwest of Hermosa Peak. Its maximum thickness is about 300 feet in Flattop.

TERTIARY SYSTEM.

EOCENE (?) SERIES.

TELLURIDE CONGLOMERATE.

Almost on the northern border of the quadrangle, on the hill east of Cascade Creek having an elevation of 12,750 feet, there is a small remnant of a coarse conglomerate which is very widely distributed in the Telluride quadrangle, after which the formation is named. The conglomerate is a continental or fresh-water deposit, formed during the later part of the great erosion epoch that succeeded the post-"Laramie" uplift of the San Juan region. The surface on which it rests in the Telluride quadrangle and adjacent country is a peneplain crossing the outcrops of the whole sedimentary section from the Cretaceous to the pre-Cambrian. This peneplain probably surrounded the Needle Mountains and other high areas in the San Juan district, and the conglomerate is the product of the erosion of these high tracts in the period immediately preceding the accumulation of the San Juan tuff, which rests with general conformity on the conglomerate.

The conglomerate of the hill east of Cascade Creek contains bowlders and pebbles of the ancient rocks of the Needle Mountains and of several Paleozoic beds.

Since the relations and character of the Telluride conglomerate are so inadequately exhibited in the Engineer Mountain quadrangle the reader is referred to the Silverton, Telluride, and Ouray folios for a fuller discussion and description of this interesting and significant deposit.

QUATERNARY SYSTEM.

GLACIAL GEOLOGY.[a]

By Allen David Hole.

DISTRIBUTION OF DEPOSITS.

The glacial deposits of the Engineer Mountain quadrangle were formed at two distinct stages of glaciation. Those of the later stage are found chiefly in the valley of Animas River and its tributaries and in the upper part of valleys tributary to Dolores River, near Blackhawk Peak and Flattop. In addition, a tongue of ice from the Animas Glacier passed over into the valley of the East Fork of Hermosa Creek, extending at its maximum about half a mile below the point of junction of the East and North forks. Except this tongue, which passed down the valley of the East Fork, and the small glacier that occupied Straight Gulch, there is no glacial terminus in this quadrangle. The terminus of the large Animas Glacier was near Durango, about 15 miles farther south, and much of the ice that passed down the valley of the Animas through the Engineer Mountain quadrangle was derived from the mountains to the north and east, so that the glaciated area of this quadrangle is in large part intermediate in position between gathering grounds and terminus.

Most of the deposits of the earlier glacial epoch lie south of Hermosa Mountain, in valleys tributary to Hermosa Creek. One area, however, is found 2 miles northeast of Hermosa Mountain, in the valley of a stream tributary to Dolores River.

EVIDENCES OF GLACIATION.

The evidences of glaciation in this quadrangle include striæ on bed rock, roches moutonnées, cirques, lakes in rock basins, hanging valleys, morainal drift, and erratic bowlders.

Striæ and roches moutonnées.—Roches moutonnées and striæ are most abundant in that part of the eastern third of the quadrangle that lies south of Engineer Mountain. The underlying rock in this area is gneiss, schist, or granite and much less soil has accumulated here than in the adjoining areas, where the underlying formation is either trachyte or some kind of sedimentary rock. The direction of the striæ is, in general, approximately parallel to the course of the stream draining the valley in which they are found; for example, (1) on the eastward-facing slope of the valley of Lime Creek, east and northeast from Engineer Mountain, the direction ranges from S. 27° E. to S. 30° W., the average being nearly due south; (2) on the terrace between Hermosa Cliffs and the canyon of Animas River, and in the area west of the canyon of Cascade Creek north of Elbert Creek, the direction ranges from S. 27° E. to S. 27° W., but by far the greater number of the striæ trend between S. 12° E. and S. 13° W.

Striæ are found not only on the lower slopes of valleys but on ridges and divides, where they afford conclusive evidence of the movement of ice from one valley to another. (See fig. 13.) Illustrations are seen in the following places:

(1) On the ridge north of Potato Hill, 3 miles southeast of Engineer Mountain, where roches moutonnées and striæ are abundant for 1½ miles along the crest of the ridge and occur up to an elevation of 11,200 feet. The average direction of the striæ is about S. 53° W.

(2) On the divide separating the valley of Cascade Creek from the upper part of the valley of the East Fork of Hermosa Creek, where the bed rock exposed is well smoothed off. No striæ were found at the crest; but between 300 and 400 feet below it, on the eastward-facing side, occur striæ bearing N. 87° W. The striæ and moraines in the valley of the East Fork of Hermosa Creek indicate that glacial ice passed over the divide in considerable amount from the valley of Cascade Creek. These striæ were probably produced by the westward movement of the ice.

[a]Study of the glacial geology has been facilitated by data and suggestions given by Whitman Cross and by assistance rendered in the field by Wilmer W. Lindley and Willard S. Markle.—A. D. H.

(3) On the ridge between Lime Creek and Animas River, where striæ having an average direction nearly due south occur up to elevations of about 10,300 feet. Those above 9500 feet are evidently due to ice that came, for the most part, from the valley of Lime Creek and moved directly across the ridge to join the Animas Glacier.

Cirques.—Cirques are not numerous in the Engineer Mountain quadrangle. Two, however, deserve special mention—the valley heading north of Grayrock Peak, tributary to Cascade Creek, and the head of Aspen Gulch, northeast of Whitecap Mountain. Both of these have the steep bounding walls, the widening valley, and the diminished gradient near the head that characterize glacial cirques. In the first cirque there is also a "rock stream" that extends across the floor in a northeasterly direction from the base of the steep wall northwest of Grayrock Peak.

Some other valleys have rather cirquelike heads, especially those of the upper tributaries of Cascade Creek coming from the west and those heading near Blackhawk Peak and Dolores Mountain. Glacial action was less vigorous, however, in the mountains of this quadrangle than in those to the north, east, and northeast, so that the cirques here are not so well developed as in those regions.

Lakes.—Lakes are found at many places within the glaciated area, but most of them are not in cirques near the heads of valleys, as are those in the higher mountains to the north and the east. Their position in the Engineer Mountain quadrangle is due chiefly to the fact that the upper parts of most valleys here lie in comparatively soft rocks. Where the underlying rock is granitic, as in the upper part of the valley of Cascade Creek near Grizzly Peak and on the more gentle slopes in the eastern third of the quadrangle, lakes are numerous. Some of these lakes lie in basins in which bed rock outcrops on all sides above the water level, but more commonly a part of the lake rim consists of soil and drift. In the basins of some of the larger lakes the water level has been considerably raised and the water-covered area greatly increased by artificial dams. The most notable example is the Ignacio reservoir (fig. 4), which covers the site of several lakes on the rock-cut terrace between Animas River and Hermosa Cliffs.

Hanging valleys.—Good examples of hanging valleys are found on both sides of the canyon of the Animas—such as the valleys of Tank Creek and of the small stream flowing from the west half a mile above Canyon Creek—and along Hermosa Cliffs—such as the upper valley of Elbert Creek. The grade of each of these valleys is comparatively low in its upper part but becomes notably steeper within half a mile or more of the valley to which it is tributary.

Moraines and drift.—Glacial drift is widely distributed over the area represented on the geological map as having been occupied by ice of the later epoch. In many places it consists of isolated erratic bowlders, the largest observed being 20 feet in diameter; in other places it is composed of small, irregular patches of sand and gravel, including rounded and subangular bowlders, some of which have well-marked striations. In a few places the drift is thick enough to conceal the underlying rocks wholly or in part. Within these areas its composition is that of typical glacial deposits—that is, it is made up of clay, sand, gravel, and bowlders, rarely showing stratification and including some striated pebbles or bowlders. The material in such areas has been mapped as heavy drift (moraine).

In most places where moraines are found the general slope of the surface is too great to permit any marked irregularity in topography such as characterizes moraines on level or nearly level areas; in a few places, however, the irregular hummocky topography is somewhat clearly marked, as in the large area south of Engineer Mountain and in the lower part of Straight Gulch. Moraines in the form of ridges occur on both sides of Canyon Creek approximately parallel to the course of Animas River, at elevations ranging from 9100 to 9800 feet, and in the valley of the East Fork of Hermosa Creek, where they extend in a nearly east-west direction at elevations ranging from 9500 to 9800 feet. The other areas shown on the map consist either of a succession of hillocks and short ridges, such as the U-shaped moraine near the Old Tollgate in the valley of the East Fork of Hermosa Creek, or of an irregularly disposed layer of drift on a somewhat steep slope, such as is seen on the northward-facing slope of the same valley. The entire amount of drift remaining in the quadrangle is small; its maximum thickness is probably not more than 100 feet; its average thickness in the areas covered is probably not more than 50 feet.

EXTENT OF LATEST GLACIATION.

The area covered by ice in the latest stage of glaciation was a little more than one-third of the area of the quadrangle, or about 86 square miles. The surface of the ice ranged in elevation from about 13,000 feet above sea level at the head of tributaries of Cascade Creek to 9200 feet along Hermosa Cliffs at the south boundary of the quadrangle, the average gradient being thus about 220 feet to the mile. The gradient for the greater part of the way, however, is much less than this, averaging but little over 100 feet to the mile in the southern half of the glaciated tract. The elevation of the surface of the tongue of ice that passed down the valley of the East Fork of Hermosa Creek ranged from 10,200 feet where it left the valley of Cascade Creek to about 8725 feet below the junction of the North and East forks, an average gradient of about 230 feet to the mile.

The ice was thickest in the canyon of Animas River and in the lower part of the canyon of Cascade Creek, reaching a maximum of nearly 2500 feet. On the broad terrace between the canyon of the Animas and Hermosa Cliffs its maximum thickness was about 1500 feet; in the small valley heading near Blackhawk Peak, 500 feet; on the divide above Coalbank Hill, 700 feet; and in the tongue extending down the East Fork of Hermosa Creek, 700 feet. The average thickness for the entire glaciated area was probably from 1000 to 1200 feet.

DRIFT OF AN EARLIER STAGE OF GLACIATION.

Patches of glacial drift and scattered erratic bowlders are found outside of what appear to be the limits of the latest glaciation. This drift, which is believed to have been deposited during an earlier stage of glaciation, occurs in largest amounts in the seven small areas shown on the geological map. At these points the deposit has the characteristic heterogeneous composition of glacial drift, including some striated bowlders. The proportion of striated bowlders, however, is smaller than that commonly seen in drift of the latest stage. Although these patches of drift have somewhat irregular surfaces, they are more even-topped than those of the later drift. Moreover, the features of the upper parts of the valleys in which they lie are less clearly characteristic of glaciation than those of valleys that were occupied by recent glaciers—that is, the valley heads are either not at all or but slightly cirque-like, the products of weathering are more abundant, and the cross sections are in general more nearly V-shaped. Besides these patches that are regarded as earlier drift there are scattered erratic monzonite bowlders at other points, as, for example, on the northward-facing slope of East Fork of Hermosa Creek 200 to 500 feet above the limit of the moraine of the latest drift, and on the west side of the valley of Hermosa Creek a little more than half a mile below the junction of North and East forks, up to about 400 feet above the edge of the terminal area of the last glaciers. These erratics, which include monzonite derived from the head of Cascade Creek, although not affording the definite proof presented by striated bowlders, nevertheless, by their positions and their shapes (which are usually subangular instead of well rounded), indicate that at an earlier stage the tongue of ice from the valley of Cascade Creek reached a much higher elevation and covered an area much larger than it did at the later advance.

If reliance can be placed on these very meager data it may be inferred that in the earlier stage glaciers must have filled practically all the valleys in the neighborhood of Hermosa Mountain, in addition to the areas covered by the later ice sheets, and that the general level of the surface of the ice was then not less than 400 to 500 feet higher than in the later stage. If this inference is correct, the area of earlier glaciation in the Engineer Mountain quadrangle was probably 50 to 75 per cent greater than that covered by the later glaciers.

AMOUNT OF DRIFT AND RATE OF RETREAT OF GLACIERS.

The meagerness of the drift in the Engineer Mountain quadrangle is due in part to the fact that with the exception noted there is no terminus within the quadrangle and in part to the fact that the erosion by glaciers was small and yielded a comparatively small load of débris. It should be remembered, however, that the amount of drift left in a given area depends in part on the rapidity with which the ice withdraws and the uniformity or lack of uniformity in the rate of its retreat. It is impossible to say whether the withdrawal from the Engineer Mountain quadrangle was rapid or not, but the absence of a well-marked series of recessional moraines seems to indicate that the rate of retreat was somewhat uniform. It is true that some irregularity of rate is indicated by small deposits which are of the nature of recessional moraines; as, for example, the low hills, U-shaped in general plan, near Old Tollgate, in the valley of East Fork of Hermosa Creek. The number of drift forms of this type is comparatively small, however, and it seems probable that irregularities in the rate of retreat were not pronounced.

AGE OF THE GLACIAL DEPOSITS.

The deposits of the latest glaciers probably correspond in age with the Wisconsin stage of glaciation in the Mississippi Valley. This correlation is made because of the small amount of change that has taken place since the disappearance of the ice, as shown by the abundance of unweathered striated bowlders in the drift, the numerous exposures of polished and striated surfaces, and the small amount of postglacial erosion in stream channels.

The age of the earlier drift can not be fixed accurately from observations made in this quadrangle. From studies made in the Telluride quadrangle, to the north, it seems probable that the earliest glacial deposits there were made at a time sufficiently remote to permit a subsequent reduction in the general level of the upper parts of the glaciated valleys amounting to perhaps 1000 feet. Other glacial deposits in that quadrangle clearly belong to a stage which is earlier than the most recent but which seems to be somewhat later than that of the earliest deposits. It is not possible with the data now at hand to differentiate clearly two distinct earlier stages of glaciation, but it is nevertheless necessary to recognize the fact that the earlier drift does not all appear to be of the same age. The earlier drift in the Engineer Mountain quadrangle seems to belong to a stage of glaciation somewhere between the earliest and the latest that occurred in this general region. The chief reasons for this conclusion are the following:

(1) These deposits lie on slopes and extend in places down to the bottoms of the valleys, showing that the valleys have not been deepened at these points since this drift was deposited. In the quadrangle to the north, on the other hand, the oldest drift occurs only on the tops of hills, ridges, and mesas, indicating that much erosion has occurred in the intervening valleys since the deposits were laid down.

(2) That the older drift in the Engineer Mountain area was not deposited at the latest stage is shown, as indicated above, by the fact that the upper parts of the valleys on whose slopes it occurs have been so much weathered and eroded as to obliterate the features that usually characterize the valleys that were occupied by the latest glaciers.

POSTGLACIAL GEOLOGY.

By Whitman Cross.

LANDSLIDES.

The landslide masses of the Engineer Mountain quadrangle are small in comparison with those of the Rico, Telluride, Silverton, Ouray, and Needle Mountains quadrangles, which have been described and illustrated in published folios. The local landslides are, however, of interest as representing various conditions and as affecting several different formations. In general, the masses that are mapped are covered by forest growth and are therefore not recent. They consist of sedimentary rocks representing former projecting points that were made unstable by some cause not readily determinable. Although the initial rock falls took place at a remote time the shattered condition of the landslide blocks has rendered them permeable to water, and permeation has led to further minor movement of many masses. Fresh scars testify to recent slumps about many of these masses. The features of the older slides have been gradually obscured and obliterated. Before their topographic detail was completely effaced the masses resembled strikingly the forms common in accumulations of glacial débris.

In the east branch of Cascade Creek, traversed by the trail to Silverton, near the northern boundary of the quadrangle, there is a landslide mass of La Plata sandstone of somewhat unusual relations. It lies in the lower part of the valley and the slide took place down a dip slope of not more than 10°. Probably this slip was caused by the saturation of the shale layers on which the upper massive La Plata sandstone rests.

About 2 miles north of Engineer Mountain, between the forks of another eastern branch of Cascade Creek, a portion of a prominent point of the red Cutler beds has become detached and has slipped in large sections down the slope, the separate masses lying at different distances from the point of detachment. The rear masses are separated at the surface from rock in place by crevices, without great dislocation. The front part has been broken off. Further sliding is undoubtedly in progress at this locality.

On the eastern slopes of the Rico Mountains, at several points, there are small landslide masses, only a few of which are represented on the map. In most of these the material that has fallen represents a ledge of intrusive porphyry, the supporting soft sedimentary rock having been worn away.

A landslide of unusual character is represented on the west slope of Flattop, where a mass of soft Cretaceous shale with a small sill of intrusive porphyry has been dislocated and has slipped in an irregular, streamlike body into the valley of Barlow Creek. This débris effectively obscures the contact between the large quartz trachyte and monzonite porphyry masses of this mountain.

On the west slope of Graysill Mountain a great amount of landslide action has taken place. The detritus has been projected into and largely filled the basin of an eastern branch of Hermosa Creek, where it is mingled with glacial matter.

The great scarp of Hermosa Cliffs has furnished many small rock falls, most of which have so disintegrated that they are scarcely distinguishable from ordinary talus accumulations. Near Castle Rock Spring, however, one landslide mass is of more distinct outline and has been represented on the map.

On the sloping sedimentary plateau east of Animas River and north of Canyon Creek many landslides have occurred on the dip slopes of the Hermosa formation. The principal areas of such débris are within the Needle Mountains quadrangle; only a part of one lies in the Engineer Mountain area.

ROCK STREAMS.

Nature of material.—The form of landslide débris that is distinguished on the map as "rock streams" is very common in the San Juan Mountains. It has been described and illustrated in considerable detail in the Silverton folio and is treated at length in a paper on landslides by Ernest Howe.[a] The rock streams of the Engineer Mountain quadrangle are described fully in that paper.

A rock stream is regarded as a landslide of special character—a rock mass which was completely broken up in falling and whose débris acquired a momentum so great that it became a rapidly flowing body and descended in streamlike form far beyond the normal limit of a landslide mass. Figures 3, 8, and 9 illustrate the streamlike outline and certain details of surface configuration which suggest and are in fact due to the motion of the mass. Many rock streams show striking resemblance to glaciers.

Nearly all the rock streams of this quadrangle are composed of material derived from intrusive bodies of quartz trachyte. The sills or laccolithic masses of this rock are intercalated between relatively soft sedimentary rocks. Recent glaciation is believed to have produced a very rugged topography, especially at Engineer Mountain. At several places huge masses of quartz trachyte have fallen from cliffs or projecting spurs and broken at once into relatively small fragments, which formed a mass of débris that has moved as a stream far down the slope. The extensive jointing of the intrusive bodies is thought to have facilitated the thorough breaking up of the falling mass.

Engineer Mountain.—Figures 7, 8, and 9 illustrate the conditions at Engineer Mountain which have led to the notable rock streams outlined on the map. Figure 7 shows the eastern face of the mountain. Here the base of the quartz trachyte mass dips away from the point of view and this fact seems to give a stability to the cliffs of intrusive rock which is lacking on the other sides. On the north face of the mountain, seen in figure 8, there is a broad cirque, the floor of which is covered with rock-stream material of very strongly marked and characteristic features. The stream extends for some distance into the forest.

The western slope of Engineer Mountain, shown in figure 9, does not now present so rugged features as do the other sides, but if the débris seen in the figure could be restored to the mountain it is plain that the peak would be of very striking relief. When it is remembered that the quartz trachyte intrusion rests on a base that is inclined several degrees toward the point of view of figure 9, it can be easily comprehended how the columnar jointing at right angles to the base has assisted in producing a condition of unstable equilibrium for projecting masses.

Most of the rock streams of the mountain are at least 50 feet thick and some of them greatly exceed that thickness. It is estimated that the rock-stream débris about Engineer Mountain equals one-fourth of the rock now in place.

Sliderock Ridge.—Conditions peculiarly favorable for rock streams existed on the faces of Sliderock Ridge after the disappearance of the recent glaciers. The various quartz trachyte intrusions here rest on soft shale and are now above timber line. The jointed condition of the quartz trachyte has led to softening of the shale by snow and rain water, and at many times and places great masses of the intrusive rock have slipped from their bases and plunged in streams down the slopes. Figure 3 represents two very striking streams on the east side of the ridge; figure 5 gives a distant view of the extensive stream on the western face. The form of this stream has been modified by a creeping of the débris down the shale slope, a movement still in progress at several points.

Graysill Mountain.—The great quartz trachyte sill of Graysill Mountain rests upon the red beds of the Cutler formation, but conditions for rock streams have not been so favorable here as at the other localities discussed. One very sharply outlined stream occurs in the cirque on the north face of Grayrock Peak and smaller ones may be distinguished at places indicated on the map.

Other streams.—A few small rock streams occur about Hermosa Peak and in the Rico Mountains, but these are comparatively insignificant and deserve no special notice.

ALLUVIUM.

The surficial deposits of gravel, soil, and swamp land represented under one color pattern on the map have accumulated under various conditions, most of which are clearly suggested by their place or manner of occurrence.

Among these deposits are the gravel and bowlder beds of Animas and other deep canyons. These consist largely of flood-plain deposits of the principal streams in the wider spaces of the canyon. Upon the gravel benches some of the

[a] Prof. Paper U. S. Geol. Survey No. 67, 1909.

side branches have laid down their flood burden in low torrential fans.

The parklike area called Purgatory, which looks like beautifully smooth bottom land at a little distance, is in fact principally a very rough torrential fan of Lime Creek. A similar area lies in the bottom of Lime Creek canyon at the southeast base of Potato Hill.

The broad upper valley now traversed by Elbert and Little Cascade creeks contains many patches of arable land which are cultivated. Some of the alluvial deposits of this valley about the former Ignacio Lakes are now drowned by the reservoir. Others are stream bottom lands and a considerable portion is wash from Hermosa Cliffs.

In Hermosa Park and along the East Fork there are gravel beds, partly soil covered, situated at too great an elevation for most crops. The highest alluvial deposits are in the swampy tract on the divide between Dolores River and Hermosa Creek.

TERTIARY IGNEOUS ROCKS.

The Mesozoic and upper Paleozoic formations of the northern part of the quadrangle have been intruded by many igneous masses, which are represented on the map. All of these are undoubtedly of Tertiary age, as has been shown in folios on the Telluride and other quadrangles where similar rocks occur. These rocks are so far removed from the pre-Cambrian intrusives in age and in mode of occurrence that they will be treated independently. The rocks will be described under the headings used on the map.

MONZONITE PORPHYRY.

Occurrence and distribution.—The part of the Engineer Mountain quadrangle that belongs topographically to the Rico Mountains is characterized by numerous intrusive masses of monzonite porphyry of character identical with that of bodies which are equally abundant in other parts of that mountain group. The Rico Mountains are in fact due in large degree to the great aggregate mass of these intrusives. The rocks and their occurrence have been described in detail in the report on the geology of the Rico Mountains by Cross and Spencer.

The occurrence of these porphyries in sills, dikes, and crosscutting or forking bodies is clearly illustrated by the map. It will be noted that the two largest masses, namely, those of Flattop and Hermosa Peak, occur farthest from the Rico center. It is probable though not demonstrable that these masses belong to the Rico center, but equally large laccoliths of the same rock occur in Grayhead and Ruffner mountains, in the Telluride quadrangle, and in other localities far from any particular center of laccolithic intrusion.

The horizons of intrusion in the Rico Mountains range from the lower Paleozoic to the Cretaceous. Apparently the Dakota sandstone was the most favorable zone for intrusion, situated as it is beneath the great mass of Mancos shale and consisting itself of alternating sandstone and shale strata. Both monzonite porphyry and quartz trachyte intrusions occur at this horizon in Hermosa Peak and Flattop.

By reference to figures 4, 5, and 6 the reader may gain some idea of the massive character and the general appearance of these large outlying bodies. They are practically of laccolithic type. In figure 5 may be seen the top and the bottom of the Flattop laccolith.

The mass of Flattop is distinctly laccolithic in form, though not of typical symmetry. Beneath the summit it is 1200 feet in thickness. Its rapid thinning out to the southeast is shown on the map. It is also well exhibited in the Telluride quadrangle, on the north and east. The general horizon of intrusion of this porphyry is the arenaceous shale member of the Dakota, which separates two relatively massive sandstones. The Hermosa Peak mass was probably of laccolithic form and was intruded at the top of the Dakota sandstone.

There is but slight metamorphism to be observed in connection with any of the monzonite porphyry intrusions. Fragments of foreign rock are also rare in most of them.

Character.—The average rock of these intrusions is a very distinct porphyry of generally light-gray tone with nearly even balance between phenocrysts and groundmass. The most abundant mineral occurring as phenocrysts is lime-soda feldspar, usually labradorite or andesine, in stout white crystals. Few of these are as much as 1 centimeter in diameter and most are much smaller. Accompanying these crystals are prisms of common hornblende and in some rocks hexagonal tablets of biotite. The gray, megascopically felsitic groundmass is a holocrystalline, usually microgranular mixture of orthoclase and subordinate quartz, with but small amounts of the dark silicates. Plagioclase appears in the groundmass but rarely.

The amounts of plagioclase and orthoclase in these porphyries are on the whole so nearly equal that they must be referred to the monzonite group, intermediate between diorite and syenite. Their quartz content makes them strictly deserving of the qualifying term quartz bearing. The usual accessory minerals are present in very small amounts.

As a consequence of the occurrence of this porphyry in bodies of many different sizes and shapes it exhibits also great variety in texture. In the larger masses the plagioclase and hornblende phenocrysts are distinct from the groundmass, and the porphyritic texture is therefore plain, but in many dikes and thin sills and in contact zones of the larger bodies in general the phenocrysts are much smaller. The rock is therefore less evidently porphyritic and is darker in color through the smaller size of the femic silicates.

MONZONITE.

Occurrence.—On the northern border of the quadrangle, where it is crossed by Cascade Creek, there is a small part of a large stock of monzonite, the greater portion of which lies in the Telluride quadrangle. The mass is irregular in form and reaches a maximum diameter of about 4 miles. Grizzly and San Miguel peaks and Rolling Mountain are composed mainly of this rock, and the great cirque at the head of Cascade Creek is excavated in it. The contacts of this mass are in most places abruptly crosscutting, like the southern one represented on the Engineer Mountain map. This contact visibly cuts through the formations from the McElmo (Jurassic) into the Mancos (Cretaceous) shale, and in the Telluride quadrangle the mass penetrates the Telluride conglomerate and San Juan tuff, proving the Tertiary age of the intrusion.

In figure 6 is illustrated the rugged form of Grizzly Peak, standing in contrast with the smooth detritus-covered slopes of the adjacent Sliderock Ridge, which is made up of other rocks. On the north slope of Grizzly Peak a wedgelike arm of the monzonite steeply upturns a mass of Telluride conglomerate and San Juan tuff. This relation may be seen somewhat indistinctly in figure 6.

This monzonite stock corresponds in character and dimensions with several other masses of monzonite, diorite, gabbro, or syenite in the Telluride quadrangle and in the central portions of the Rico and La Plata mountains. In all these masses the granular stock rock is found to be more recent than any intrusive porphyries with which it comes into contact.

Character.—The rock of the stock here under consideration is a medium to coarse grained dark-gray granular mass consisting of labradorite and orthoclase in nearly equal amounts, with a variable and subordinate content of quartz, these white or colorless constituents being approximately equal in amount to the dark silicates—augite, hypersthene, and biotite. These three occur in variable proportions, the biotite being, however, in all places the least important element.

The mass is not uniform in constitution, the northern portion being much richer in feldspar and in quartz. In the Telluride folio it was called quartz monzonite. The various facies of the mass grade into one another in most places without abrupt transitions.

Metamorphism.—In the vicinity of the monzonite stock near Cascade Creek the various sedimentary beds traversed are considerably metamorphosed for a distance of several hundred yards from the intrusive mass. Shales of the Mancos and McElmo formations are altered into dense, hard greenish hornstone-like rocks. This change is accompanied by the formation of epidote, augite, and other less abundant silicates and by a considerable increase in the quartz content of the rocks.

QUARTZ TRACHYTE.

Occurrence and distribution. — The rock called quartz trachyte on the map is an intrusive that is comparable with the monzonite porphyry in all features of its occurrence. The large masses of Engineer and Graysill mountains are thick sills or laccoliths intruded somewhat irregularly in the Cutler formation. Thin sills of the same rock penetrate the Rico formation and the upper part of the Hermosa formation in the valley of Cascade Creek. The uppermost intrusions are in the Cretaceous Mancos shale or in the Dakota sandstone of Sliderock Ridge.

In figures 7 and 8 the lower contact of the quartz trachyte mass of Engineer Mountain is seen. Graysill Mountain exhibits a large mass of the same rock, and in the northern portion of the mountain a part of the sedimentary cover is still visible, the mass wedging out to the north, as represented on the map.

The thick sill of Hermosa Peak is intruded in the Dakota sandstone at the same general horizon that is occupied by the laccolith of monzonite porphyry forming the summit. It is believed that the mass at the summit has been tilted by the other intrusion, but proof of the relative age of the two was not obtained.

The tendency of the quartz trachyte to invade a sedimentary formation along some favorable plane of separation is strikingly illustrated by a thin sill in the La Plata sandstone, which is practically continuous from Section Point for several miles eastward, though not represented on the map for the whole distance owing to the exaggeration which would be required for its expression.

The quartz trachyte masses of the Engineer Mountain quadrangle were evidently intruded at about the same time as the monzonite porphyry bodies and under the same conditions. It is probable that the quartz trachyte is slightly younger than the porphyry, but the place, in Flattop, where the rocks probably occur in contact is obscured by landslide débris. The quartz trachyte is faulted in Graysill Mountain but appears to be later than a small fault on the west side of Dolores River, for a sill of the intrusive ends at this fault plane.

No exposure of a rock closely comparable with this quartz trachyte has been observed elsewhere in the San Juan region, its restriction to this area notably contrasting with the wide distribution of rocks of the monzonite porphyry type.

Character.—The quartz trachyte is an ash-gray or light-pinkish rock exhibiting as a rule a few more or less tabular feldspar phenocrysts and minute black biotite flakes in a very strongly dominant groundmass. A trachytic habit is pronounced in the larger bodies, due to a rude parallelism of the feldspar tablets, a texture which is barely discernible in the groundmass. In the contact zones and in some other places a fluidal texture is apparent. The rock of the smaller masses has generally the aspect of a felsite porphyry.

Microscopical examination shows the rock to consist mainly of alkali feldspars and a highly sodic plagioclase with an important but often exceedingly inconspicuous amount of quartz. These constituents make up more than 90 per cent of the mass of all the various bodies. The other minerals noted are biotite, hornblende, augite, magnetite, apatite, and titanite. Of these only the biotite is especially characteristic of the rock.

The feldspar phenocrysts are mainly oligoclase or albite-oligoclase, though orthoclase, anorthoclase, and perhaps andesine are believed to occur less commonly. The groundmass feldspars are partly soda orthoclase and partly anorthoclase, which occur in prismoids or overlapping scales whose exact character is difficult of determination. Quartz occurs between these feldspars in minute, irregular interstitial particles as a cement. In some places the quartz is developed in anhedral grains more like those of the monzonite porphyry. Rarely clusters of quartz grains make this mineral assume almost the rôle of a phenocryst, but such aggregates have not been anywhere recognized megascopically.

The term trachyte is applied to this rock because its megascopic appearance and microscopic texture are as a rule typically trachytic—that is, the groundmass has a marked fluidal fabric and in many places the more or less tabular feldspar microlites are nearly parallel in position, causing a satiny sheen and making the texture megascopically prominent. The rock thus stands in marked contrast with the monzonite porphyry, which has a notably granular groundmass.

Chemical composition.—A specimen of fresh and typical quartz trachyte from the southeast slope of Grayrock Peak has the following chemical composition:

Analysis of quartz trachyte from Grayrock Peak, Colorado.

[Analyst, George Steiger, U. S. Geological Survey.]

SiO_2	70.73
Al_2O_3	14.22
Fe_2O_3	1.59
FeO	.59
MgO	None.
CaO	.72
Na_2O	4.96
K_2O	5.57
$H_2O-110°$	1.16
$H_2O+110°$	.32
TiO_2	.34
ZrO_2	.04
P_2O_5	.03
MnO	.11
BaO	.01
	100.39

This analysis confirms the statement, based on microscopical study, that the rock consists principally of potash and soda feldspar and quartz. The amount of quartz must be nearly 20 per cent. No magnesia was found by the analyst, but the rock must contain a small amount in the biotite, which does not exhibit the properties of the iron-rich variety. The sample taken for analysis probably contained less than the average amount of biotite.

The quantitative classification of this rock places it in the magmatic subrang liparose (I.4.1.3). Among rocks whose chemical composition is known this quartz trachyte is very closely related to quartz keratophyre (bostonite) of Marblehead Neck, Massachusetts (Washington and Sears), quartz syenite porphyry of the Little Rocky Mountains, Montana (Pirsson), and syenite porphyry of Clinton County, New York (Cushing).

LAMPROPHYRIC DIKE ROCKS.

Distribution and character.—The northwestern part of the Engineer Mountain quadrangle is characterized by many small dikes of dark and mainly aphanitic rocks, the nature of which can be determined only by microscopical examination. The more prominent of these are represented on the map. Most of these dikes are only a few feet wide and some measure less than a foot.

The lamprophyric rocks are of several kinds, but all exhibit much similarity in the character of some of their constituents. The most important and distinct varieties are monchiquite, augite camptonite, and kersantite.

Monchiquite.—The most distinct and also most abundant group of lamprophyric dike rocks is characterized by a dense black groundmass which strongly preponderates over the dark phenocrysts of green augite. The groundmass is almost glassy in appearance in some specimens and has a smooth or conchoidal fracture.

Microscopical study shows that augite and olivine are abundant in a groundmass of brown hornblende, augite, and occasional brown biotite, with magnetite and apatite, all of which are embedded in an isotropic base, brownish as a rule but in some slides colorless. Pirsson has shown that the corresponding base of similar rocks is the mineral analcite. The augite as seen in thin sections is pale green and in all these rocks it is more abundant than hornblende or biotite. Olivine occurs only in phenocrysts and is more extensively altered than the other minerals.

The monchiquite dikes are restricted to the vicinity of the masses of quartz trachyte, which are cut by some of them. It is believed that the two rocks represent complementary differentiation products. The occurrences in the Engineer Mountain quadrangle seem to prove that monchiquite and bostonite are not necessarily connected in origin with foyaitic or theralitic parent magmas, as some eminent petrographers have supposed.

Augite camptonite.—Another group of dikes is composed of rock which is nearly related to the monchiquites as to the constituents augite, hornblende, biotite, and olivine but which has a matrix of plagioclase feldspar that is generally more abundant than the base of the monchiquites. The augite camptonites are gray rather than black and their holocrystalline texture is in most specimens evident on examination with a hand lens. The feldspathic base in some specimens is very subordinate in amount and the rock closely resembles monchiquite.

The rock in some dikes of this group contains a small amount of orthoclase and quartz and in certain rocks the orthoclase becomes sufficiently abundant to bring them almost into a monzonitic group of lamprophyres.

The augite camptonite dikes occur principally on the eastern slope of the Rico Mountains and in the valley of the North Fork of Hermosa Creek. The dikes crossing the broad ridge southeast of Grayrock Peak also belong to this group.

Kersantite.—A single dike in a small western tributary of Cascade Creek entering that stream at an elevation of 9850 feet is so rich in brown biotite, with subordinate augite, that it seems to be properly referable to kersantite. The character of the cloudy and somewhat decomposed feldspathic base is not fully determinable and possibly the rock should be classed as minette.

Andesite.—Two dikes near the northern quadrangle line north of Jura Knob, which are grouped with the lamprophyric dikes on the map, are really more closely allied to pyroxene andesite through the abundance of a microlitic plagioclase feldspar groundmass, but the dark-brown biotite of one of them has so strongly the habit of that mineral in the camptonites and monchiquites as to indicate a relationship to those rocks.

STRUCTURE.

Introduction.—The geographic position of the Engineer Mountain quadrangle is such that its sedimentary formations naturally exhibit in their attitudes the broad San Juan structure modified by uplifts of more local extent about the Needle, Rico, and La Plata mountains. Some structural features—such as those seen in the pre-Cambrian rocks and in the most recent faults—are not distinctly related to any of these central movements. The structures belonging to different epochs or originating in distinct centers will be discussed separately.

Structure of the Archean schists.—The Archean rocks belong to a large and complex system of which so small a part is exposed in the San Juan region that no comprehensive statement can be made as to the relations of the local structure to that of the corresponding schists and gneisses elsewhere in Colorado. It is plain, however, that in degree of dynamic metamorphism and in complexity of structural relations the Archean schists of the Animas Valley are comparable with those of other portions of the Rocky Mountain province.

The schists traversed by the Animas Canyon in the Engineer Mountain quadrangle strike in general northeast-southwest and dip to the southeast with variable though great steepness, in many places approaching verticality and in others passing it so that they dip steeply to the northwest. The huge masses of granite and gabbro that have been intruded into the schists have disturbed their structure somewhat, but far less than might be reasonably expected in view of the fact that the visible granite greatly exceeds the schists in volume. Indeed, the Twilight granite mass itself possesses a gneissoid texture of fluidal origin, which harmonizes with the earlier structure of the intruded schists.

Near the southern line of the quadrangle the schists bend until the strike is east-west, but they exhibit many local irregularities in structure as well as extensive brecciation, both features being presumably due to the granite mass, which approaches within half a mile of the quadrangle border. Only a few square miles of this granite mass are exposed, as it is covered by Paleozoic beds on the west, south, and east, and it may be of great size.

The schists extend up the Animas Canyon through the heart of the Needle Mountains with a strike somewhat east of north, turning to nearly east-west in the southern zone of the Silverton quadrangle, beyond which they are covered by volcanic rocks.

Structure of pre-Cambrian sediments.—The quartzite and slate bands of the Uncompahgre formation north of Potato Hill represent, as has been said, closely compressed infolded and sheared beds of a synclinorium, bounded on each side by faults which separate them from schists. This structure can not be made out in the Engineer Mountain quadrangle but is shown in the Needle Mountains quadrangle, where the synclinorium widens and partly opens out, displaying some of the compressed folds of the complex. For details of this structure the reader is referred to the Needle Mountains folio.

From all available evidence it appears that the Uncompahgre beds seen in the Engineer Mountain quadrangle belong to an east-west zone of much crushed and sheared rock which extends eastward across the north part of the Needle Mountains and westward an unknown distance beneath the Paleozoic formations. The relations are shown in structure section B–B. The westward extension is demonstrated by the existence in the heart of the Rico Mountains, in the valley of Silver Creek, about 2 miles northwest of Blackhawk Peak, of typical quartzites of the Uncompahgre formation in small blocks thrust up by faults near the center of the uplift, as described in the Rico folio.

From the exposures in the Needle Mountains quadrangle it is probable that the Uncompahgre strata are present beneath the Paleozoic formations to the north of the outcrops in the Engineer Mountain area as far as a profound fault which separates them from schists. This fault runs nearly east-west and is about 1 mile south of the Telluride quadrangle line.

A consideration of the degree of deformation to which the Uncompahgre strata were subjected makes the conclusion plausible that these beds are of pre-Cambrian age.

Structure due to Paleozoic or Mesozoic movements.—The various earth movements occurring between Cambrian and Tertiary time are not recorded in the structure of the Paleozoic and Mesozoic formations except for relations of overlap and local unconformity which are almost insignificant. Two faults which record movement in the interval between Dolores (Triassic) and La Plata (Jurassic) time were found southwest of Hermosa Peak. To the erosion following this displacement is due the relative thinness of the Dolores between these faults, as represented on the geological map and on section A–A. The La Plata above is slightly disturbed by later movements on these fault planes.

San Juan dome.—As has been noted, the sedimentary formations dip broadly away from the San Juan mountain region on the north, west, and south. The structure here is therefore comparable to that of a huge dome, but the symmetry of the dome was probably broken by local uplift at certain centers within the broader area. Thus the Needle Mountains district appears to be a center of such local movement. In the Engineer Mountain quadrangle it is scarcely possible to recognize the tilted position of any beds as due to the general San Juan elevation alone, although all the beds have undoubtedly undergone deformation from that movement. The more local uplifts obscure the effect of the broader one.

Needle Mountains dome.—The dips of the Paleozoic formations in the eastern half of the Engineer Mountain quadrangle are due mainly to the Needle Mountains uplift. The thin formations that rest on granite or schist in the extreme southeastern portion of the quadrangle, on both sides of Canyon Creek, dip west of south at an angle that carries them down to Animas River a few miles south of the quadrangle line. These same formations extend eastward along the south slope of the Needle Mountains and rise to an elevation of 13,000 feet opposite the center of that group.

Northward along the west side of the Animas from the southern border of the quadrangle the strike of the Paleozoic beds gradually changes and the dip becomes first westerly and, farther north, near the center of the quadrangle, northwesterly. Opposite Potato Hill the beds are more steeply upturned and their general structure is modified by some local folds. Their structure is shown on the geological map by the dip and strike symbols and by the distribution of the formations.

The zone of folding and faulting above the belt of Uncompahgre beds breaks up the simple domal structure, but this appears again in the valley of Cascade Creek and east of it, adjacent to the Telluride quadrangle, where the dips are very regular to the northwest.

The structure here described is illustrated in figures 2, 4, 7, 8, 14, and 15.

Rico Mountains dome.—In the northwest quarter of the quadrangle the structure is plainly due to the uplift centering in the Rico Mountains. This is shown on the geological map by the distribution of the formations and the strike and dip symbols, and also in figures 5 and 6 of the illustration sheet. From figure 5, especially, one can gain an idea of the amount of the uplift. The point of view for this figure, near the summit of Blackhawk Peak, is almost at the top of the Cutler formation. In Section Point, 2 miles away and 700 feet lower, the Dolores and La Plata formations, next above the Cutler, are seen still dipping away under the influence of the domal uplift.

The Rico Mountains quaquaversal fold, which has been described in detail in the Rico folio, is believed to be primarily the result of a local uplift that was genetically related to the broader San Juan movement and augmented by displacement due to a large number of laccolithic intrusions. For the La Plata sandstone at the apex of the dome the structural deformation is estimated at nearly 4000 feet, and the aggregate additional elevation from the intrusions may be about 600 or 700 feet. The dome is 15 to 20 miles in diameter.

On the east the Rico structure dies out or is neutralized by the larger Needle Mountains structure, disappearing only 3 or 4 miles from Blackhawk Peak, west of the median line of the quadrangle. To the south the influence of the Rico uplift may be recognized for about 7 miles from Blackhawk Peak. From that point to the southwest corner of the quadrangle the strata have a slight westerly dip, which seems to belong to the structure of the Needle Mountains uplift.

La Plata Mountains dome.—The La Plata Mountains, carved out of a domal uplift in which intrusive sills and laccoliths play the same part as in the Rico Mountains, are situated a few miles southwest of the Engineer Mountain quadrangle. The dome structure due to the La Plata uplift is not directly evident in the quadrangle, but its influence is seen in the fact that the strata on South Fork of Hermosa Creek do not dip strongly to the southwest. In fact, the beds begin to rise very gently near that stream, and at short distances south and west of the corner of the Engineer Mountain quadrangle northeast dips become pronounced.

Fault zones.—Displacements of Paleozoic or Mesozoic strata on fault planes are not very extensive in the Engineer Mountain quadrangle, and most of those observed fall within one of two fault zones. The first of these to be mentioned is an east-west zone that crosses the northern part of the quadrangle above the belt of buried Algonkian quartzites and slates. In fact, most of these displacements, if not all of them, appear to represent renewed movement on some of the pre-Cambrian faults, affecting the Uncompahgre strata as has been described.

The northern border of the exposed Algonkian beds is a fault that brings them into contact with the Carboniferous Hermosa. The Hermosa beds are upturned against this fault, which passes westward into the sedimentary area, where it appears as a fracture in the crest of an anticlinal fold. The fault was not traced continuously and it undoubtedly passes into a fold, which in turn dies out upward, so that the total disturbance is slight in the Cutler beds.

In like manner the fault north of Coalbank Hill, which dislocates the lower Paleozoic beds about 300 feet, seems to correspond to one of the older faults in the pre-Cambrian complex. This also dies out rapidly toward the west by passing into an anticlinal fold, and it could not be distinguished on the slopes of Engineer Mountain.

A minor fault, shown on the map, between these two larger ones is so nearly in line with the strike of the vertical Uncompahgre beds below that it is believed to have similar relations to an old plane of movement.

The second pronounced fault zone passes in a northwest-southeast direction through Hermosa Park and appears prominently on the map through the repeated dislocation of the Rico formation on North Fork of Hermosa Creek. Here the Rico contacts are successively brought up by step faults from 50 to 150 feet on the northeast side except along one plane. The map represents most of these dislocations as local, but they may extend in both directions farther than they were observed, for their identification in the Cutler beds to the northwest is difficult, owing to the lack of good exposures of these crumbling strata, while to the southeast, in the area of the Hermosa formation, the rocks are hidden by a dense growth of aspen. This fracture zone strikes for the Rico Mountains but does not directly connect with any of the fault systems in that center of uplift. Farther southeast several small faults are displayed in Hermosa Cliffs, and two of these seem to correspond with the outer fractures of the zone crossing Hermosa Park. Actual continuity can not be demonstrated, however, for the faults can not be traced across the forested spaces. All these faults are approximately vertical and appear to represent stretching rather than compression of the strata, being in this respect unlike the dislocations of the first zone described.

Certain small faults affecting the lower Paleozoic beds below Hermosa Cliffs seem possibly connected in origin with the faults of the above-described zone, but a direct connection, if such exists, can not be established on account of the mask of alluvial deposits.

HISTORICAL GEOLOGY.

GENERAL STATEMENT.

The geological history of the Engineer Mountain quadrangle is in most respects very similar to that of adjacent quadrangles, already presented in considerable detail in published folios. The processes by which the rock formations were made, the changes to which they have been subjected, the earth movements by which they have been brought to their existing attitudes, and the erosion by which the land forms of various epochs have been produced were all of wide effect. Only with respect to certain intrusions and the recent physiographic development has the history of the quadrangle been of such local character as to require special treatment. The reader is referred to the Needle Mountains, La Plata, Rico, and Telluride folios for a fuller discussion of the geologic development of the region.

PRE-CAMBRIAN HISTORY.

Archean period.—The schists and gneisses of the Animas Valley record all that can now be known concerning the development of the region prior to the deposition of the sediments of the Needle Mountains group. It is not certain which extremity of the schist section is to be regarded as the upper and which the lower. As appears from the descriptions, the schists have resulted from the metamorphism of at least two kinds of igneous rocks, and there appears to have been some irregular mingling of the different materials. Some narrow dikes of basic rock were intruded into the schists and the whole complex has been crushed and recrystallized, producing the gneisses and schists. This complex is thus comparable to similar masses seen in many other regions and referred to the Archean.

The Twilight granite appears to have been intruded into the schists at a time so much earlier than the injection of the other intrusive rocks that it may be plausibly referred to Archean time.

Deposition of Algonkian sediments. — The quartzites and slates of the Uncompahgre formation belong to the upper part of the sediments called the Needle Mountains group. The lower formation of that group, the Vallecito conglomerate, may have been deposited in the Engineer Mountain quadrangle, but if so it was cut out by the structural movements described.

The total thickness of the Uncompahgre deposits is unknown but was surely several thousand feet. They consisted of quartzose sandstones, clays, and shales with some conglomerate, the alternation of materials testifying to oscillations of level—to shallower and deeper waters. The beds have yielded no fossils to show the life of the time.

The pebbles of quartzite in the Vallecito conglomerate and in certain layers of the Uncompahgre show that land areas adjacent to the Algonkian seas did not exhibit prominently such schists as are now seen in the Animas Canyon. The pebbles are of quartzite and prove the existence of still earlier sediments.

These earlier sedimentary beds, of which no trace now remains in the Engineer Mountain quadrangle, probably belonged to what is called the Irving greenstone, exposed in the eastern part of the Needle Mountains. Although the greater portion of the known Irving formation consists of greenstones and massive diabasic rocks, these are intimately mingled with subordinate quartzites. It is therefore possibly that these earlier quartzites were much more prominently developed in areas from which the sand of the Algonkian sediments was derived.

Folding of Algonkian sediments.—A time of great earth movement succeeded the deposition of the Uncompahgre formation. The beds were uplifted, folded, crushed, and sheared, and also metamorphosed. The principal zone of folding, as shown by the present distribution of the rocks, passed in an east-west direction through the Engineer Mountain quadrangle. It undoubtedly continued westward, for Algonkian quartzites are exposed in the heart of the Rico Mountains. There is no reason to doubt the great extent of the uplift that produced the folding, for the Uncompahgre beds of Uncompahgre Canyon show similar features of structure, formed, no doubt, during the same period.

Intrusion of granite and other rocks.—The Eolus granite batholith and several others in the Needle Mountains area were intruded in the schists after the folding of the Algonkian strata, as is shown by the penetration of quartzites of the Uncompahgre by granite in a few places and by a certain metamorphism of the slates. The staurolitic schists that replace some slates in the Needle Mountains are the product of metamorphism at certain periods of granitic intrusion. The fact that the Eolus granite and the other large intrusive bodies exhibit so little textural modification shows that they were not present at the time of the great metamorphism of the Algonkian sediments. The gabbroic mass of the Animas Canyon is apparently of same general age as the Eolus granite.

EVENTS OF THE PALEOZOIC ERA.

Cambrian erosion, subsidence, and deposition.—Very little is known of Cambrian history in the San Juan region. During the greater part of Cambrian time the Engineer Mountain quadrangle belonged to a large continental area. There was extensive erosion, producing in the end a nearly plane surface. Upon this the Ignacio sediments were deposited in pronounced unconformity with older formations. They are made up mainly of quartz, with very subordinate shales and no limestones. The land areas adjacent to the Ignacio seas can not at present be outlined. The deposits have the character of shallow marine sediments. The trail markings and mud cracks on certain beds probably indicate land at about sea level.

Ordovician and Silurian hiatus.—The only evidence now available concerning the history of the district in Ordovician and Silurian time consists of the fact that the thin Ignacio quartzite is almost everywhere overlain by Devonian beds with apparent conformity. No angular unconformity is known, and overlap of the Devonian beds on the pre-Cambrian rocks, though observed locally, is remarkably rare. It would seem certain from these facts that the region was one of very low relief during practically the whole of these two periods. There can have been no great uplift, for the ensuing erosion would have cut through and removed the Ignacio beds much more extensively.

Elbert sedimentation.—The fishes of the Elbert formation are regarded by Doctor Eastman as of Upper Devonian age. It is probable, then, that the conditions that prevailed during Ordovician and Silurian time continued through the earlier part of the Devonian. The sediments of the Elbert indicate peculiar conditions, varying from place to place. After the formation of impure limestone or sandstone, there appears to have been uplift producing inclosed basins. Probably the climate of the time was arid, as indicated by the salt shales which have been described. Then there was subsidence, resulting in the deposition of earthy limestones, which contain few or no fossils. The conditions appear to have changed gradually to those favoring the deposition of marine limestone with abundant life, represented by the fossils of the Ouray formation. These later conditions seem to have continued through the Ouray epoch and to have extended into the earlier part of the Carboniferous.

Early Carboniferous uplift.—Again the land rose a little above sea level, apparently without folding in this vicinity, and the upper part of the Ouray limestone was subject to some erosion. This may have been marine, from strong currents or wave action. If the limestone actually emerged from the sea its surface was gradually modified by slight erosion and by deep solution crevices. When the limestone again sank below the ocean its surface was exceedingly rough in detail.

Molas sedimentation.—The beds of the Molas formation represent the beginning of a long period of marine sedimentation, which continued through all of Pennsylvanian (upper Carboniferous) time. The reddish color of the Molas sediments may indicate an arid climate for the time immediately preceding their deposition. The deposits filled the solution crevices and erosion channels in the surface of the Ouray limestone. The accumulation of chert derived from the Ouray formation possibly represents the gathering of nodules resulting from the waste or solution of the limestone in adjacent land areas.

Hermosa epoch.—The great series of beds of alternating shale, sandstone, and limestone of the Hermosa formation demonstrates the recurrence of certain conditions from time to time and, in the aggregate, a long-continued subsidence, which permitted the accumulation of over 2000 feet of strata.

Deposition of the Rico and Cutler formations.—Although marine fossils occur in the Rico formation, the general character of the strata indicates that during its deposition the conditions were changing. The marine limestones are thin and subordinate as compared with those of the Hermosa. The sandstones of the Rico are coarse, and the formation includes grits and conglomerates. These testify to elevation and to shore or even continental conditions of deposition. The rare limestones of the Cutler formation are unfossiliferous so far as observed, and intraformational conglomerates of limestone are rather characteristic of that formation. Conglomerates of accumulation are more and more prominent. This change in lithologic character represented in the Rico and Cutler formations suggests that, while no important break in sedimentation took place from the Hermosa to the Cutler, there was gradual uplift, with a cessation of marine conditions, and that in some adjacent tract, not yet located, the elevation resulted in an area which was subjected to extensive denudation. The detritus produced by this denudation was apparently deposited by fluviatile or fresh-water agencies on the marine deposits of the Rico formation.

EVENTS OF THE MESOZOIC ERA.

Pre-Dolores uplift and erosion.—If the Dolores formation is of late Triassic age, as is indicated by its fossils, there is, below the saurian conglomerate, a stratigraphic break which corresponds in time to the greater part of the Triassic period and so much of the Permian as is unrepresented in the Cutler formation. In the Engineer Mountain and adjacent quadrangles the Dolores rests on the Cutler with so nearly conformable relations that the stratigraphic break is scarcely identifiable there. This fact seems to show that during the time represented by the break in question there was in this region a land area of comparatively low relief, where erosion could not have been very effective. On the northern side of the San Juan, however, in the Ouray quadrangle, there is angular unconformity below the Dolores, showing that in that district folding and much greater erosion preceded the deposition of the Dolores. It seems possible that Ouray may be near the southern border of a district of pronounced uplift and erosion.

Triassic sedimentation.—The character of the lower Dolores sediments speaks for the recurrence of land conditions similar to those which prevailed during the Cutler epoch. The limestone conglomerate of the Dolores formation is apparently of intraformational character, representing thin limestones that were broken up in place and mingled with sand and clay. The disconnected and more or less worn bone fragments of the conglomerate also indicate that continental deposition was prevalent in the earlier part of the Dolores epoch. The succeeding fine-grained sandstones may have been shore deposits, but no fossils have been found in them to indicate marine conditions. The upper sandstone of the Dolores appears to represent, in part at least, the great Vermilion Cliff sandstone of the Plateau country.

Post-Triassic deformation and erosion.—The Dolores epoch was closed by another elevation, with resultant erosion. Although this movement was very important, as shown by the overlaps of the La Plata sandstone in many parts of Colorado, there is little evidence of its magnitude in the Engineer Mountain quadrangle or adjacent districts. An erosional break is to some extent indicated by variations in the thickness of the upper sandstone of the Dolores. That faulting took place during this time of uplift is shown southwest of Hermosa Peak, where, as the map exhibits, there are two small faults between which the Dolores formation is greatly reduced in thickness. The La Plata sandstone, resting on this thin remnant of the Dolores, is also slightly displaced on the same lines of fracture, apparently by repeated movement on the old fault planes.

Deposition of the La Plata sandstone. — The La Plata sandstone, of apparent Jurassic age, represents conditions of deposition that were remarkably constant for a long time—conditions that led to the deposition of very fine cross-bedded quartzose sandstone except for a time near the middle of the epoch, during which unfossiliferous limestone was formed. This limestone may have been of fresh-water origin, although there is nothing in the character of the La Plata sediments to indicate the proximity of land areas. The formation is continuous with the great White Cliff sandstone of the Plateau country.

McElmo sedimentation.—During the McElmo epoch there was an alternation of conditions, leading to the deposition of fine-grained quartzose sandstone and of marl or shale with occasional gypsum. Fossils found in this formation on Grand River in western Colorado show that dinosaurs, which were at least closely allied to those of the Morrison epoch, existed in McElmo time in this region.

Lower Cretaceous hiatus.—No evidence of deposits formed during the Lower Cretaceous or Comanche epoch have been found in western Colorado. The conglomerate at the base of the Dakota sandstone rests with apparent conformity on the McElmo formation except at one locality—an exception of unproved importance. On the trail leading eastward from Cascade Creek, near the northern line of the quadrangle, there is an apparent local overlap of the Dakota on different beds of the upper McElmo section. The exposure is not good enough to show whether this relation is due to primary overlap or to thrust faulting. The beds are near a large intrusive stock of monzonite and are considerably disturbed, and it is not safe to infer that there is an original unconformity at this point.

Upper Cretaceous sedimentation.—The cycle of Upper Cretaceous sedimentation, producing the beds ranging from the Dakota to the "Laramie" inclusive, appears to have been of the same general character in the area of the Engineer Mountain quadrangle as in the Durango and other districts to the south. Apparently all older formations of the San Juan region were covered by several thousand feet of deposits in later Cretaceous time—at least there is no known evidence to indicate land areas in this province during that time.

EVENTS OF THE CENOZOIC ERA.

TERTIARY PERIOD.

Post-Cretaceous uplift and erosion.—The San Juan region, including the Engineer Mountain quadrangle, was undoubtedly embraced in the area of uplift that included the whole Rocky Mountain province. This movement finally brought that province above sea level and in many districts produced great folding and faulting. Although a record of this time is almost lacking in the Engineer Mountain quadrangle, a part of it is very clearly preserved in the adjacent Telluride and Silverton quadrangles. The Telluride conglomerate rests upon a peneplain that transgresses all formations from the Cretaceous Mancos to the pre-Cambrian. It thus records in its materials only the later part of a period of enormous erosion which had greatly denuded a large uplifted tract. The Needle Mountains and parts of the San Juan region north of them clearly represent the mountainous district from which the Telluride conglomerate was derived. The relations of the conglomerate to the high summits of the Needle Mountains show that it was probably deposited over the greater part of the Engineer Mountain quadrangle, decreasing in thickness to a minimum in a zone near the present slopes of the West Needle Mountains.

Volcanic eruptions.—The principal events of San Juan development during Tertiary time consisted of great volcanic eruptions, between which there were intervals of quiet when widespread and deep erosion took place. Although volcanic rocks are not present in the Engineer Mountain quadrangle, it is certain that the San Juan tuff, exposed in the Telluride quadrangle, once covered a large part of the Engineer Mountain area. The débris constituting the San Juan tuff was derived from a great volcanic mass of earlier formation, situated at some point in the eastern portion of the San Juan Mountains not yet definitely determined. If the Needle Mountains existed in nearly their present elevation during early Tertiary time, they may have served as a barrier to protect the southeastern portion of the Engineer Mountain quadrangle from burial by the San Juan tuff. The central part of the San Juan region contains a record of a series of eruptions, to which reference has been made, and it seems probable that the eruptions continued during nearly the whole of the Tertiary era.

Igneous intrusions.—The Rico and La Plata mountains represent local centers of igneous intrusion of the laccolithic type. The mountains themselves are in part due to the uplift of sedimentary beds by intruding magmas, but it is clear that a general domal uplift, with upthrust faulting, played an important part in the formation of the Rico Mountains. The eastern summits of the Rico Mountains come within the Engineer Mountain quadrangle, and the domal structure, which has been described and illustrated in some detail, extends for some miles eastward from the base of the mountains.

The effect of the La Plata uplift is less evident in the Engineer Mountain area, but, as has been noted in discussing the structure, the normal southwesterly dip of the strata has been so changed by the La Plata movement that the strata lie in a nearly horizontal position. The intrusive sills and dikes of the Rico center are numerous in the Engineer Mountain area, as is shown by the geological map. The large laccolithic masses of monzonite porphyry seen in Hermosa Peak and Flattop were doubtless intruded in the same general period as the smaller masses directly connected with the Rico center. The large trachyte intrusions of Engineer Mountain, Graysill Mountain, and Sliderock Ridge may be more recent than the monzonite porphyries or may be of earlier age. No evidence has been found to determine the relative dates of their intrusion.

Earth movements.—Aside from the local uplifts of the Rico and La Plata mountain centers a general uplift of the San Juan district took place in Tertiary time, very probably at intervals or in stages, during different epochs. The effect of such movements can not now be differentiated from that of the post-"Laramie" uplift. The faulting of the trachyte sheets of Graysill Mountain shows that movement of this kind took place after the intrusions occurred. These faults are not of great importance and it is not clear how many of the other dislocations represented on the map may be of contemporaneous origin.

QUATERNARY PERIOD.

Glaciation.—The higher portions of the Rocky Mountain region were occupied by glaciers until very recently; indeed, remnants of these glaciers still exist at a few localities in Colorado. Within the last few years evidence has been found in the San Juan region that the recent glaciation was by no means so extensive as that of an earlier ice occupation. The later ice sheets and streams have within their limits obliterated the markings and cleared away the detritus of earlier glaciers, so that one must go above or beyond the boundaries of the more recent ice to find traces of the ice of the older stage. In the course of studies on the lower slopes of the San Juan beyond the morainal limits of the recent glaciers many high gravel plains and terraces and some ancient morainal accumulations have been found which testify to a long and probably complex early glaciation.[a]

Evidence of earlier glaciation in other parts of the Rocky Mountain region has been announced by R. D. Salisbury and associates as a result of a series of special investigations which have been carried on under the auspices of the United States Geological Survey. The extension of these researches into the San Juan district made cooperation desirable, and in 1908 Allen D. Hole was assigned to the special study of the Engineer Mountain quadrangle, under the supervision of Professor Salisbury. Mr. Hole furnished the section on glacial geology given on pages 8 and 9.

Denudation and physiographic development.—The Engineer Mountain quadrangle occupies such a position with relation to the San Juan area that it must have been at least partly covered by volcanic rocks at the close of Tertiary time. The removal of these materials and the deep carving of the sediments beneath them must have been accomplished by streams that have been at work on the volcanic plateau since the Tertiary period. The rate and character of the erosion have been affected by regional earth movements and by the glacial occupation at different times.

The physiographic history of the San Juan region during Quaternary time is extremely complex, deserving special study, and arrangements have been made to have this study begun under the immediate direction of W. W. Atwood in connection with a general geological survey of the region. It is therefore not desirable to attempt here a detailed discussion of the physiographic development of the Engineer Mountain quadrangle, for this will be undertaken by Mr. Atwood.

Landslide action.—One of the processes that has been active in modifying the topography of the quadrangle during Quaternary time has produced several large detrital masses. Under the conditions that prevailed after the last glacial epoch, since the disappearance of the ice, great masses of rock have fallen from undercut cliffs or pinnacles, forming the rock streams or the less fully broken up and disintegrated landslide bodies shown on the geological map. These rock falls have occurred at many different times, and are still liable to happen. It may be said that landslides involving cliffs of the Cutler formation north of Engineer Mountain are still in progress, for many of the crevices separating blocks of the mass are clearly of very recent formation.

ECONOMIC GEOLOGY.

EXTENT OF MINERAL RESOURCES.

The natural resources of the Engineer Mountain quadrangle that may be appropriately considered in this place are not extensive compared with those of adjacent areas. Metalliferous deposits of value have not been found in the Engineer Mountain quadrangle beyond the limits of the Rico Mountains. The valuable nonmetalliferous substances, such as limestone and building stone, are either better developed or may be more easily exploited in the adjacent quadrangles. It therefore seems probable that few of the mineral resources thus far discovered in this quadrangle will be utilized in the near future.

METALLIFEROUS DEPOSITS.

Rico Mountains.—The central portion of the Rico Mountains contains deposits of gold, silver, copper, lead, zinc, and iron ores of several types. The development of the district began about thirty years ago and has continued with varying production to the present time. A report on the ore deposits of the Rico Mountains by F. L. Ransome was published in the Twenty-second Annual Report of the United States Geological Survey, in 1902. The deposits in the Engineer Mountain part of the Rico Mountains were described in Mr. Ransome's report, to which the reader is referred for details. A map accompanying that report embraced several summits situated in the Engineer Mountain quadrangle.

The important mines east of Dolores River in the Rico Mountains include those of Newman Hill, Nigger Baby Hill, and lower Silver Creek. All these are within 1½ miles of the western boundary of the Engineer Mountain quadrangle, but the important metallic deposits of the quadrangle occur only in the drainage basin of Silver Creek.

Near the head of Allyn Gulch, northwest of Blackhawk Peak, there are several prospects or mines on a system of fissure veins. The most prominent of these fissures is the Blackhawk fault, shown on the geological map. Several branch fissures, on which mineralization is more pronounced, occur northeast of the main fault. The Privateer and Leila Davis mines, situated on two of these branch fissures, are indicated on the map. The Little Maggie and Allegheny mines are just west of the boundary of the quadrangle, and the noted Blackhawk mine is near the mouth of Allyn Gulch.

Some prospecting has been done at the head of Deadwood Gulch south of Dolores Peak, but none of the prospects has proved to be important.

Cascade Creek basin.—Adjacent to the monzonite stock, the southern portion of which lies in the Engineer Mountain quadrangle, there has been some mineralization which is probably connected in origin with the stock. Some prospecting has been done on veins that traverse the Dakota and McElmo formations, particularly east of Cascade Creek, but these prospects were long ago abandoned and no information has been obtained concerning the nature of the developments in them.

Pre-Cambrian area.—The pre-Cambrian rocks of the Needle Mountains quadrangle contain a few veins of metalliferous deposits, which have been described in the Needle Mountains folio. In many places in these old rocks in the Engineer Mountain quadrangle, as in pre-Cambrian rocks elsewhere, there is more or less indication of mineral deposition and some prospecting has been done in the schists and granites of the quadrangle, but in no place has any valuable deposit yet been found.

The fault vein between the Uncompahgre quartzite and the Ouray limestone, which passes just north of the summit of Coalbank Hill, has recently been prospected on the Delayed claim. The limonitic material found where the limestone is upturned against the fault is said to contain silver ore and a crosscut tunnel is now being driven to intersect the vein at a point several hundred feet lower. Present developments do not show the existence of valuable ore deposits in this vein.

NONMETALLIFEROUS DEPOSITS.

The abundant limestone in the quadrangle has not yet been put to any large or important practical use. The Ouray limestone is suitable for use as a flux in smelting and a quarry has been opened in it a few miles south of the Engineer Mountain quadrangle, near the railroad. The material has been used at the Durango smelters.

Building stone of good quality could no doubt be obtained at many places in the Animas Canyon within the quadrangle, but no demand now exists that would justify the opening of quarries.

Subbituminous coal of inferior quality occurs in thin seams in the shaly parts of the Dakota sandstone. Unsuccessful attempts to utilize this coal have been made in the Rico and Telluride quadrangles, where it is better developed than in the Engineer Mountain area. There is no coal on the grade misnamed Coalbank Hill, east of Engineer Mountain.

WATER RESOURCES.

The principal perennial streams of the Engineer Mountain quadrangle are Animas River and Lime, Cascade, and Hermosa creeks, all of which are tributary to the Animas. There is but little arable land in the quadrangle and owing to the high elevation not many kinds of crops can be raised. The water of the Animas is ultimately utilized in irrigating fertile bottom or terrace lands in the Ignacio quadrangle or farther south in New Mexico. Storage of the waters of the Engineer Mountain area for irrigation has not yet been attempted.

The only notable use made of the waters in the quadrangle is by the Animas Power and Water Company, which diverts Cascade Creek into the Ignacio reservoir, as shown by the topographic map. This reservoir serves as a source of supply for a power plant in the Animas Canyon at Tacoma, from which the power is transmitted to Silverton and other mining centers in the San Juan region.

May, 1909.

[a] Howe, Ernest, and Cross, Whitman. Glacial phenomena of the San Juan Mountains: Bull. Geol. Soc. America, vol. 17, 1906, pp. 251–274.

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

TOPOGRAPHY

COLORADO
ENGINEER MOUNTAIN QUADRANGLE

LEGEND

RELIEF
printed in brown

Figures *showing heights above mean sea level instrumentally determined*

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

DRAINAGE
printed in blue

Streams

Intermittent streams

Flumes

Lakes, ponds, and reservoirs

Marshes

CULTURE
printed in black

Roads and buildings

Private and secondary roads

Trails

Railroads

Bridges

U.S. township and section lines and located corner

County lines

Triangulation stations

Bench marks

E.M. Douglas, Geographer in charge.
Triangulation by E.M. Douglas.
Topography by W.M. Beaman.
Surveyed in 1897-98.

TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION 1909.

Scale $\frac{1}{62500}$

Miles

Kilometers

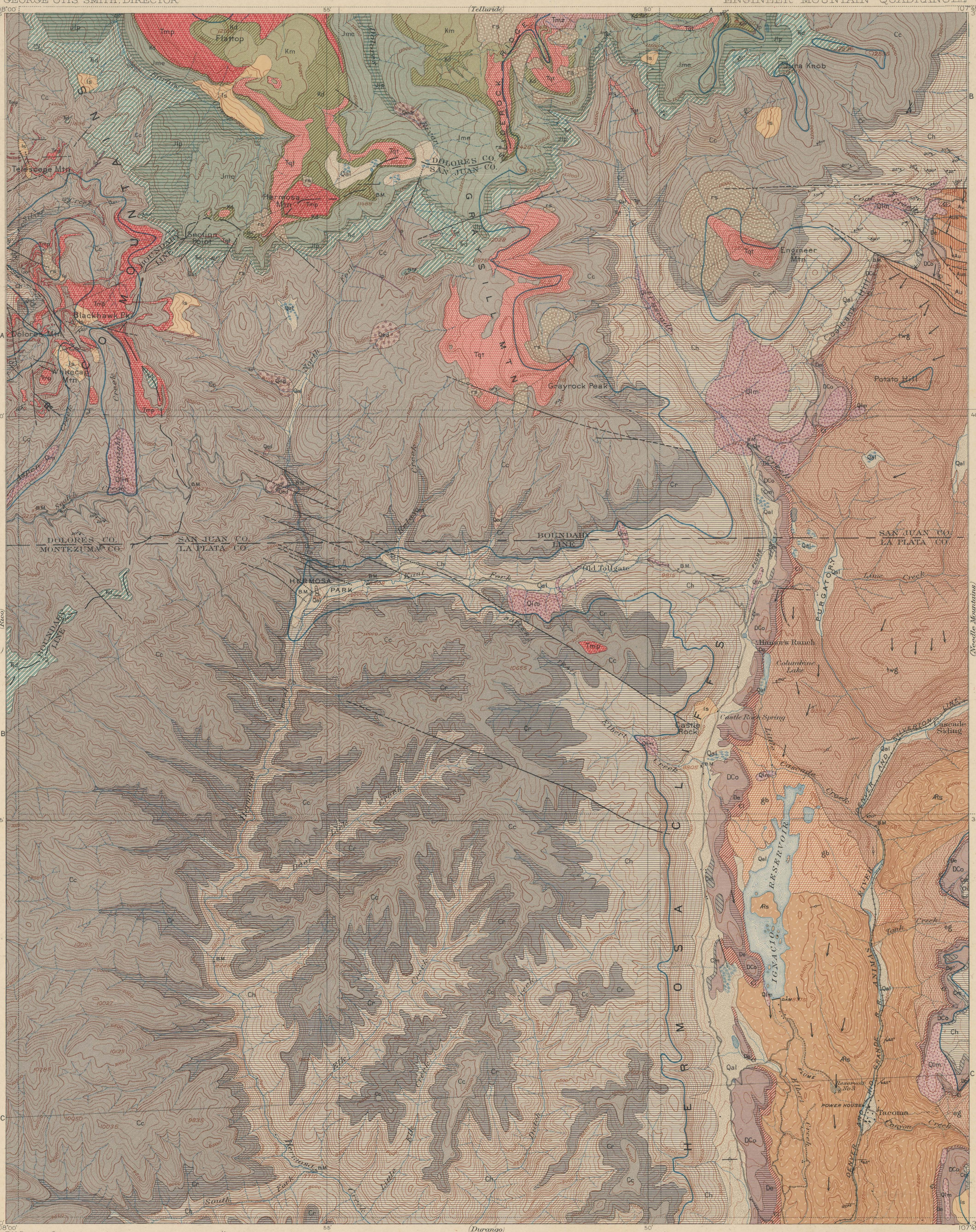
Contour interval 100 feet.
Datum is mean sea level.
Dotted lines show corrected position of meridians and parallels.

Edition of June 1908, reprinted Aug. 1909.

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

AREAL GEOLOGY

COLORADO
ENGINEER MOUNTAIN QUADRANGLE



E.M. Douglas, Geographer in charge.
Triangulation by E.M. Douglas.
Topography by W.M. Beaman.
Surveyed in 1897-98.

TRUE NORTH — MAGNETIC NORTH 14½°
APPROXIMATE MEAN DECLINATION 1909.

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 100 feet.
Datum is mean sea level.
Dotted lines show corrected position of meridians and parallels.

Edition of Sept. 1909.

Geology by Whitman Cross,
assisted by A.C. Spencer, Ernest Howe,
A. Johannsen, W.H. Emmons, and H. Bancroft.
Glacial geology by A.D. Hole.
Survey completed 1908.

LEGEND

Rock streams (rs)
(loose rock and soil having the appearance of talus; occupies the floors of cirques)

Landslides (ls)
(a confused mixture of soil and large and small blocks of rock from cliffs and slopes above)

SEDIMENTARY ROCKS

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

QUATERNARY

Recent

Alluvium (Qal)
(torrential fans and stream gravels)

Pleistocene

Upper limit of later glaciation

Moraines of later glaciation (Qlm)
(thick drift)

Earlier glacial drift (Qed)

TERTIARY

Eocene?

Telluride conglomerate (Tt)
(pebbles and bowlders of schist, quartzite, and limestone)

UNCONFORMITY

CRETACEOUS

Mancos shale (Km)
(dark fossiliferous shale with local calcareous and sandy layers)

Dakota sandstone (Kd)
(indurated quartzose sandstone with carbonaceous shale; locally contains coal)

JURASSIC

McElmo formation (Jme)
(alternating sandstones and shales)

La Plata sandstone (Jlp)
(white massive sandstone with thin blue limestone or calcareous shale)

UNCONFORMITY

TRIASSIC

Dolores formation (Trd)
(red grits, sandstones, and shales, with several layers of fossiliferous conglomerate near base)

UNCONFORMITY

CARBONIFEROUS

Permian?

Cutler formation (Cc)
(sandstone, grit, conglomerate, and some calcareous shale; prevailing color red)

Pennsylvanian

Rico formation (Cr)
(sandstone, limestone, and shale, of red or gray color; fossiliferous)

Hermosa formation (Ch)
(sandstone, shale, and limestone, of grayish color; fossiliferous)

Molas formation (Cm)
(red calcareous shale containing limestone and chert nodules; fossiliferous)

UNCONFORMITY

DEVONIAN

Ouray limestone (DCo)
(white or light-pink, saccharoidal limestone, with a few quartzite layers; fossiliferous)

Elbert formation (De)
(thin-bedded, calcareous and sandy shale, buff and yellow, with pseudomorphs of salt crystals; fossiliferous)

UNCONFORMITY

CAMBRIAN

Upper Cambrian?

Ignacio quartzite (Ci)
(thin-bedded, gray or pink, wavy quartzite, with trail markings on shaly partings)

UNCONFORMITY

ALGONKIAN

Uncompahgre formation (Au, Aus)
(massive and thin-bedded, light to dark quartzite, locally conglomeratic, with dark shale, slate, and argillite, Aus)

Legend is continued on the left margin.

LEGEND
(continued)

METAMORPHIC ROCKS OF UNKNOWN ORIGIN

(Areas of metamorphic rocks of unknown origin are shown by hachures)

ARCHEAN

Schist and gneiss (Ars)
(quartz-mica-schist and amphibolite with some granite-gneiss)

IGNEOUS ROCKS

(Areas of igneous rocks are shown by patterns of triangles and rhombs; metamorphism is indicated by hachures)

TERTIARY

Lamprophyric dikes (lp)

Quartz trachyte (Tqt)
(a porphyritic rock occurring in sills and laccoliths)

Monzonite (Tmz)
(a granular rock forming a large stock)

Monzonite porphyry (Tmp)
(the common intrusive rock of the Rico Mountains; occurs in dikes and sheets and small laccoliths)

ALGONKIAN OR CAMBRIAN

Earlier than Ignacio quartzite

Gabbro (gb)
(a batholith cutting gneiss and schist)

Eolus granite (eg)
(coarse, pink hornblende-biotite-granite)

Twilight granite (twg)
(light grayish-pink gneissoid granite, which predominates in the area indicated)

Faults

Concealed faults
(covered by surficial deposits)

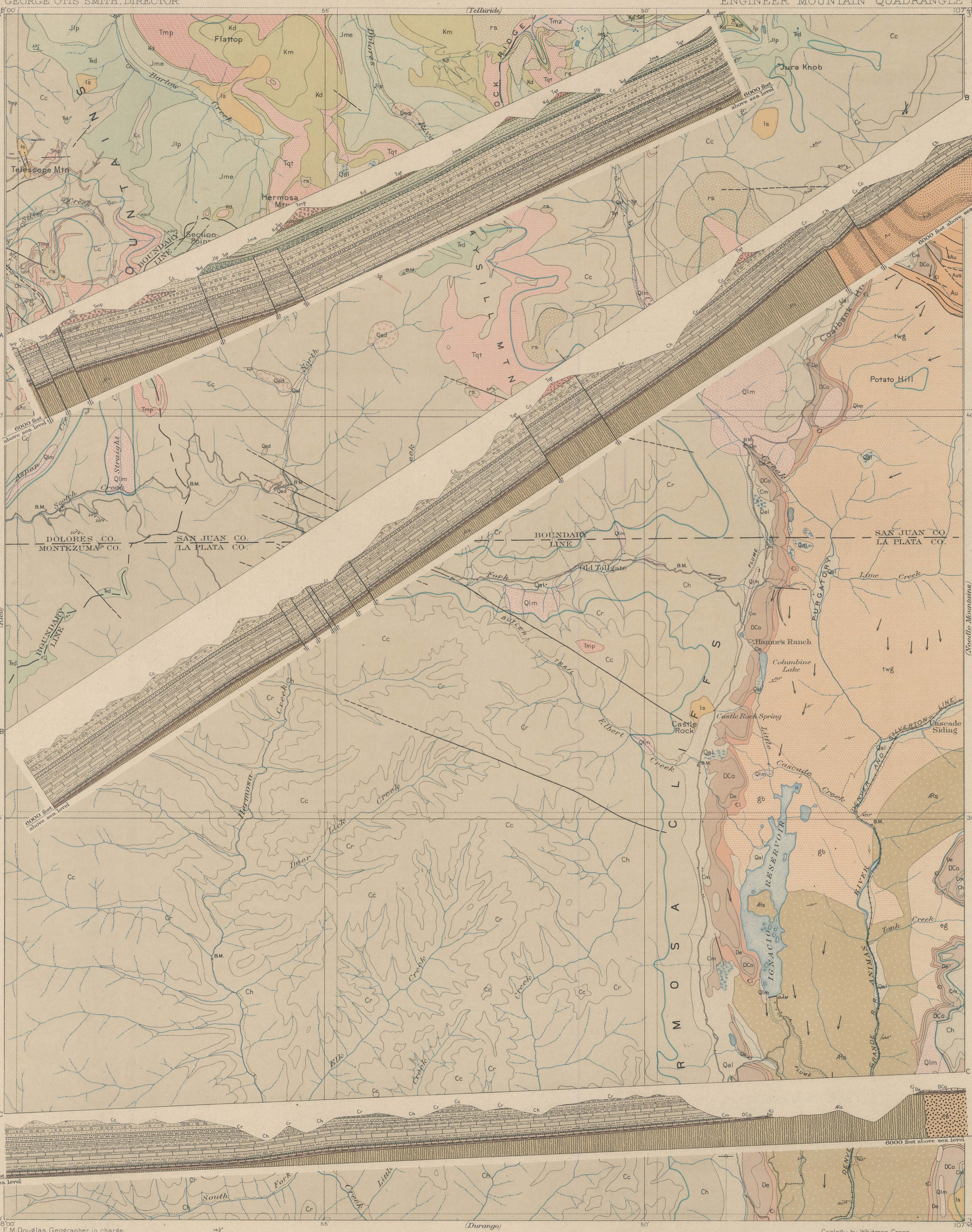
45° *Strike and dip of stratified rocks*
Strike of vertical strata

Glacial striæ
x *Silver prospect*

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR.

STRUCTURE SECTIONS

COLORADO
ENGINEER MOUNTAIN QUADRANGLE



LEGEND

SHEET SYMBOL / SECTION SYMBOL

Rock streams rs (loose rock and soil having the appearance of talus; occupies the floors of cirques)

Landslides ls (a confused mixture of soil and large and small blocks of rock from cliffs and slopes above)

SEDIMENTARY ROCKS

QUATERNARY

Recent

Alluvium Qal (torrential fans and stream gravels)

Pleistocene

Upper limit of later glaciation

Moraines of later glaciation Qlm (thick drift)

Earlier glacial drift Qed

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JURASSIC

McElmo formation Jme (alternating sandstones and shales)

La Plata sandstone Jlp (white massive sandstone with thin blue limestone or calcareous shale)

UNCONFORMITY

TRIASSIC

Dolores formation ₨d (red grits, sandstones, and shales, with several layers of fossiliferous conglomerate near base)

UNCONFORMITY

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Permian?

Cutler formation Cc (sandstone, grit, conglomerate, and some calcareous shale; prevailing color red)

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Rico formation Cr (sandstone, limestone, and shale, of red or gray color; fossiliferous)

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UNCONFORMITY

DEVONIAN

Ouray limestone DCo (white or light-pink, saccharoidal limestone, with a few quartzite layers; fossiliferous)

Elbert formation De (thin-bedded, calcareous and sandy shale, buff and yellow, with pseudomorphs of salt crystals; fossiliferous)

UNCONFORMITY

CAMBRIAN

Upper Cambrian?

Ignacio quartzite €i (thin-bedded, gray or pink, wavy quartzite, with trail markings on shaly partings)

UNCONFORMITY

ALGONKIAN

Uncompahgre formation Au, Aus (massive and thin-bedded light to dark quartzite; locally conglomeratic with dark shale, slate, and argillite, Aus)

Legend is continued on the left margin.

LEGEND

(continued)

METAMORPHIC ROCKS OF UNKNOWN ORIGIN

SHEET SYMBOL / SECTION SYMBOL

ARCHEAN

Schist and gneiss ꭿs (quartz-mica-schist and amphibolite with some granite-gneiss; intrusive granite, gabbro, and Uncompahgre formation may be included in symbol on sections)

IGNEOUS ROCKS

TERTIARY

Lamprophyric dikes lp

Quartz trachyte Tqt (a porphyritic rock occurring in sills and laccoliths)

Monzonite Tmz (a granular rock forming a large stock)

Monzonite porphyry Tmp (the common intrusive rock of the Rico Mountains; occurs in dikes and sheets and small laccoliths)

ALGONKIAN OR CAMBRIAN

Earlier than Ignacio quartzite

Gabbro gb (a batholith cutting gneiss and schist)

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Twilight granite twg (light grayish-pink gneissoid granite, which predominates in the area indicated)

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Concealed faults (covered by surficial deposits)

45° Strike and dip of stratified rocks

Strike of vertical strata

Glacial striæ

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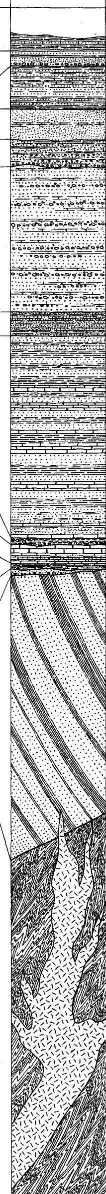
COLUMNAR SECTION

GENERALIZED SECTION FOR THE ENGINEER MOUNTAIN QUADRANGLE.

SCALE: 1 INCH = 1000 FEET.

System.	Series.	Formation.	Symbol.	Columnar Section.	Thickness in Feet.	Character and Distribution of Formations.
CRETACEOUS	UPPER CRETACEOUS	Mancos shale.	Km		0–300	Soft dark-gray or almost black carbonaceous clay shale containing thin lenses or discontinuous layers of impure limestone. Embraces the Colorado group and a part of the Pierre division of the Montana. Fossils more or less abundant in the limestone layers.
		Dakota sandstone.	Kd		100–150	Gray or rusty brown quartzose sandstone or quartzite with a variable conglomerate, containing small chert pebbles at or near base. Carbonaceous shale partings at several horizons and low-grade coal. Some indistinct fossil leaves.
JURASSIC		McElmo formation	Jme		400–500	A complex of alternating friable fine-grained yellowish or grayish sandstones and shales. The sandstones are rarely over 20 feet thick. In many places they include flakes of greenish clay or shale. The shales are chiefly green but are locally pink, dark red, or chocolate-brown. Some shale layers are sandy; others highly calcareous. No fossils.
		La Plata sandstone.	Jlp		250–400	Principally two massive friable white sandstone beds, with a narrow band of dark limestone or calcareous shale between them. The sandstones are quartzose, of even grain, cross-bedded, and form massive cliffs. The limestone or calcareous shale is locally brecciated and recemented. No determinable fossils.
		UNCONFORMITY				
TRIASSIC		Dolores formation.	Ꞓd		150–400	Fine-grained bright-red sandstone and shale. Near the base is a fine limestone conglomerate containing teeth of a crocodile (*Belodon*) and of a megalosauroid dinosaur; also rare Triassic gasteropod shell similar to *Viviparus*.
		UNCONFORMITY				
CARBONIFEROUS	PERMIAN?	Cutler formation.	Cc		1000–2000	A complex of bright-red sandstones and lighter-red or pinkish grits and conglomerates alternating with sandy shales and earthy or sandy limestones of several shades of red.
	PENNSYLVANIAN	Rico formation.	Cr		200–350	Dark reddish-brown sandstone and pink grit, with intercalated greenish or reddish shale and sandy fossiliferous limestone.
		Hermosa formation.	Ch		2000–2200	Series of limestones, grits, sandstones, and shales of variable distribution and development. Limestone in thick, massive blue-gray beds predominates in the middle and upper parts of the section, the lower portion being mainly greenish sandstone and shale, with a few limestone layers. Numerous invertebrate fossils occur in shales and limestones.
		Molas formation.	Cm		0–75	Red calcareous shale and sandstone, containing pebbles of Mississippian chert and limestone and limestone lenses with Pennsylvanian fossils.
		UNCONFORMITY				
	MISS.	Ouray limestone.	DCo		100–300	Buff or white limestone, compact above, thin-bedded below, with shale and quartzitic partings. Mississippian fossils in upper third; Devonian in lower portion.
DEVONIAN		Elbert formation.	De		80±	Thin-bedded limestone, sandstone, and shale containing casts of salt crystals. Devonian fish remains occur rarely near top.
		UNCONFORMITY				
CAMBRIAN	UPPER CAMB.?	Ignacio quartzite.	Ꞓi		0–80	Massive quartzite, conglomerate locally near base, thin-bedded with shaly partings in middle portion.
		UNCONFORMITY				
ALGONKIAN		Uncompahgre formation, with shale members.	Au (Aus)			Massive and some thin-bedded quartzites and occasional bands of shale or slate. Quartzites range in color from white through pink, brown, and purple to black. Shales are rusty brown or black.
ARCHEAN		Schist and gneiss. Granite and gabbro, intrusive in pre-Cambrian rocks.	Æs			Quartz-mica and amphibolite schist and less prominent granite gneiss, much crumpled and contorted.

ILLUSTRATIONS I

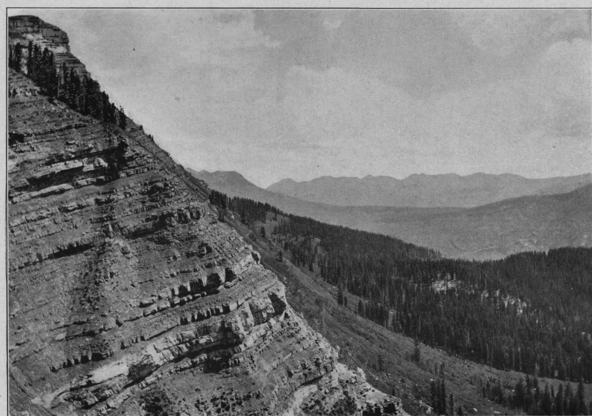


FIGURE 2.—SCARP OF HERMOSA FORMATION EAST OF ENGINEER MOUNTAIN.
Illustrates the manner in which massive limestone and sandstone beds alternate with soft shale. Looking north. Pass of Coalbank Hill on the right. Mountains near Silverton in the distance.

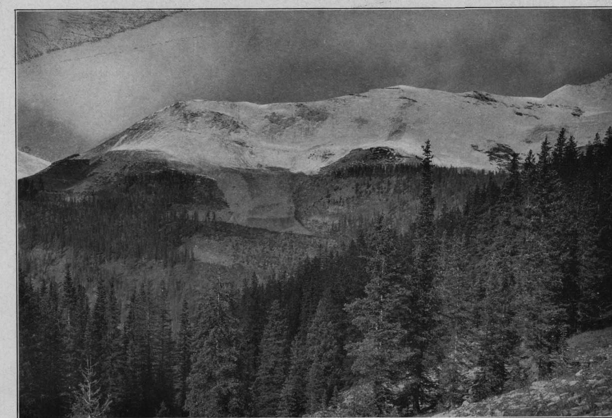


FIGURE 3.—SLIDEROCK RIDGE FROM THE EAST, LOOKING ACROSS CASCADE CREEK.
Shows a characteristic rock stream of trachytic debris from a sill in Cretaceous beds forming the crest of the ridge.

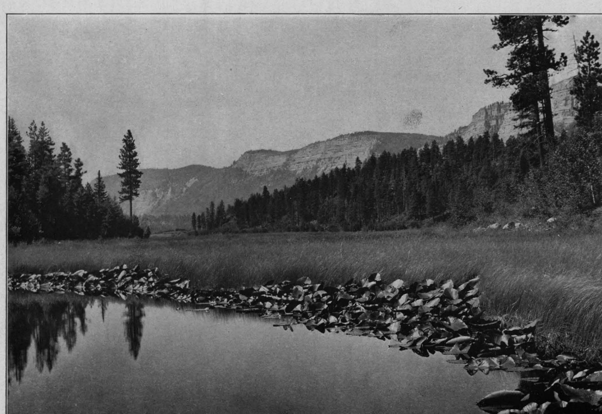


FIGURE 4.—HERMOSA CLIFFS SEEN FROM LILY POND IN AREA NOW COVERED BY IGNACIO RESERVOIR.
Shows relation of the broad bench occupied by Ignacio Reservoir to the scarp of Hermosa Cliffs, which rise 1800 feet above the bench.

FIGURE 5.—WESTERN SAN JUAN MOUNTAINS FROM BLACKHAWK PEAK.
Shows the character of the country between the San Juan Mountains, in the distance, and the Rico Mountains. On the right is Hermosa Peak; in Section Point the white La Plata sandstone and red Dolores beds dip away from the point of view under the influence of the Rico Mountains uplift.

FIGURE 6.—VIEW LOOKING EASTWARD ACROSS BARLOW CREEK TOWARD FLATTOP, THE WESTERN PEAKS OF THE SAN JUAN MOUNTAINS, AND HERMOSA PEAK.
Barlow Creek valley in the foreground; beyond it, on the left, the porphyry laccolith of Flattop, capped by Cretaceous beds. The highest summit, in the distance, is Grizzly Peak, carved in a monzonite stock; to the right of it is Sliderock Ridge, with a great rock stream of quartz trachyte debris. On the right is Hermosa Peak, the upper part of which is intrusive monzonite porphyry; the lower slopes are of quartz trachyte belonging to a sill which extends from the ridge on the extreme right to the white cliffs in the middle ground. On the left of Hermosa Peak is the bare peak of Engineer Mountain, and the quartzite peaks of the Needle Mountains in the distance.

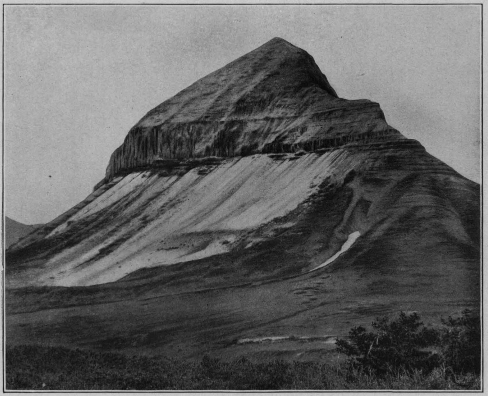


FIGURE 7.—ENGINEER MOUNTAIN FROM THE EAST.
The basal contact of the quartz trachyte laccolith is at the top of the talus slope. Shows the columnar structure of the quartz trachyte and the absence of rock streams on this side.

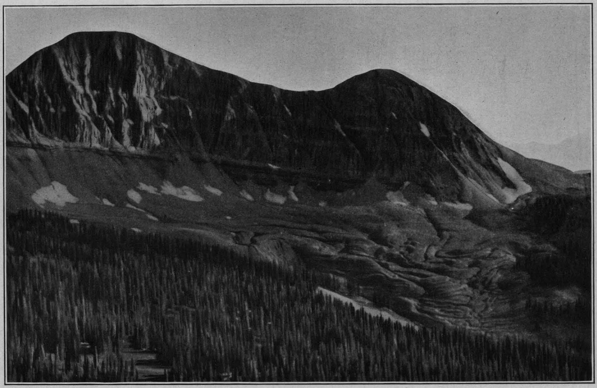


FIGURE 8.—ENGINEER MOUNTAIN FROM THE NORTH.
Shows cliffs of columnar quartz trachyte, inclined strata at the base of the intrusion, and a rock stream of quartz trachyte debris with characteristic surface details.

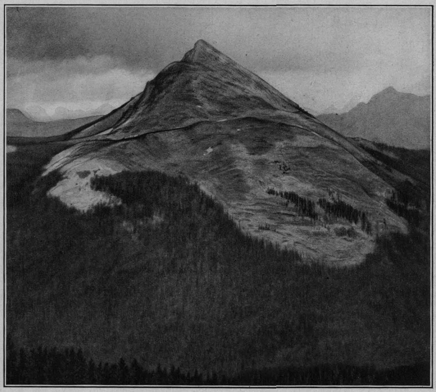


FIGURE 9.—ENGINEER MOUNTAIN FROM THE WEST.
Shows a rock stream descending from the quartz trachyte laccolith of the summit.

FIGURE 10.—HORNBLENDE SCHIST IRREGULARLY INTRUDED BY TWILIGHT GRANITE, LITTLE CASCADE CREEK.

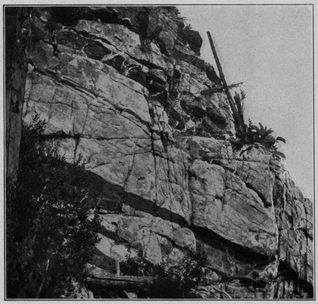


FIGURE 11.—HORNBLENDE SCHIST SPLIT INTO SLABS BY TWILIGHT GRANITE, LITTLE CASCADE CREEK.

FIGURE 12.—HORNBLENDE SCHIST IRREGULARLY INTRUDED BY TWILIGHT GRANITE, LITTLE CASCADE CREEK.

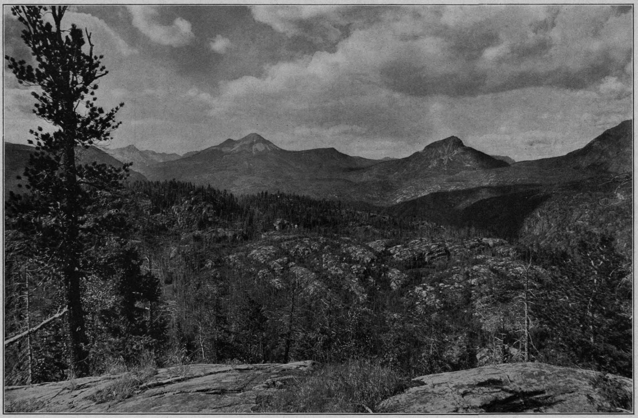


FIGURE 13.—ENGINEER MOUNTAIN AND POTATO HILL FROM RIDGE NORTH OF LITTLE CASCADE CREEK.
View looking diagonally across the canyon of Cascade Creek toward Potato Hill on the right and Engineer Mountain on the left. On the extreme right the slope rises to the West Needle Mountains. The roche moutonnee forms in the middle and foreground were produced by the west lobe of the Animas Glacier.

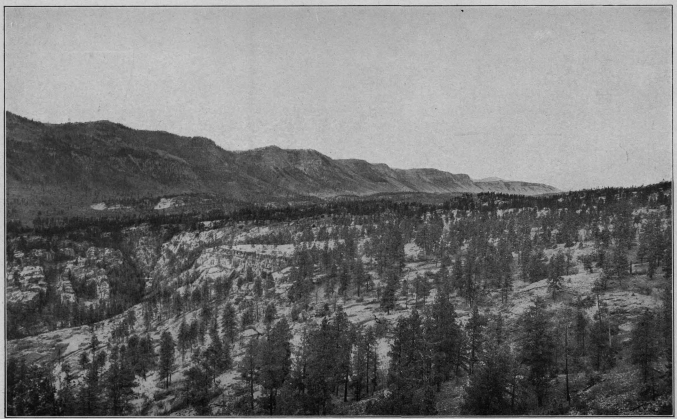


FIGURE 14.—VIEW LOOKING UP ANIMAS VALLEY FROM THE EAST SIDE NEAR CARSON CREEK, DURANGO QUADRANGLE.
Shows the long line of Hermosa Cliffs in the Engineer Mountain quadrangle in relation to the broad Animas Valley. The ledge and bench of Ouray limestone are visible at the base of the cliffs. On the right is the pre-Cambrian area; the gorge of the Animas near its mouth appears on the left.

FIGURE 15.—VIEW LOOKING WESTWARD ACROSS NORTHERN PART OF ENGINEER MOUNTAIN QUADRANGLE FROM NORTH END OF WEST NEEDLE MOUNTAINS.
Shows the structure of the Carboniferous beds in the middle ground. . At the right the Telluride conglomerate rests unconformably on the Paleozoic beds. The dark point on the left is Jura Knob.

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