DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

GEOLOGIC ATLAS

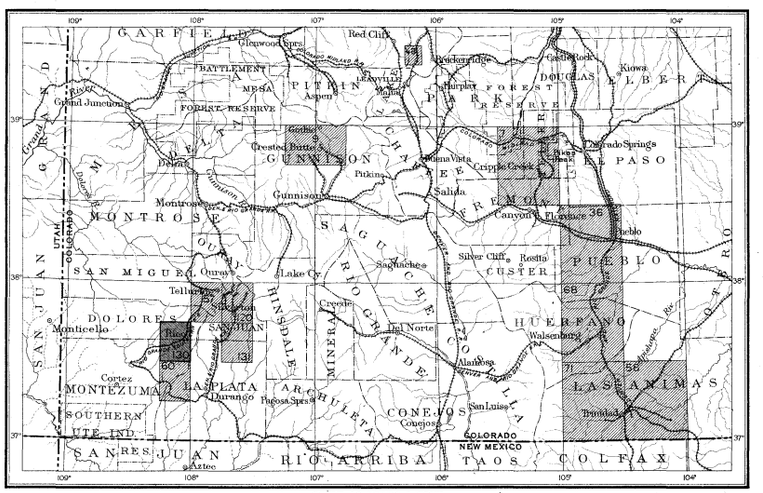
OF THE

UNITED STATES

RICO FOLIO

COLORADO

INDEX MAP



SCALE: 40 MILES-1 INCH

RICO FOLIO

OTHER PUBLISHED FOLIOS

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GEORGE W. STOSE, EDITOR OF GEOLOGIC MAPS S. J. KUBEL, CHIEF ENGRAVER

1905

GEOLOGIC AND TOPOGRAPHIC ATLAS OF UNITED STATES.

The Geological Survey is making a geologic map of the United States, which is being issued in parts, called folios. Each folio includes a topographic map and geologic maps of a small area of country, together with explanatory and descriptive texts.

THE TOPOGRAPHIC MAP.

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

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

The manner in which contours express elevation, form, and grade is shown in the following sketch and corresponding contour map (fig. 1).

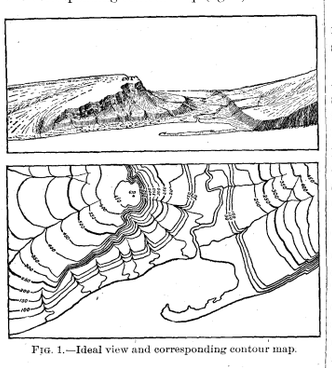

FIG. 1.—Ideal view and corresponding contour map.

The sketch represents a river valley between two hills. In the foreground is the sea, with a bay which is partly closed by a hooked sand bar. On each side of the valley is a terrace. From the terrace on the right a hill rises gradually, while from that on the left the ground ascends steeply, forming a precipice. Contrasted with this precipice is the gentle slope from its top toward the left. In the map each of these features is indicated, directly beneath its position in the sketch, by contours. The following explanation may make clearer the manner in which contours delineate elevation, form, and grade:

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

2. Contours define the forms of slopes. Since contours are continuous horizontal lines, they wind smoothly about smooth surfaces, recede into all reentrant angles of ravines, and project in passing about prominences. These relations of contour curves and angles to forms of the landscape can be traced in the map and sketch.

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

For a flat or gently undulating country a small contour interval is used; for a steep or mountainous country a large interval is necessary. The smallest interval used on the atlas sheets of the Geological Survey is 5 feet. This is serviceable for regions like the Mississippi delta and the Dismal Swamp. In mapping great mountain masses, like those in Colorado, the interval may be 250 feet. For intermediate relief contour intervals of 10, 20, 25, 50, and 100 feet are used.

Drainage.—Watercourses are indicated by blue lines. If a stream flows the entire year the line is drawn unbroken, but if the channel is dry a part of the year the line is broken or dotted. Where a stream sinks and reappears at the surface, the supposed underground course is shown by a broken blue line. Lakes, marshes, and other bodies of water are also shown in blue, by appropriate conventional signs.

Culture.—The works of man, such as roads, railroads, and towns, together with boundaries of townships, counties, and States, are printed in black.

Scales.—The area of the United States (excluding Alaska and island possessions) is about 3,025,000 square miles. A map representing this area, drawn to the scale of 1 mile to the inch, would cover 3,025,000 square inches of paper, and to accommodate the map the paper would need to measure about 240 by 180 feet. Each square mile of ground surface would be represented by a square inch of map surface, and one linear mile on the ground would be represented by a linear inch on the map. This relation between distance in nature and corresponding distance on the map is called the *scale* of the map. In this case it is "1 mile to an inch." The scale may be expressed also by a fraction, of which the numerator is a length on the map and the denominator the corresponding length in nature expressed in the same unit. Thus, as there are 63,360 inches in a mile, the scale "1 mile to an inch" is expressed by $\frac{1}{63,360}$.

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

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

The atlas sheets, being only parts of one map of the United States, disregard political boundary lines, such as those of States, counties, and townships. To each sheet, and to the quadrangle it represents, is given the name of some well-known town or natural feature within its limits, and at the sides and corners of each sheet the names of adjacent sheets, if published, are printed.

Uses of the topographic map.—On the topographic map are delineated the relief, drainage, and culture of the quadrangle represented. It should portray to the observer every characteristic feature of the landscape. It should guide the traveler; serve the investor or owner who desires to ascertain the position and surroundings of property; save the engineer preliminary surveys in locating roads, railways, and irrigation reservoirs and ditches; provide educational material for schools and homes; and be useful as a map for local reference.

THE GEOLOGIC MAPS.

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

KINDS OF ROCKS.

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

Igneous rocks.—These are rocks which have cooled and consolidated from a state of fusion. Through rocks of all ages molten material has from time to time been forced upward in fissures or channels of various shapes and sizes, to or nearly to the surface. Rocks formed by the consolidation of the molten mass within these channels—that is, below the surface—are called *intrusive*. When the rock occupies a fissure with approximately parallel walls the mass is called a *dike*; when it fills a large and irregular conduit the mass is termed a *stock*. When the conduits for molten magmas traverse stratified rocks they often send off branches parallel to the bedding planes; the rock masses filling such fissures are called *sills* or *sheets* when comparatively thin, and *laccoliths* when occupying larger chambers produced by the force propelling the magmas upward. Within rock inclosures molten material cools slowly, with the result that intrusive rocks are generally of crystalline texture. When the channels reach the surface the molten material poured out through them is called *lava*, and lavas often build up volcanic mountains. Igneous rocks thus formed upon the surface are called *extrusive*. Lavas cool rapidly in the air, and acquire a glassy or, more often, a partially crystalline condition in their outer parts, but are more fully crystalline in their inner portions. The outer parts of lava flows are usually more or less porous. Explosive action often accompanies volcanic eruptions, causing ejections of dust, ash, and larger fragments. These materials, when consolidated, constitute breccias, agglomerates, and tuffs. Volcanic ejecta may fall in bodies of water or may be carried into lakes or seas and form sedimentary rocks.

Sedimentary rocks.—These rocks are composed of the materials of older rocks which have been broken up and the fragments of which have been carried to a different place and deposited.

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

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

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

The surface of the earth is not fixed, as it seems to be; it very slowly rises or sinks, with reference to the sea, over wide expanses; and as it rises or subsides the shore lines of the ocean are changed. As a result of the rising of the surface, marine sedimentary rocks may become part of the land, and extensive land areas are in fact occupied by such rocks.

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

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

From time to time in geologic history igneous and sedimentary rocks have been deeply buried and later have been raised to the surface. In this process, through the agencies of pressure, movement, and chemical action, their original structure may be entirely lost and new structures appear. Often there is developed a system of division planes along which the rocks split easily, and these planes may cross the strata at any angle. This structure is called *cleavage*. Sometimes crystals of mica or other foliaceous minerals are developed with their laminæ approximately parallel; in such cases the structure is said to be schistose, or characterized by *schistosity*.

As a rule, the oldest rocks are most altered and the younger formations have escaped metamorphism, but to this rule there are important exceptions.

FORMATIONS.

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

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

AGES OF ROCKS.

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

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

(Continued on third page of cover.)

As sedimentary deposits or strata accumulate the younger rest on those that are older, and the relative ages of the deposits may be determined by observing their positions. This relationship holds except in regions of intense disturbance; in such regions sometimes the beds have been reversed, and it is often difficult to determine their relative ages from their positions; then *fossils*, or the remains and imprints of plants and animals, indicate which of two or more formations is the oldest.

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

It is often difficult or impossible to determine the age of an igneous formation, but the relative age of such a formation can sometimes be ascertained by observing whether an associated sedimentary formation of known age is cut by the igneous mass or is deposited upon it.

Similarly, the time at which metamorphic rocks were formed from the original masses is sometimes shown by their relations to adjacent formations of known age; but the age recorded on the map is that of the original masses and not of their metamorphism.

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

Symbols and colors assigned to the rock systems.

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

Patterns composed of parallel straight lines are used to represent sedimentary formations deposited in the sea or in lakes. Patterns of dots and circles represent alluvial, glacial, and eolian formations. Patterns of triangles and rhombs are used for igneous formations. Metamorphic rocks of unknown origin are represented by short dashes irregularly placed; if the rock is schist the dashes may be arranged in wavy lines parallel to the structure planes. Suitable combination patterns are used for metamorphic formations known to be of sedimentary or of igneous origin.

The patterns of each class are printed in various colors. With the patterns of parallel lines, colors are used to indicate age, a particular color being assigned to each system. The symbols by which formations are labeled consist each of two or more letters. If the age of a formation is known the symbol includes the system symbol, which is a capital letter or monogram; otherwise the symbols are composed of small letters. The names of the systems and recognized series, in proper order (from new to old), with the color and symbol assigned to each system, are given in the preceding table.

SURFACE FORMS.

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

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

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

THE VARIOUS GEOLOGIC SHEETS.

Areal geology map.—This map shows the areas occupied by the various formations. On the margin is a *legend*, which is the key to the map. To ascertain the meaning of any colored pattern and its letter symbol the reader should look for that color, pattern, and symbol in the legend, where he will find the name and description of the formation. If it is desired to find any given formation, its name should be sought in the legend and its color and pattern noted, when the areas on the map corresponding in color and pattern may be traced out.

The legend is also a partial statement of the geologic history. In it the formations are arranged in columnar form, grouped primarily according to origin—sedimentary, igneous, and crystalline of unknown origin—and within each group they are placed in the order of age, so far as known, the youngest at the top.

Economic geology map.—This map represents the distribution of useful minerals and rocks, showing their relations to the topographic features and to the geologic formations. The formations which appear on the areal geology map are usually shown on this map by fainter color patterns. The areal geology, thus printed, affords a subdued background upon which the areas of productive formations may be emphasized by strong colors. A mine symbol is printed at each mine or quarry, accompanied by the name of the principal mineral mined or stone quarried. For regions where there are important mining industries or where artesian basins exist special maps are prepared, to show these additional economic features.

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

The geologist is not limited, however, to the natural and artificial cuttings for his information concerning the earth's structure. Knowing the manner of formation of rocks, and having traced out the relations among the beds on the surface, he can infer their relative positions after they pass beneath the surface, and can draw sections representing the structure of the earth to a considerable depth. Such a section exhibits what would be seen in the side of a cutting many miles long and several thousand feet deep. This is illustrated in the following figure:

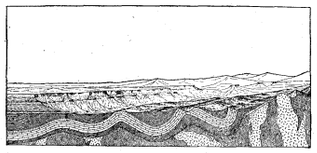

Fig. 2.—Sketch showing a vertical section at the front and a landscape beyond.

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

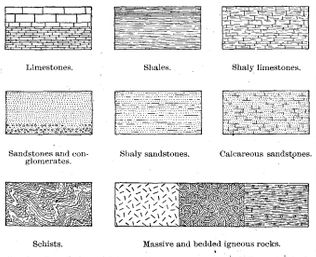

Fig. 3.—Symbols used in sections to represent different kinds of rocks.

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

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

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

On the right of the sketch, fig. 2, the section is composed of schists which are traversed by masses of igneous rock. The schists are much contorted and their arrangement underground can not be

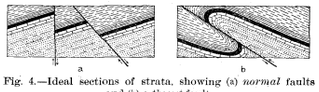

Fig. 4.—Ideal sections of strata, showing (a) *normal* faults and (b) a *thrust* fault.

inferred. Hence that portion of the section delineates what is probably true but is not known by observation or well-founded inference.

The section in fig. 2 shows three sets of formations, distinguished by their underground relations. The uppermost of these, seen at the left of the section, is a set of sandstones and shales, which lie in a horizontal position. These sedimentary strata are now high above the sea, forming a plateau, and their change of elevation shows that a portion of the earth's mass has been raised from a lower to a higher level. The strata of this set are parallel, a relation which is called *conformable*.

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

The horizontal strata of the plateau rest upon the upturned, eroded edges of the beds of the second set at the left of the section. The overlying deposits are, from their positions, evidently younger than the underlying formations, and the bending and degradation of the older strata must have occurred between the deposition of the older beds and the accumulation of the younger. When younger rocks thus rest upon an eroded surface of older rocks the relation between the two is an *unconformable* one, and their surface of contact is an *unconformity*.

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

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

Columnar section sheet.—This sheet contains a concise description of the sedimentary formations which occur in the quadrangle. It presents a summary of the facts relating to the character of the rocks, the thickness of the formations, and the order of accumulation of successive deposits.

The rocks are briefly described, and their characters are indicated in the columnar diagram. The thicknesses of formations are given in figures which state the least and greatest measurements, and the average thickness of each is shown in the column, which is drawn to a scale—usually 1000 feet to 1 inch. The order of accumulation of the sediments is shown in the columnar arrangement—the oldest formation at the bottom, the youngest at the top.

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

CHARLES D. WALCOTT,

Director.

Revised January, 1904.

DESCRIPTION OF THE RICO QUADRANGLE.

By Whitman Cross and F. L. Ransome.

GEOGRAPHY AND GENERAL GEOLOGY OF THE QUADRANGLE.

By Whitman Cross.

INTRODUCTION.

The Rico quadrangle is situated in southwestern Colorado, about 50 miles west of the Continental Divide, in the zone bordering the San Juan Mountains, almost at the head of the Dolores River. It is bounded by meridians 108° and 108° 15′ west longitude and parallels 37° 30′ and 37° 45′ north latitude, embracing about 236 square miles.

GENERAL RELATIONS OF THE QUADRANGLE.

Relations to the plateau country.—The Rico quadrangle lies in the north-south zone that marks the eastern border of a very notable plateau surface which covers the greater part of the area between the Colorado River in Utah and the San Juan Mountains of Colorado. Below the gently undulating surface of this plateau many canyons have been carved by streams, one of the principal gorges being that of the Dolores River. Entering its canyon valley within the Rico quadrangle this stream flows with irregular course for about 18 miles in a southwesterly direction and then swings to a general north-northwest trend, which it maintains for over 100 miles to the Grand River.

The larger part of the plateau surface lying between the Dolores and Colorado rivers is called the Great Sage Plain, while its direct continuation eastward and toward the head of the Dolores is named the Dolores Plateau.

This broad plain surface is due chiefly to a heavy sandstone, the Dakota (Cretaceous), and its undulations are in part structural, in harmony with the slightly varying dips of the sandstone, and in part owing to remnants of the soft, thick shale formation normally overlying the sandstone. The Great Sage Plain of Utah has a general elevation of 6000 to 7000 feet above the sea. Eastward the Dolores Plateau gradually rises with the dip of the sandstone until, on the western border of the Rico quadrangle, it has an altitude of over 9000 feet. Beyond that line it rises more rapidly as the Dakota sandstone and other formations take part in the local structures of the Rico and La Plata Mountains, to be described in detail.

Relations to the San Juan Mountains.—The southwestern front of the volcanic San Juan Mountains lies 6 to 8 miles northeast of the Rico quadrangle. The intervening space is characterized by irregular foothill topography, with features due in part to the upturning and erosion of various sedimentary formations about the ancient San Juan center of uplift and in part to large masses of intrusive igneous rocks. These intrusions are similar in character to those of the Rico Mountains.

No surface volcanic rocks of the San Juan succession occur in the Rico quadrangle. It is probable, however, that the San Juan volcanics once extended over this area and have been removed by erosion. In support of this idea may be mentioned the fact that only a few miles north of the Rico area, on the south slopes of the San Miguel Mountains, a line of high peaks which are geologically as well as topographically western outliers of the San Juan Mountains, remnants of the horizontal surface lavas of that district, as well as great masses of intrusive rocks, are found. The base of the surface volcanics in the San Miguel peaks stands at about 12,000 feet, which is higher than any portion of the Rico quadrangle except certain points in the local area of uplift in the Rico Mountains. The Rico area is geologically related to the San Juan region chiefly in regard to pre-Tertiary formations and structure and the Quaternary erosion of streams heading on the San Juan flank.

Features of the Rico Mountains.—The small group of mountains in the northeastern section of the quadrangle is in large degree a local center of uplift which is apparently independent of igneous intrusion; but it is also to an important extent characterized by many injected laccolithic masses. The intrusive rocks are of kinds common in the so-called laccolithic mountain groups of the plateau country, embracing the La Plata, El Late, Carriso, Abajo, La Sal, and Henry mountains, most of which are plainly visible from the Rico summits. This character of the Rico group was not recognized during the Hayden Survey.

The sedimentary section.—In general the section of sedimentary formations exposed in the valley of the Dolores River is that normal to the zone about the San Juan Mountains. It is, for example, like that shown in the adjoining Telluride quadrangle by the erosion of the San Miguel River, and extends from the Mancos (Cretaceous) shales down into the Carboniferous red beds. But in consequence of the Rico uplift and its bisection by the Dolores the lower Paleozoic formations are shown locally, and even certain quartzites of the Algonkian. The formations thus revealed in the Dolores Valley have the general character of the complete section more perfectly exposed in the Animas Valley, about 12 miles to the east. The Mesozoic formations are the same that characterize the canyons of the plateau country to the west, but it is known that most of those formations exhibit progressive changes as distance from the Colorado mountain area increases. These changes have not yet been examined in detail.

GEOGRAPHY AND TOPOGRAPHY OF THE QUADRANGLE.

The Rico quadrangle presents three especially prominent types of topographic forms, each dominating a considerable part of the area. These notable features are (1) the Dolores Plateau, (2) the Rico Mountains, and (3) the Dolores Valley, with its many lateral branches.

The Dolores Plateau.—The western half of the Rico quadrangle belongs to the Dolores Plateau. A glance at the topographic map shows that between the Dolores River and Stoner Creek there is a gently inclined mesa crossed by the western meridian of the quadrangle at an elevation of about 9400 feet. The flat crest of the narrow ridge between Stoner Creek and the West Dolores is clearly a remnant of the same plateau level and on the northern line of the quadrangle it appears again.

South of the Dolores the same notable mesa feature may be recognized. The actual extent of the mesa surface in the quadrangle may be most clearly appreciated by an examination of the geological map, where its outline is shown by means of the mapping of the distribution of the Dakota sandstone, its floor. The mesa remnants are bounded by distinct scarps formed by the sandstone.

The plateau feature gradually disappears as its sandstone floor comes under the influence of the local domal uplifts of the Rico and La Plata mountains. The contours of the map clearly express the changing dip of the Dakota sandstone, and with it the changing slope of the mesa surface itself as those mountains are approached. West of the Rico Mountains the dip slope of the mesa reaches an elevation of 11,500 feet on the ridge west of Eagle Peak. This corresponds closely to the level attained by the similar plane on the east side of Bear Creek, north of the La Plata Mountains, for across the southern part of the quadrangle the mesa floor is affected in precisely similar manner by the uplift of those mountains, the steeper slopes of which begin a mile or two south of the quadrangle line. Between the Rico and La Plata mountains the mesa is cut off by the Dolores Valley and does not reappear on the eastern side because of the upturning of all formations on this general line, under the influence of the broad San Juan structure.

Almost the entire surface of these mesa or plateau remnants is covered by a forest growth in which white pine and aspen are the chief elements. The mesa border southwest of Bear Creek is especially characterized by a magnificent growth of stately aspens. At lower levels piñon, white pine, cedar, and scrub oak become more and more prominent.

The Rico Mountains.—The summits of this compact and rather isolated group lie within an oval area about 7 miles in diameter from east to west and 5 miles from north to south. The peaks are nearly all included within the northeast section of the Rico quadrangle, but a few lie east of the one hundred and eighth meridian, in the Engineer Mountain quadrangle.

The topographic map of the quadrangle shows the general character of the mountains as compared with the plateau area and the long lateral ridges of the Dolores Valley. The special sheet exhibits the finer details of form and includes the peaks situated east of the quadrangle line.

From these maps it may be seen that the Rico Mountains consist of a circle of high and rugged peaks, divided into two crescent-shaped halves by the Dolores Valley. There are twelve peaks, each exceeding 12,000 feet in elevation above sea level, and the narrow crest connecting them rarely sinks below 11,500 feet on either side of the river. In passing through the group the Dolores receives several important tributaries on each side, which expose the internal structure of the group in many important respects. These lateral gulches are all deep, with steep sides, and their streams are still actively engaged in the work of erosion.

The characteristic forms of peaks and gulches are illustrated in the photographs reproduced in this folio. Fig. 1 in particular shows the details of form commonly present in the higher summits on the eastern side of the river.

Timber line in the Rico Mountains lies between 11,500 and 12,000 feet, and its course may be traced in several of the illustrations of the folio.

The Dolores Valley.—The Dolores River has carved its valley through the heart of the Rico Mountains, and near the western boundary of the quadrangle it enters a canyon, cut far below the plateau level, in which it flows to its junction with the Grand River. The branches of the main stream within the area are all short, except Bear Creek, which heads a few miles to the south in the La Plata Mountains. The West Dolores Valley is nearly as large as the main fork, but lies wholly within the plateau region. The extreme head of the Dolores is at the northeast base of the Rico Mountains.

The canyons of the Dolores River, Lost Canyon, Stoner Creek, and the West Dolores are characteristic of the drainage channels of the plateau country. The sides are steep and are modified by many minor scarps representing resistant sandstone strata.

GEOLOGICAL INVESTIGATION OF THE REGION.

The Hayden Survey.—The country adjacent to Rico was visited by geologists of the Hayden Survey in 1874 and 1876. In the former year F. M. Endlich examined the district to the east, the one hundred and eighth meridian, passing through Telescope Mountain, being apparently the general western boundary of his field of work. In 1876 W. H. Holmes made a rapid reconnaissance over the plateau country to the west. The complicated geology of the Rico uplift, coming on the border zone between the fields of different men working in different seasons, did not receive adequate attention, and the Hayden map of this area is, therefore, quite unsatisfactory.

J. B. Farish and T. A. Rickard.—The only geological explorations of the quadrangle since the time of the Hayden Survey have been connected with mining developments in the Rico Mountains. In the course of descriptions of some of the mining properties near Rico there have been brief discussions of the geology of the mountain group. These discussions were for the most part founded on observations near and in the mines of Newman Hill. In 1892 John B. Farish read a paper before the Colorado Scientific Society entitled "On the Ore Deposits of Newman Hill, near Rico, Colorado" (Proc. Colorado Sci. Soc., vol. 4, pp. 151–164). The description of the ore deposits was preceded by some general remarks on the geology. The structure of the mountains was recognized by Farish as a domal uplift.

A detailed description of the Enterprise mine was published in 1896 by T. A. Rickard, then superintendent of the mine (Trans. Am. Inst. Min. Eng., vol. 26, pp. 906–980). In this paper there are but few statements concerning the general geology. The strata about Rico are said to be fossiliferous and to belong to the lower Carboniferous, and the common igneous rock is called porphyrite, and is concisely described by R. C. Hills. Rickard refers to "a large dike of porphyrite" crossing the valley north of Rico, "making a fault which breaks the continuity of the country on either side." It would appear that this reference must be to the mass of schists with small dikes of hornblendic porphyry; but the position and importance of the fault are not further indicated.

U. S. Geological Survey.—In the course of the present resurvey of the Rico quadrangle the geologic complications in the Rico Mountains were found to be so great that a detailed topographic map and a special report on its geology and mineral resources were found necessary. This report appeared in the Twenty-first Annual Report of the Geological Survey under the title, "Geology of the Rico Mountains, Colorado," by Whitman Cross and Arthur Coe Spencer. As the Rico Mountains are the most important and most complex part of the quadrangle the text of this folio is in large degree descriptive of the phenomena exhibited in the mountains. But as only the broader features of the geology can be treated in this place the reader will often be referred for details to the publication just cited, which will be called in general terms "the Rico report." The special map of that report is republished in this folio as the economic sheet.

A report on the ore deposits of the Rico Mountains, by Frederick Leslie Ransome, appeared in the Twenty-second Annual Report of the Geological Survey, Part II, pp. 229–397. A summary of that report constitutes the section of this folio on "Economic geology."

Folios presenting the geology of the Telluride quadrangle on the northeast and of the La Plata quadrangle on the south have been issued. Those of the Engineer Mountain and Durango quadrangles, respectively east and southeast of the Rico, are in preparation.

CULTURE.

The agricultural development within the Rico quadrangle is limited to small areas of bottom land, principally in the valley of the West Dolores and to a less extent in that of the main river. The level expanses of the plateau are not available for cultivation, because of the lack of water. They afford excellent grazing land in many places.

Metalliferous deposits in the Rico Mountains have led to extensive mining operations and the foundation of the town of Rico, situated on the river in the heart of the mountain group. The Rio Grande Southern Railroad crosses the quadrangle, following the valley of the Dolores River.

DESCRIPTIVE GEOLOGY.

THE ROCK FORMATIONS.

SEDIMENTARY AND METAMORPHIC ROCKS.

ALGONKIAN SYSTEM.

Introductory statement.—The rocks which are described as Algonkian occupy a small area in the center of the Rico Mountains, where they have been exposed by the carving of the Dolores Valley through the heart of the uplift. They comprise quartzites and quartzitic schists and are similar to the series of rocks exposed in the Uncompahgre Canyon on the north side of the San Juan Mountains and in the Needle Mountains on the south side of the San Juan. In the latter region they were represented on the Hayden map as "metamorphic Paleozoic."

The quartzites of the Animas Canyon section through the Needle Mountains have been examined by Emmons and Van Hise, who have assigned them to the Algonkian system. The correctness of this assignment is confirmed by recent work of the Geological Survey in the Needle Mountains and the discovery of Cambrian fossils in the lowest Paleozoic formation of that area, which rests unconformably on the quartzites and other pre-Cambrian rocks. In the Silverton folio the quartzites, slates, and conglomerates of this ancient complex were called the Uncompahgre formation. The Uncompahgre quartzites and slates are underlain in the Needle Mountains by a thick conglomerate called the Vallecito formation. The Vallecito and the Uncompahgre together constitute the Needle Mountains group, according to the nomenclature proposed in the Needle Mountains folio.

UNCOMPAHGRE FORMATION.

Character.—The Algonkian rocks, very imperfectly exposed at Rico, consist of quartzites and quartzitic schists bearing small amounts of mica. The quartzites are found only in the valley of Silver Creek, in small upthrust fault blocks, and are not distinguishable in character from other massive quartzites, to be described later, which are supposed to be of Cambrian age; but the visible thickness and the structural attitude of the Algonkian rocks make it impossible to refer them to the thin Cambrian formation of this region. They are white or tinged with brown, with occasional red or rusty bands. They are composed almost entirely of quartz, occurring usually in small, even-grained particles, but sometimes in the form of pebbles less than an inch in diameter. The rock is completely indurated by the interstitial deposition of quartz, so that it is now glassy quartzite, very resistant to erosion. Distinct partings between the beds of quartzite are nowhere observable in present exposures. However, the bedding or stratification planes may frequently be made out from a study of the massive quartzites, where differences of grain are found or where cross-bedding is observable. Ripple-marked surfaces are also occasionally seen.

Occurrence.—There are six separate areas of quartzite in the valley of Silver Creek, and of these one, that below Allyn Gulch, is certainly Algonkian, as must be inferred from its great mass; another, on the opposite side of Silver Creek, is probably of that age; while the others have been assigned to the Paleozoic. In the place first mentioned the quartzites have their greatest development. They are bounded on the east by a well-marked fault, shown in the Laxy mine; thence toward the southwest they may be traced for a quarter of a mile along the hillside, on the slope of which their outcrops are to be seen between the elevations of 9200 and 9500 feet, showing a continuous exposure at one place to a thickness of 350 feet, though from the structure it is probable that a greater thickness is present. The strike and dip may be determined in this region and, while both are variable, the former is generally about N. 10°–30° E. and the latter is steeply toward the south of east. On the north, south, and west the boundaries of this mass of quartzite are not known, since they are covered by surface débris; but from the adjacent occurrences of porphyry belonging to the thick sill of Newman Hill it is almost certain that the quartzite is limited on the south and west by faults, in the manner indicated on the map, while on the north it may connect underneath the valley wash with the quartzite on the north side of Silver Creek.

Within the area just mentioned the rocks are very imperfectly exposed, except in local patches, but from these and from the data derived from tunnels and prospects it is definitely known that the northern limit is along the Last Chance fault, which has a nearly east-west course. The highest exposures are near this fault, at about 9400 feet, and the quartzite can not extend much beyond this point, since green shales and sandstones are exposed at about the same elevation in the draw below the Alma Mater mine.

SCHIST.

Character.—The remaining rocks of probable Algonkian age may be termed schists, since they have a more or less distinct foliated structure, not due to original bedding, but superinduced by metamorphism under stress. In these schists the stratification may be made out in some cases by differences in the character of adjacent bands, and to this structure the foliation is generally, though not always, parallel. The direction of foliation does not vary greatly from east and west, and its position is nearly vertical wherever observed.

The schists are dense bluish-gray rocks, the foliation being caused by the arrangement of very minute particles of biotite and actinolite, not recognizable to the unaided eye. A delicate luster is visible on the planes of easier fracture, but the schistosity is never very highly developed and the rocks often break readily across the structure with almost conchoidal fracture.

In a few places the rock has quite clearly the character of a mashed product, apparently derived from a porphyry in which there were phenocrysts of quartz and feldspar. There is a slight development of tourmaline in such rocks.

Intruded into these schists, in general parallel to the structure, but sometimes crosscutting, are many thin dikes of a dark porphyritic rock. These are prominent on both sides of the river, but have not been found in the Algonkian quartzites nor in any other rock than the schists; hence they are supposed to be very old intrusions, independent of the other eruptions of the region. This idea is substantiated by the mashing of some of the dikes. Stout prisms of hornblende are the only prominent crystals of the rock. There is also much secondary hornblende and epidote revealed by the microscope. The former subordinate feldspathic constituent is so much crushed and altered that the original character can not be determined. Plagioclase was probably predominant over orthoclase.

Occurrence.—The Algonkian schists occur only in the Dolores Valley just above Rico in small upthrust fault blocks, and the structure about them is so complicated, as shown by the special sheet, that the relations of the schists to the Algonkian quartzites and of the latter to small areas of Paleozoic quartzites have not been satisfactorily demonstrated in all cases.

CAMBRIAN (?) SYSTEM.

IGNACIO QUARTZITE.

Introductory statement.—The lowest member of the Paleozoic section displayed in the Rico Mountains is a quartzite which was grouped with the overlying limestone in the Rico report, both being referred to the Devonian, though with a reservation as to the quartzite, since it was recognized that that formation might be much older than the limestone. Recent investigations in the quadrangles lying east of the Rico have shown not only that the quartzites are probably of Saratogan (Upper Cambrian) age, but that another thin formation deserving recognition occurs between the quartzites and the Devonian limestone. This intermediate formation consists, as known in the Animas Valley, of thin-bedded limestones and calcareous shales with varying amounts of thin quartzites, the whole less than 100 feet in thickness. Fragments of fish scales and bones have been found in these beds and although but a few specifically determinable forms have yet been obtained, it is considered probable by Dr. C. R. Eastman, who has studied them, that these fossils are identical or closely related to fish remains occurring in the Catskill formation of the upper Devonian, in Pennsylvania. In the Silverton folio the fish-bearing series of beds was named the Elbert formation. The observations made at Rico do not indicate the presence of the Elbert beds at that locality, but it is possible that the limited exposures and the more or less metamorphosed condition of the rocks may have hindered recognition of the characteristic features of this formation.

The lowest lithologic division of the Paleozoic section in the Animas Valley is made up of quartzites, and varies in thickness from a few feet up to 200 feet. A single fossil shell, determined by Charles D. Walcott as *Obolus* sp.? and resembling certain Upper Cambrian species, has been found in these quartzites, and therefore it seems at present best to refer the formation to the upper or Saratogan series of the Cambrian. In the Silverton folio this was named the Ignacio formation, from its occurrence near the Ignacio Lakes in the Engineer Mountain quadrangle.

The Ignacio beds at Rico.—The quartzites here provisionally referred to the Ignacio formation may be seen in the bed of the Dolores River just above Rico and along the west bank of the stream. These strata dip at an angle of a few degrees southward, passing under the mineralized limestone of the Atlantic Cable claim. They were encountered beneath that limestone in the bore hole sunk on the claim mentioned. It is probable that the quartzites reach a thickness of at least 200 feet.

This basal quartzite is a massive rock, very dense and highly indurated. Its colors are dull yellow-white with red and brown stains. There is a slight variation in grain, the mass of the formation being fairly homogeneous. The stratification is sometimes discernible, though usually obscured by jointing and rifting. The formation is not clearly distinguishable from the Algonkian quartzite except by its more regular bedding and by the conformable attitude which it bears to the overlying Paleozoic rocks.

Occurrence.—The most clearly defined quartzites of the Ignacio formation occur in the valley of the Dolores River, just north of Rico and south of the Smelter fault. Certain other quartzites, which are associated with Algonkian schists on both sides of the river near the Last Chance fault, have also been referred to this formation. Still other quartzites, mapped as Devonian on the special map accompanying the Rico report, occur in the valley of Silver Creek. These quartzites seem to occur in conformity with the Carboniferous rocks of Newman Hill. If they are Cambrian, however, the absence of the Devonian limestone above them must be explained. In the Rico report, to which the reader must be referred for further discussion of this question, it was assumed that the Devonian limestone had been removed by erosion at this point before the deposition of the Hermosa (Carboniferous).

DEVONO-CARBONIFEROUS ROCKS.

OURAY LIMESTONE.

Name and definition.—The presence of Devonian strata in southwestern Colorado was first recognized in 1874, through collections of fossils made by F. M. Endlich, of the Hayden Survey, on the southern slopes of the Needle Mountains. The name Ouray limestone was proposed by A. C. Spencer, in 1900, after the strata had been reexamined in connection with the U. S. Geological Survey work, from the town of Ouray, on the southern border of which is a prominent outcrop of the limestone.

The name was proposed by Spencer for the Devonian limestone member of the pre-Carboniferous Paleozoic, excluding the quartzites and shales here called the Ignacio and Elbert formations, although they were thought to be possibly of Devonian age. It was supposed by Spencer that the whole limestone complex in question must be of Devonian age, but as will be shown, it has been proved that an indefinite but subordinate part of the most prominent limestone ledge of the Ouray is Mississippian. Since it is impossible to draw a line between the two portions, the Ouray becomes a lithologic unit transgressing the faunal boundary between the Devonian and Carboniferous systems.

General lithologic character.—The Ouray formation as at present known has a thickness varying from 100 to 300 feet. The upper and major part of the formation is massive limestone, either in one bed or with such thin intercalated shales that the ability of the limestone to resist erosion, and thus to cause mesas, benches, and prominent cliffs as characteristic topographic forms, is always notable. Below the more massive portion a third or less of the section is made of well-bedded limestone with distinct shaly layers and, rarely, thin quartzites, between them. Some of the lower layers have a wavy bedding, some are arenaceous or earthy, and large chert concretions, free from fossils, are common at a horizon near the base. The lowest stratum is characterized usually by crinoid stems and rarely a cup coral.

The greater part of the formation is dense, compact limestone, but portions of the upper ledge are coarsely crystalline. In general, the rock is nearly white, straw yellow, or buff, with local pinkish tones. Some of the lower beds are strongly yellow and these are commonly more or less sandy. The contrast with the dark-gray, dense limestones of the Hermosa is marked, layers of such character occurring only near the base of the Ouray.

The Carboniferous portion of the Ouray is lithologically indistinguishable from the Devonian.

Faunas and correlation.—The Devonian invertebrate fauna of the Ouray occurs from near the base to a horizon which in many places is not far below the top of the upper, massive ledge. The greater number of species occur in this upper horizon, but many of them range to within a few feet of the base.

The Mississippian fauna has been found at several localities in the Animas Valley in coarsely crystalline beds near the top of the formation.

Fossils have not been found at Rico, but have been obtained at Ouray and at several localities on the southern slope of the San Juan, including that where Endlich first found a few characteristic Devonian species.

The invertebrate fauna of the Devonian portion of the Ouray has been fully described by G. H. Girty, and compared with similar faunas hitherto collected in Colorado, but not recognized as distinct from the forms of the Mississippian. It is represented more or less fully in older collections from the Elk Mountains, at Glenwood Springs on Grand River, near the head of White River, and on East Monarch Mountain, Chaffee County. Full correlations of the sections in these localities with that of the San Juan region can not be made, however, until further examinations have been carried out. Concerning the fauna Mr. Girty writes:

> In general the Devonian fauna of the Ouray belongs to late middle or, more probably, to upper Devonian time. It is but distantly related to the Devonian faunas of New York, and its relation with those of the Mississippi Valley, or even with other known western Devonian faunas, is not close. It shows many points of approximation to the Athabascan fauna described by Whiteaves, and is somewhat strikingly similar to the Devonian of Russia.

The following named species are particularly characteristic of the Devonian portion of the Ouray fauna:

Schuchertella Chemungensis.	Camarotœchia Endlichi.
Productella semiglobosa.	Camarotœchia contracta?
Athyris Coloradoensis.	Naticopsis? humilis.
Spirifer conicultus.	Orthoceras sp.
Spirifer disjunctus var. Animasensis.	

As to the Mississippian fauna of the Ouray limestone Mr. Girty makes the following statement:

> The fauna which at one time occupied the higher beds of the Ouray limestone is very different from the assemblage of Devonian types which occurs below, and belongs to a phase of Carboniferous life which was widely distributed over the continental sea. It is found in the

The coarser sandstones are usually cross-bedded and occur in massive beds from 2 or 3 to 25 feet in thickness. Some of the coarse sandstones are of very much lighter color than the mass of the formation. When fine grained the sandstones are usually somewhat laminated and pass into sandy shales. The shales, aside from the sandy varieties, are of two kinds—the fine-grained, unlaminated, red, marly beds, similar to those of the Cutler, and the equally fine-grained, laminated clay shales of a green color.

Intercalated with the sandstones and shales, which are for the most part very calcareous throughout, there are several beds of impure limestone, some as earthy, gray, sometimes nodular bands associated with the marly shales, and others as sandy limestone of a red color, in strata from 6 inches to 2 feet in thickness. The latter, and a 6-inch layer of limestone which was taken as the upper limit of the formation in Scotch Creek, are very fossiliferous. The sandy fossiliferous bands have a characteristic appearance wherever they are found, since the fossils are preserved in white calcite, in sharp contrast to the red matrix of calcareous sand. They are found in the lower third of the formation, and while some of them are of local development and may be seen to grade both vertically and horizontally into the sand rock with which they are usually associated, at least one band is known to be persistent in the Rico region, and its equivalent has been recognized in those parts of the Animas Valley where its horizon has been studied. This fossiliferous band thus becomes diagnostic of the Rico formation, and is especially valuable in the study of the stratigraphy of the region, since it occurs within a few feet of shales which contain Hermosa fossils. At Rico its position varies little from 30 feet above the Fusulina limestone of the Hermosa formation, from which it is separated by green micaceous shales carrying shell fragments and crinoid stems, and is thus a reliable guide in defining the two formations. The formation is without any definite limit at the top, since the rocks which follow immediately above the highest known fossil-bearing beds are similar in every respect to the strata of the lower series; nor is it possible to apply the change in color as a criterion, except in a very general way; so that it has been found necessary to assume the thickness of the formation as equal to the greatest known thickness between the base and the uppermost fossiliferous stratum. In Scotch Creek the thickness on this basis would be 237 feet; on the north side of Silver Creek, near Uncle Ned Draw, it would be about the same; but on the south slope of Nigger Baby Hill it is more than 300 feet. In drawing this upper boundary on the map the formation has been represented as about 325 feet in thickness.

The measured section taken in the lower part of Scotch Creek, which is given in the next column, illustrates the features brought out in the foregoing description.

Immediately below the lowest fossiliferous limestone there are 25 feet of micaceous calcareous shales, carrying a few shell fragments and representing the topmost beds of the Hermosa formation.

Correlation.—Permian fossils, consisting for the most part of plant remains, were reported from various parts of Colorado by members of the Hayden Geological Survey (Report on the geology of the Grand River division, by A. C. Peale: U. S. Geol. and Geog. Surv. Terr. for 1875, p. 74), but the collections and the systematic study of the formations were not sufficiently complete to establish the presence of rocks of this age in such development that they could be separated from the Triassic above or from the Pennsylvanian below. Investigations in the Rico district have been the first to reveal the occurrence of strata containing a fauna with Permian affinities as a definitely separable formation within the limits of Colorado.

The fossils of the Rico formation consist almost entirely of marine invertebrate types. The fauna is a mixed one, containing forms of both Permian and Pennsylvanian affinities. For this reason it is regarded as transitional and since no distinctive and unequivocal Permian fauna has come to light from the Rico beds the term Permo-Pennsylvanian is retained for them.

In comparing this fauna with those of the Kansas section, as worked out by Prosser, it is found to correspond more nearly with that of the Neosho and Chase formations, the "Permo-Carboniferous" of Meek and other writers, than with the Marion formation, which is regarded as answering more strictly to the true Permian.

A full list of fossils from the Rico formation may be found in the report by Cross and Spencer. Mr. Girty supplies the following partial list of characteristic forms:

Productus cora.	Allerisma terminale.
Seminula subtilita.	Schizodus pandatus?
Limipecten occidentalis.	Pleurophorus subcostatus.
Myalina Wyomingensis.	Edmondia gibbosa.
Myalina subquadrata?	Loxonema plicatum.
Myalina perattenuata?	Naticopsis monilifera.
Pseudomonotis Hawni.	Strophostylus remex.
Pseudomonotis equistriata.	Bulimorpha ehrysalis.
Pseudomonotis Kansasensis.	Euphemus nodicarinatus.
Aviculipinna Nebraskensis.	

Section of the Rico formation on Scotch Creek.

	Feet.
22. Two fossiliferous limestones, each 6 inches to 1 foot thick, separated by about 3 feet of green shale	4
21 Poorly exposed slope, containing several thin beds of light-colored sandstone and in the upper part red sandy shale	20
20. Arkose sandstone, rather coarse, containing some pebbles up to 1½ inches in diameter; color, pink	7
19. Shale and thin-bedded sandstone	7
18. Earthy limestone, unfossiliferous	1
17. Shales, forming a slope with a few thin bands of fine-grained sandstone; color, gray, green, and red	18
16. Massive arkose sandstone of a red color, quite conglomeratic in the middle, resting upon a pink arkose conglomerate 2 feet thick	22
15. Crumbling shale, containing nodules of gray limestone; color, red	20
14. Sandy fossiliferous limestone; red	2
13. Series of variable sandstones; in the upper part the sandstone is thin bedded and alternates with shale; in the lower part the sandstones are of coarser grain; one layer showed probable worm borings; color, dark red, except for a few gray streaks	27
12. Gnarly limestone, earthy in the upper part	4
11. Friable sandstone and thin shale layers; color, dark red	15
10. Thin-bedded sandstone, passing downward into massive arkose sandstone and conglomerate; color, reddish	16
9. Crumbling shales of a dark-red color, containing band of gnarly limestone in the middle part	10
8. Arkose sandstone and conglomerate, pink or white, 2 to 3 feet	3
7. Micaceous calcareous sandstone and shining shales; color, dark red	3
6. Fossiliferous limestone, 1 foot to 15 inches	1
5. Micaceous sandstone, showing poikilitic structure, and containing some fossils; the upper part is rather massive; the lower part rather thin bedded and shaly	9
4. Fossiliferous limestone, 18 inches to 2 feet	2
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PERMIAN (?) SERIES.

CUTLER FORMATION.

Name and definition.—This formation is defined as including the Carboniferous portion of the "Red Beds" lying above the Rico formation where that is present, or, where that can not be distinguished, as succeeding the Hermosa formation.

Owing to the existence of a stratigraphic break above the Cutler formation on the northern slope of the San Juan it can not at present be asserted that the full thickness of the Cutler is shown at any point. But in the Rico quadrangle and adjacent territory the unconformity referred to has not been detected and the Cutler strata are overlain by the Dolores (Triassic) beds. The Cutler formation embraces an observed maximum of nearly 1600 feet of alternating sandstones, sandy and calcareous shales, grits, and conglomerates, with occasional impure limestones or marls.

The name is derived from Cutler Creek, a tributary of the Uncompahgre River a few miles north of Ouray, and it was first used as a formation name in the Silverton folio.

Description.—The principal features of the Cutler formation are, on the one hand, the heavy grits and conglomerates and, on the other, rather crumbling, calcareous sandstones free from pebbles and grading into sandy marls or impure limestones of conchoidal or irregular fracture. The grits and conglomerates occur in massive beds reaching a maximum thickness of 40 feet. Their alternation with finer-grained and softer beds causes a succession of benches and ledges on numerous lateral ridges of the Dolores Valley. The grits are usually rich in pink feldspar and white quartz and are either gray in color or have a much lighter pink tone than the average of the formation. Pebbles are scattered sparingly through the grit layers, causing transitions to conglomerate, and the gravel matrix is abundant in the latter strata.

The pebbles of the conglomerate average but a few inches in diameter, but are occasionally more than a foot. The clastic materials of the Cutler beds are derived chiefly from granites, schists, and the ancient quartzitic sediments of the San Juan region.

The coarser strata are often rich in feldspar. Limestone pebbles characterize certain conglomerates, but are comparatively rare. Certain much-decomposed porphyritic rocks have been noted in the Cutler conglomerates of the Dolores Valley, but such materials are much more abundant in the conglomerates of the Uncompahgre Valley.

A calcareous cement is common in all the Cutler sediments. Not infrequently certain marly strata grade into sandy limestones which have a peculiar conchoidal fracture. There are local occurrences of thin reddish or gray limestones, which appear to be homogeneous on freshly fractured planes, but look rather like conglomerate on weathered faces. In some cases there is an apparent gradation from massive limestone to a rock with many rounded fragments in a scanty matrix of sand. These appear to be intraformational conglomerates.

Nearly all the fine-grained strata are deep red in color and in such cases contain a ferritic pigment in minute particles. The color is never so bright red in the Cutler beds as in the overlying Dolores formation. The grits and conglomerates are grayish or pinkish in color, owing chiefly to the abundance of pink grains of feldspar.

A characteristic of the shaly strata is the abundance of mica, commonly muscovite, but in some cases biotite. Such strata are notably fissile as compared with the more calcareous layers.

Distribution.—The Cutler formation has a wide distribution throughout the quadrangle, as will be evident on a glance at the map. In the main Dolores Valley the terraces or benches caused by the more massive grit conglomerate are very striking. The formation appears also in the valley of the West Dolores River, but is there by no means so prominent as in the main valley. The formation occurs chiefly in the region east of the Rico quadrangle, in the Animas Valley and its various branches.

Age and correlation.—The Cutler formation is provisionally assigned to the Permian series on account of its stratigraphic position. It succeeds the Rico beds, whose fauna shows some affinities with that of the Permian of the Mississippi Valley, but is perhaps more closely allied to the fauna of beds underlying the Permian of that area. Above the Cutler beds occurs the stratigraphic break discovered at Ouray below the Dolores (Triassic) conglomerate. If the Carboniferous section is complete in the San Juan region the Permian portion is surely represented in the Cutler formation.

It is of course possible that the pre-Dolores uplift and erosion may have occurred in Permian time, and in that case the Cutler beds are referable either to the early Permian or to the late Pennsylvanian epoch.

A reference of the Cutler beds to the Permian seems natural at the present time, because of the current assignment to the Permian of somewhat similar formations in the Zuñi Plateau of New Mexico, in the Grand Canyon region, in Wyoming, Kansas, Oklahoma, and other districts. In all these cases invertebrate faunas have been obtained which are, to say the least, much younger in aspect than the Rico fauna. The Cutler beds may for the present be considered as corresponding more or less closely to these upper portions of the Paleozoic section now commonly called Permian.

TRIASSIC (?) SYSTEM.

DOLORES FORMATION.

Name and definition.—The name Dolores was originally proposed in the Telluride folio (1899) for the Triassic strata of southwestern Colorado and adjacent territory. When the formation was established it was recognized that future discoveries might show that the major part of the "Red Beds" may belong to the Carboniferous system, although the fossil content of the beds had already demonstrated the correctness of the common view that the upper portion, at least, was Triassic.

Deducting the Cutler beds, which were provisionally assigned to the Dolores in the Telluride and La Plata folios and in the Rico report, there remain to the Dolores formation in its normal development several hundred feet of typical "Red Beds," consisting chiefly of vermilion sandstones and calcareous sandy shales. At the base is a variable section of shale, sandstone, and limestone conglomerate, scattered through which are fossil remains. This section is not always of reddish color, as it presents gray or greenish hues in many places. These variably fossiliferous strata always occur at the base of the formation so far as known. In the San Juan region the formation is delimited both above and below by stratigraphic breaks, which are, however, not demonstrable as such at many places. The upper limit of the Dolores, adjacent to the San Juan Mountains, is probably everywhere the plane of pre-La Plata (Jurassic?) erosion. That erosion was greatest to the north of the San Juan, and it is possible that in the plateau country of Utah the Triassic beds may preserve their full thickness.

The name was chosen because of the typical exposures of the upper "Red Beds" in the Dolores Valley in the Rico quadrangle.

Description.—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 the aggregate some 250 feet in thickness. This series of beds is characterized by the limestone conglomerates and by the fact that the strata are more often greenish or gray than distinctly red in color. All the known fossils of the formation also occur in these beds.

The limestone of the conglomerate is usually very fine grained and seldom resembles the limestone of the Carboniferous. No fossil-bearing pebbles have been observed. Commonly the pebbles are very small, and they are often so minute and so uniform in size as to suggest a pisolitic character, an impression which is, however, not confirmed by microscopical examination. The diameter of the pebbles reaches several inches in some cases, but averages only a small fraction of an inch. 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. In some places a ledge 20 feet in thickness may consist chiefly of conglomerate with numerous sandy partings, while only a few yards away the same beds may consist chiefly of sandstone with numerous thin layers of conglomerate, some of them less than an inch in thickness. Other bands of conglomerate are more persistent, but it seems probable that no single stratum of conglomerate is continuous for any great distance.

These peculiar conglomerates are most common in association with a series of thin-bedded gray sandstones and greenish shales aggregating 50 to 75 feet in thickness. Carbonized plant stems are common in these beds, but determinable leaves have not been obtained.

Limestone conglomerate always occurs at the base of the formation, or is, at least, present in the lowest beds in the variable manner described. Cross-bedding is common in the sandy conglomeratic strata. Wavy ripple marks, trail markings, and mud cracks are occasionally found in the finer-grained sandy shales.

The upper portion of the formation is usually a succession of fine- and even-grained quartzose sandstones and sandy shales, in many places presenting no distinct subdivisions. It varies from place to place, being massive and resistant to erosion or friable and crumbling. The color is generally bright vermilion and these strata thus stand in marked contrast to the La Plata sandstone above, which throughout the San Juan district is nearly white.

The thickness of the Dolores formation varies greatly throughout the Rico and adjacent quadrangles. This is chiefly due to the pre-La Plata erosion. About the La Plata Mountains the formation reaches nearly 800 feet in thickness. Thence northward it becomes much thinner, being about 400 feet near the northern line of the Rico quadrangle, locally but 30 feet on the San Miguel River, near Ouray about 50 feet, and still farther north disappearing entirely.

Distribution.—As the geological map clearly shows, the Dolores is one of the most widely distributed and prominent formations of the quadrangle. The brilliant cliffs of the upper massive sandstones are striking features of both the main Dolores Valley and its western branch. As the strata rise toward the Rico Mountains they are less prominent, but many striking cliff exposures exhibiting the characteristic vermilion color may be seen.

The lower division, with its fossiliferous limestone conglomerates, is well exposed in many localities and its general gray-green color often causes it to be conspicuous. The railroad cuttings from the mouth of Bear Creek westward for several miles exhibit this section of the formation very well.

Age and correlation.—The Dolores formation is regarded by paleontologists as of Triassic age, this determination being based on the scanty, yet widely distributed vertebrate, invertebrate, and plant remains obtained from it. The limestone conglomerates usually contain fragmentary bones and fairly well-preserved teeth of crocodiles and dinosaurs of Triassic types. According to F. A. Lucas, the former belong to the genus *Belodon* or allied forms and the latter to the megalosauroid genus *Palæoctonus*. The limestone conglomerates are so often characterized by these remains that careful search of a good exposure seldom fails to reveal bone or tooth fragments.

A small gasteropod shell, determined by T. W. Stanton as belonging to *Viviparus* or some closely related genus, has been found in the limestone conglomerate in the Rico and La Plata quadrangles. A single determinable plant, stated by David White to resemble the Triassic species *Pachyphyllum münsteri*, was found in a railroad cut near the northern border of the quadrangle.

Correlation of the Dolores formation with strata of supposed or determined Triassic age in other parts of Colorado, or in the adjacent portions of Utah, Arizona, and New Mexico, is at present complicated by the fact that in most places the "Red Beds" sections have not been studied in detail.

The fact that vertebrate fossils have been obtained at various times from the Triassic strata of New Mexico, Arizona, Utah, and Wyoming suggests that the fossiliferous portion of the Dolores may be represented over a wide area. But close correlation is manifestly impossible until the local faunas have been more thoroughly studied. This question has been discussed by the writer at greater length in the Telluride and La Plata folios, and still more fully in a paper entitled "The Red Beds of southwestern Colorado and their correlation," read before the Geological Society of America at the Philadelphia meeting, 1904.

JURASSIC SYSTEM.

LA PLATA SANDSTONE.

Name and definition.—The La Plata formation was first 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 calcareous member between them, lying at the base of the fresh-water complex commonly assigned to the Jurassic in western Colorado. The base of the formation is the well-known plane of unconformity at which the lower sandstone overlaps all older sedimentary rocks to the Archean, as shown north of the San Juan Mountains and elsewhere. This angular unconformity is probably responsible for the gradual decrease in the thickness of the Dolores formation from the La Plata Mountains northward, but it is not clearly exhibited at any special locality in the Rico quadrangle. The upper limit of the La Plata is drawn at the base of the marked clay shale of greenish or reddish color which signalizes the beginning of the alternating shales and sandstones grouped in the McElmo formation. No determinable fossils have been found in the La Plata formation adjacent to the San Juan Mountains.

Description.—The total thickness of the La Plata ranges from 250 to 500 feet in the Rico quadrangle. It decreases to a minimum of 100 feet in the Telluride quadrangle, and increases to an unknown maximum toward the west. The sandstones are very white, massive, fine and even grained in texture, and consist chiefly of quartz. They present in some places bands 75 feet or more in thickness, within which the stratification is hardly discernible except in large exposures. Such beds often form steep cliffs or smooth and rounded faces of bare rock. The sandstone is normally very friable and in some of the more massive layers a marked cross-bedding appears which is sometimes brought out by lines of shading rather than by change in character of the sandy particles. Intricate and delicate veining of secondary white quartz occasionally appears in the more massive layers.

The lower sandstone, while usually of white color, is in some places brilliantly colored in varying shades of orange and yellow. This coloration ordinarily extends quite irregularly from the base of the formation upward and is usually very distinct from the vermilion of the underlying Dolores sandstone. The intermediate calcareous member of the formation is less homogeneous than the sandstones between which it lies. Within the Rico quadrangle it varies in thickness from 75 to 260 feet. It consists of an alternation of sandstones, some of which are red and some white, with sandy and calcareous shales, which in many places grade into thin limestones. One of the bands of red sandstone in this complex is characterized by little rosettes or angular grains of carnelian.

Distribution.—The La Plata sandstones form a very conspicuous member of the sedimentary series, commonly appearing at a certain distance below the Dakota sandstone which forms the scarp of the Dolores Plateau. The white sandstones contrast markedly with the bright red of the Dolores formation below and the duller tones of the McElmo above. Such massive sandstones naturally produce cliffs and the prominent ledge outcrops can often be seen for long distances. As the map shows, there is a tendency to the formation of projecting shoulders composed of the La Plata, while the bench above them marks the base of the McElmo. Some of the western peaks of the Rico Mountains are capped by the La Plata, but it has been eroded from the eastern summits.

Age and correlation.—The age of the La Plata formation is indicated by its stratigraphic position rather than by any other evidence. The only fossils thus far obtained from it in the region adjacent to the San Juan Mountains are some small and unidentified fish remains.

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 in the limestones occurring near the base of the Gunnison.

MCELMO FORMATION.

Name and definition.—The name McElmo was proposed in the Telluride folio for the series of shales and sandstones which lie between the La Plata and Dakota formations. This series is somewhat variable in thickness, ranging from 400 to 1000 feet in the part of southwestern Colorado which has been examined. The vertical limits of the McElmo formation are accurately determinable through the uniform character of the La Plata and Dakota sandstones between which it lies. The series itself is variable in character and no satisfactory criterion for its subdivision has been found.

Description.—In the Rico quadrangle the McElmo has a fairly uniform thickness of somewhat less than 500 feet. It is here composed more largely of shales than in the Telluride quadrangle, where its thickness on the San Miguel River is nearly 1000 feet and where sandstone forms the most important element of the formation. Shale and sandstone alternate in variable proportions. The shales are usually apple-green, but are sometimes of a deep Indian-red color, with occasional variegated bands of red and green. The shales are fine grained or sandy and occur in homogeneous bands, often several feet in thickness, with but little or no distinct lamination. The sandstones are also even grained and friable in texture, those of the lower portion resembling the La Plata sandstones, while at least one of the upper beds is very similar to the Dakota sandstone. The arenaceous layers are white or yellowish and are often found to grade horizontally into sandy shale and thence into clay shale. In the upper portion of the section there is a fine-grained conglomerate which is practically identical in character with the lowest conglomerate of the Dakota. The frequence of crumbling beds in the formation causes numerous gaps in all discovered exposures, and no detailed section can be given.

Distribution.—The distribution of the McElmo formation within the Rico quadrangle is limited to a narrow band between the La Plata and the Dakota sandstones. It occurs immediately beneath the plateau scarp caused by the Dakota and is usually marked by a débris-covered slope with numerous benches representing the sandstone layers. On account of the generally soft and friable nature of the strata, outcrops of notable extent are much less common than in the more uniform sandstone formations both above and below.

Age and correlation.—As mentioned above, the McElmo formation appears on stratigraphic and lithologic grounds to occupy the place of Lower Cretaceous sediments. But the age is provisionally 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 recently 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 group. That the McElmo, Morrison, and Como formations embrace certain equivalent strata is a conclusion scarcely open to further question. That the three formations are coextensive and thus fully equivalent can not be considered as demonstrated by present knowledge.

CRETACEOUS SYSTEM.

SECTION OF SOUTHWESTERN COLORADO.

No strata of Lower Cretaceous age corresponding to those of the section so well developed in Texas have been positively recognized in this part of Colorado. The Upper Cretaceous series is represented in southwestern Colorado by an important succession of formations, but is not lithologically divisible, for purposes of mapping, into the same formation units which have been adopted elsewhere. In consequence of this unusual character of the Upper Cretaceous section it has been necessary to establish certain new formations. The whole section is characteristically developed in the Animas Valley and its subdivision will be fully discussed in the Durango folio.

The Cretaceous formations distinguished in southwestern Colorado are as follows:

(1) *Dakota.*—The apparent equivalent of the well-known, widespread sandstone formation.

(2) *Mancos.*—A shale complex more than 1000 feet in thickness, which from its invertebrate fossils must be supposed to represent the Benton, Niobrara, and part of the Pierre formations, as commonly distinguished at the eastern base of the Front Range in Colorado.

(3) *Mesaverde.*—A series of alternating sandstones and shales, with some seams of excellent coal. Invertebrate fossils, which are not uncommon at several horizons, place this formation in the lower part of the Montana group.

(4) *Lewis.*—A sandy clay shale, reaching an observed thickness of nearly 2000 feet. The only identifiable fossil as yet found in the formation indicates that it is stratigraphically below the Fox Hills division of the Montana group.

(5) Above the Lewis shale is a second series of sandstones, shales, and coals bearing some resemblance to the Mesaverde formation but differing in detail. This series has not yet been fully examined. It may contain equivalents of the Fox Hills and Laramie divisions, as ordinarily recognized.

(6) *Animas beds.*—A complex of tuffs or conglomerates, mainly of andesitic débris. The fossil plants obtained from the tuff layers indicate a correlation with the Denver and other post-Laramie formations referred by paleontologists to the Mesozoic, although they are stratigraphically known to be later than the great revolution which terminated the conformable succession of Cretaceous sediments.

Of these formations the Dakota and Mancos only are present in the Rico quadrangle. In the La Plata folio may be found descriptions of the formations from the Dakota to the Lewis shale, inclusive.

DAKOTA SANDSTONE.

Description.—The Dakota formation of the Rico quadrangle has the general character common to it in Colorado. It is composed of variable gray or brownish quartzose sandstones, often cross bedded, with a peculiar conglomerate at or near the base and several shale layers at different horizons. Its thickness in the Rico quadrangle ranges from 100 to 250 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 very variable in development. Conglomerate of this character is not, moreover, strictly confined to the base of the section. The sandstones occur in beds reaching 30 to 40 feet in thickness. They are separated by clay shales which are usually carbonaceous and as a rule carry thin seams of coal. These shaly 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 has been mined on the west bank of the Dolores River, just north of the Rico quadrangle. It is known to occur at several places in the western part of the quadrangle and also in the vicinity of Lost Canyon, and it seems probable that one or more thin coal seams are present wherever the formation is represented on the map. This coal is not comparable in quality with the excellent seams of the Mesaverde formation and can not be of much economic value except in the plateau country remote from railroads.

Distribution.—The Dakota sandstone is, as a rule, much more highly indurated than the La Plata or McElmo sandstones. It therefore resists erosion and becomes prominent in scarps facing the canyons that cut below it in the plateau region. This formation is the floor of the plateau over hundreds of square miles.

The Dakota sandstone is seldom well exposed in its entire thickness in the Rico quadrangle. The upper part is wanting in almost all of the exposed sections. It is assumed that approximately 50 feet of the formation is missing from the mesas west of Bear Creek and north of the Dolores River—that is, erosion has not only cleared away the Mancos shales from above it, but has also removed the upper part of the Dakota, which is less resistant than the lower portion on account of the presence in it of many thin shale layers.

MANCOS SHALE.

Name and description.—The body of shale which lies above the Dakota sandstone was named the "Mancos shale" in the Telluride folio on account of its characteristic development in the Mancos Valley, especially about the town of Mancos. In the Telluride quadrangle the formation is present as a succession of dark clay shales nearly 2000 feet in thickness, 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 always somewhat sandy. Thin calcareous layers become limestones in places and are often rich in fossils. Quartz sand also locally increases in amount, but no limestone or sandstone layer is sufficiently developed to be traced for considerable distances. Invertebrate fossils frequently occur in the Telluride quadrangle at horizons about 125 and 225 feet

above the Dakota. The common fossils of these horizons, *Ostrea lugubris* and *Gryphæa newberryi*, are characteristic of the Benton shale division of the Colorado group. At higher horizons other fossils are known which are characteristic of the Pierre division of the Montana group. It is therefore believed that the Mancos shale embraces equivalents of the Benton, Niobrara, and Pierre formations, though not extending to the top of the latter.

Distribution.—There are two areas of Mancos shale within the Rico quadrangle. One of these is at the head of Priest Gulch, where it has been preserved by a northeast-southwest fault as represented on the map. In this locality one of the fossiliferous bands is exposed. The other area lies to the west of Bear Creek, on the northern slopes of the La Plata Mountains. At this place approximately 600 feet of shales are present, but the exposures are very poor because of the dense covering of spruce forest and a local slipping or creeping of the shales. The lower fossil layers were found in this region.

QUATERNARY SYSTEM.

Varieties of Quaternary deposits.—The surface deposits of the Rico Mountains are of diverse character and origin, and they are not in all cases easily separable. They add greatly to the labors of the geologist, since they cover several areas in the central part of the region to such an extent that it has been found impossible to work out the geology of the solid rocks underneath. The surface materials have been represented on the map in five divisions, as follows: (1) Principally landslide débris; (2) principally talus and wash, with glacial gravels, soils, etc.; (3) valley alluvium; (4) torrential fans; (5) calcareous tufa.

Outside of the mountainous area the valley alluvium is the only one of these formations of sufficient importance to be given representation on the map.

LANDSLIDE DÉBRIS.

While landslide blocks of any considerable magnitude are not strictly to be classed with detrital material of much finer fragments in process of transportation by ordinary agencies, those of the Rico Mountains are, in fact, very intimately mingled with talus and wash débris and may be described most conveniently in this place. In the Rico report a special chapter was devoted to landslides, giving many details as to their character and distribution and discussing their origin. The treatment of these masses in this folio must be concise and the reader desiring further information is referred to the report.

Description of landslide masses.—The areas represented on the map as occupied by landslide débris exhibit a confused aggregate of rock masses or blocks which have slipped down the slope from some higher position. The blocks are often several yards, or even a few hundred feet, in diameter. When composed of sedimentary rocks it is found that dip and strike are discordant and irregular and it seldom happens that adjacent blocks consist of the same strata, for the amount of slipping varies greatly.

In several areas the landslide débris occupies the whole slope from the crest of a ridge to the stream bed of the adjoining gulch. In other places the upper limit is a cliff, a scar formed in part by the detachment of the landslide blocks. Both sedimentary and igneous masses are involved, even the massive monzonite stock of Darling Ridge having been extensively affected.

The greater part of the landslide action occurred long ago, but the individual blocks of the original slips have been in most cases shattered by their fall into minor masses which have slipped farther, and the movement is still in progress in many places. Naturally the shattered blocks suffer rapid disintegration through the action of water and frost, so that in some areas there are now very few outcrops to show the character of the material beneath grassy or timbered slopes. The ridge between Burnett and Sulphur gulches exhibits this advanced state of disintegration. Pl. XIX of the Rico report shows the character of the crest of the ridge.

The detailed topography of a landslide slope is eminently characteristic. There is no surface drainage system in most cases, because water naturally sinks through the numerous fractures to solid bed rock and ravines caused by torrents are often filled by subsequent slipping. Lateral trenches, lying above the larger blocks, are more prominent than erosional ravines. But the continual disintegration of all landslide blocks modifies the topographic detail until it comes to resemble that common in areas of glacial gravels.

On the illustration sheet (figs. 3, 5, and 6) will be found three views representing landslide areas, from which some idea may be obtained of the magnitude of the movement and the characteristic appearance of the slopes in their present condition. The explanations accompanying the views call attention to their more instructive features. In the Rico report will be found nine other views illustrating the varying characters of different slide masses.

Distribution.—Important landslide areas occur in the central portion of the Rico Mountains on both sides of the Dolores River. The larger areas lie to the west of the river and either side of the great monzonite stock of Darling Ridge. One large area extends from near the summit of Telescope Mountain to the river.

The only slide mass of importance situated on the outer slope of peaks of the Rico dome is that on Landslip Mountain, south of Burnett Creek. Other smaller slides were found in the outer zone, but they have usually become so greatly broken up and mingled with talus that they are not distinguished on the map as landslide débris.

On the various ridges radiating from the Rico dome the landslide phenomena soon become limited to small avalanche falls from a high cliff or pinnacle, such as are common in all areas of rugged topography.

The significance of the distribution of the landslides is considered in the section on "Geological history."

TALUS AND WASH.

Extensive areas in the Rico Mountains, especially adjacent to landslide masses, are covered by a varying mantle of surficial rock débris, soil, etc., which has effectually interfered with the mapping of the underlying solid-rock boundaries. It has thus been necessary to represent such areas on the maps.

Talus.—Accumulations from the wasting of cliffs are related in origin to landslides, but are composed of many small blocks loosened by frost action or by heavy rains, whereas landslides, though they may eventually become very much broken, are at first essentially large masses. Huge talus heaps are of frequent occurrence in the Rico Mountains, and while in many cases their even slopes are covered with vegetation, in other cases they are entirely bare and then plainly show the manner in which they are formed. Such masses entirely conceal the contacts of the alunite rock of Calico Peak.

Related to talus are the materials dislodged by avalanches and deposited where their force is spent. Much of the loose material upon Newman and C. H. C. hills has been brought down in this way.

The deposits of Papoose Gulch and in the head of Marguerite Draw east of Mount Elliott have been considered as connected with former great snow banks. Probably this is, in part at least, their true origin, but avalanches may have been also concerned in their formation.

Surface wash.—In regions where the agents of erosion have been as active as at Rico rocks do not decay in situ by surface weathering, and consequently residual soils, such as cover the rocks in many low-lying regions, do not accumulate. Surface wash is composed almost entirely of fragments derived from the higher slopes of the mountains or from the disintegration of landslide masses which, gradually moving toward the valleys under such effective aids to gravity as snow, rain, and frost, have been spread in varying thickness over extensive slopes, hiding the underlying formations as completely as the more massive landslide materials have done.

As in the case of all the surface deposits, the representation of wash on the map is generalized and the indicated boundaries are to be taken as approximate. The symbol under which talus and wash are included is intended to apply to all areas not referable to either landslides, valley alluvium, or torrential fans. It thus comprises the materials of mixed origin covering Newman Hill and the opposite slope west of the river.

ALLUVIUM.

The alluvial deposits of the Rico quadrangle shown on the map are confined to the flood plains of the principal streams. They are not continuous, being interrupted by torrential fans, landslides, or stretches of solid rock.

One notable flood-plain deposit extends for a mile and a half above Burns. It is clearly due to the damming of the river by a landslide from C. H. C. Hill, forcing the stream against the cliffs of Sandstone Mountain. It is estimated that the depth of alluvium at Burns may be as much as 75 feet, since it seems probable that the grade of the river bed previous to the landslide was nearly uniform.

On the West Dolores the valley bottom is wide and a continuous band of alluvium follows its course across the quadrangle. The materials of the valley deposits are, as usual, coarse gravels and sands which the streams have derived from their tributaries and which have been rolled along until deposited on the broad flats of low grade.

TORRENTIAL FANS.

The steeper gulches which open directly into the Dolores Valley within the Rico Mountains have all contributed detritus faster than the river has been able to carry it off, so that the débris has accumulated in low conical banks at the mouths of the gulches. Such accumulations are commonly known as alluvial cones or torrential fans. They are a characteristic feature of the union of streams of steep grade with those of low declivity, since the transporting power of the steeper streams is suddenly diminished when their grade is reduced. The side streams at Rico do not at ordinary times carry any appreciable load of gravel, transportation being confined to times of flood. Heavy showers and cloud-bursts sweep any available débris into the steep gullies, and these, carried down to the main valley, are dropped and the channel of the stream becomes inclosed by natural dikes, so that on becoming choked at any time the torrent will take a new course and, changing from time to time, will finally have swept through an arc limited by the valley walls and varying usually from 90 to 120 degrees. It is thus by changing its channel that the stream is able to build up the fan-shaped heap at its mouth.

At Rico many of the characteristics of torrential fans are beautifully illustrated. An inspection of the special map will show the extent of the principal ones and the different relative positions of the stream channels upon the cones; in several cases the contouring indicates the lines of former channels. The typical appearance of the torrential fans is shown in fig. 4, from a photograph of the Aztec fan.

A portion of the surface materials upon the hillside west of Rico may have been formed in the same manner as the fans of the lower valley, which they very closely resemble as topographic features. These have not, however, been distinguished from the adjacent surface wash.

CALCAREOUS TUFA.

Spring deposits.—The Rico Mountains are well watered, and even in the driest seasons most of the gulches contain very considerable streams which are fed by springs. The water of the springs is usually impregnated either with lime or with iron, probably of rather superficial origin, and locally these ingredients are frequently present in sufficient amounts to separate from solution and form deposits upon the surface or in the interstices of gravel or other loose surface materials. In some cases the waters, besides their mineral contents, are impregnated or accompanied by gases, such as sulphureted hydrogen and carbonic acid gas.

The generally calcareous nature of the spring water at Rico is a direct result of the richness of the prevailing sedimentary formations of the central region in carbonate of lime, but in most cases the amount of this substance held in solution is not sufficient to give rise to important deposits of tufa. There are, however, several such deposits which are situated upon the lower slopes in localities where loose materials cover the solid rock for some distance above the springs.

The principal deposits of calcareous tufa have been outlined on the maps, by reference to which their extent and distribution may be seen.

At one locality the tufa has been quarried for a kiln and has found a considerable use, since it is conveniently located and produces lime of good quality.

Iron-bearing springs also occur at several places in the Rico Mountains, and have left local deposits of iron oxide, cementing surface débris and forming what is commonly known as "iron cap." Though occurring at other places, these ferruginous conglomerates are especially in evidence in Silver Creek above the Fort Wayne tunnel, in the upper part of the northern and western branches of Horse Gulch, and in the lower part of Horse Gulch at the base of the northern landslide area.

IGNEOUS ROCKS.

Introductory statement.—By far the greater number of the igneous rocks occurring in the Rico quadrangle are directly connected with the eruptive center in the Rico Mountains. A very few masses near the southern border belong to the La Plata center, and it may be assumed that the small dikes at some distance from either mountain group are genetically related to one or the other of these eruptive areas.

A very large share of the igneous bodies occur within the bounds of the Rico special district and were described in some detail in the special report. The Telluride and La Plata folios also contain descriptions of the same or similar rock types, so that it seems unnecessary to present in this folio more than a general statement as to the petrographic character of the various types.

The igneous rocks are distinguished on the map under five heads: Hornblendic monzonite-porphyry, pyroxenic monzonite-porphyry, monzonite, Calico Peak porphyry dikes, Calico Peak porphyry alunitized, and basic dikes. All are considered to be of Tertiary age.

HORNBLENDIC MONZONITE-PORPHYRY.

The intrusive sheets and dikes occurring in the Rico Mountains are nearly all of one chemical and mineralogical rock type, but present many minor textural variations, which were no doubt caused by slight local differences in the conditions attending their consolidation. These modifications do not obscure the similarity in composition when the rocks are studied under the microscope, but some masses are too fine grained for the unaided eye to recognize their constitution with certainty, and decomposition often renders the character obscure.

The rock of the larger sheets and of many dikes is a very distinct porphyry of general light-gray tone, with an even balance between phenocrysts and groundmass. The most abundant phenocryst is a plagioclase, determined in some cases to be labradorite, developed in the common stout prismatic crystals. Dark-green hornblende in small prisms is the only other constant and essential phenocryst. Small quartz crystals, almost invariably well rounded by resorption, are sparingly present in a few cases, but can usually be detected in the hand specimen only on close scrutiny with a lens. The gray and homogeneous-appearing groundmass consists of orthoclase and quartz.

The most striking variation in texture noticeable in these rocks arises from the development of the plagioclase phenocrysts. These are much more abundant than hornblende and, as a rule, are larger. But they may be nearly uniform in size or present a gradation from the largest to those scarcely distinguishable by the naked eye. In the sheet crossing the Dolores Valley at Montelores, for example, the plagioclase crystals are uniformly 2 to 3 millimeters in diameter wherever that mass was examined. More commonly there are numerous crystals of 5 millimeters or more, though seldom reaching a size of 1 centimeter, in diameter. The common color of the plagioclase is white, and the centers of the larger crystals may be clear and glassy. In many places the crystals have become clouded by ferritic particles and muscovite.

The predominant porphyry of the Rico Mountains, above described, is practically identical with the principal rock type occurring in precisely the same manner in the Henry, Carriso, El Late, and La Plata mountains, and in many places in Colorado.

PYROXENIC MONZONITE-PORPHYRY.

Two long dikes of the Rico quadrangle belong to a variety of monzonite-porphyry different from the common form of the Rico Mountains. One of these dikes crosses the Dolores River a short distance above the mouth of Bear Creek and has been traced for several miles up the valley of the latter stream. It appears to belong to the La Plata center of eruption. The other dike of similar rock crosses the head of Priest Gulch, and from its course would seem to be connected with the Rico center.

These two porphyries contain a larger amount of feldspar than the prevalent porphyry of the Rico Mountains, and the dark silicate was probably wholly augite, for cross sections of the prisms are octagonal, but no traces of its unaltered substance have been found. The feldspar phenocrysts are all plagioclase and the felsitic groundmass mainly alkali feldspar, the two kinds being nearly equal in amount in the rock as a whole. It is supposed that the groundmass feldspar is orthoclase rich in soda, from the scale-like shape of the particles and the general resemblance of these rocks to certain porphyries of the La Plata Mountains which were called syenite-porphyry in the La Plata folio. Quartz occurs but rarely in the groundmass.

MONZONITE.

The mass of the large stock west of Rico is a gray granular rock containing orthoclase and plagioclase in about equal amounts, carrying a little quartz in most places, and having a variable development of augite, hornblende, and biotite. The feldspathic constituents strongly predominate over the ferromagnesian silicates. The rock thus belongs in the group intermediate between the syenites and diorites to which Brögger has given the name monzonite, from the type locality of Monzoni, near Predazzo, in Tyrol.

The rock is, as a rule, of medium grain, the variation in this respect ranging from rather coarse to fine grain, but not to a texture that is strictly aphanitic. With a hand lens nearly all the mineral particles can sometimes be recognized in the coarser specimens, including apatite, titanite, and magnetite. The texture is ordinarily typically granular, with local tendency to a development in which large grains of orthoclase include all other constituents. This texture is rarely very prominent megascopically, but almost invariably appears in some degree under the microscope.

The darker modifications are also the finer grained and often owe their shade to the finer particles of the dark silicates. The two feldspars are distinguishable in some places through the pinkish color of the orthoclase, but this is entirely lacking in many areas and the rock has then the appearance of a diorite, the term which would have been applied to these masses a few years ago. While this granular rock is similar to the prevalent porphyry of the mountains in chemical constitution, augite is much more abundant in it than hornblende, which is the characteristic dark silicate of the porphyries. Monzonites very similar to that at Rico occur in large stocks in the Telluride and La Plata quadrangles and have been fully described in the published folios.

CALICO PEAK PORPHYRY.

A rock of unusual character occurs in dike form on the north slope and elsewhere in the vicinity of Calico Peak, and in a sheet-like body in Dakota sandstone at the head of Priest Gulch. This rock is a porphyry of most marked appearance, characterized by large orthoclase phenocrysts in considerable abundance, some of them exceeding an inch in length. Associated with these prominent crystals are many smaller ones of plagioclase and augite, biotite, or hornblende. Quartz crystals are rare. The groundmass has much plagioclase and little or no quartz. On the whole it is estimated that the rock is much nearer the stock monzonite in composition than would be inferred at first sight. In the development of green augite and brown biotite there is a further link connecting this peculiar type with the monzonite. None was sufficiently fresh for analysis, but it is probable that the rock is somewhat richer in alkali feldspar than the monzonite, and hence approaches a quartz-bearing syenite-porphyry.

In point of time these dikes cut the earlier and common monzonite-porphyry, but have not been observed in contact with the granular stock rock nor with the basic dikes described below.

Dikes of this rock in Johnny Bull Gulch have undergone alteration like that of the Calico Peak rock, and resemble the latter very closely.

CALICO PEAK PORPHYRY, ALUNITIZED.

The cone of Calico Peak is made up of a light-colored rock which is either nearly white or stained various shades of red and yellow, often in brilliant hues. The rock has either a marked porphyritic structure or is highly brecciated. No contacts were seen, owing to the extensive talus slopes which conceal it on all sides. The alteration is so extreme that it is not certain that all of the rock belongs to a single mass, though it is apparently of that character.

The rock of the greater part of the peak was plainly porphyritic and contained many large feldspar crystals, and from this fact it is supposed that the rock was originally of the type of monzonite-porphyry with large phenocrysts of glassy orthoclase which has been described above as Calico Peak porphyry and which occurs in fresh form only in the vicinity of Calico Peak in long dikes as represented on the maps. In its present condition the rock of the peak contains no dark silicates; the former feldspar phenocrysts are represented either by a mass of white kaolin or by a granular mass of a nearly colorless mineral, ordinarily too fine grained for recognition. The altered groundmass is grayish in tone and may be fine or coarse grained. In some places the rock has become largely a porous quartzitic mass. The room of the larger feldspar crystals is seldom completely filled by the alteration product, which usually appears as an aggregate of rude plates, a definite crystal outline being, however, rare. These plates are rough crystals of alunite, the basal plane predominating and being bordered by the low hemihedral pyramid commonly developed in this mineral. No good crystals of polished faces were found.

At several places the freshly fractured rock was found to exhibit a very distinct yellow color in the porous areas representing feldspar phenocrysts, the color being due to native sulphur in minute round crystalline particles.

The more massive rock found in many places consists of a coarse-grained aggregate of irregular rude tablets with kaolin filling the interstices. Small veins of uniform fine grain also traverse the rock locally, the character of the material being unrecognizable megascopically.

Microscopical and chemical study of the Calico Peak rocks resulted in the identification of the principal substance of the mass as alunite, a hydrous sulphate of alumina and the alkalies, and shows that kaolin and quartz are the only other minerals of importance present in the specimens examined.

The alteration of the porphyry of Calico Peak into a rock consisting largely of alunite can be explained only as the result of the attack of sulphurous agents, and from the circumstances of occurrence there can be no doubt that the action is to be attributed to solfataric emanations of the Rico eruptive center in the period of waning igneous activity.

The general character of the Calico Peak rock is similar to that of the quartz-alunite rock occurring in the Rosita Hills, Custer County, Colo., described in the Seventeenth Annual Report of the United States Geological Survey (pt. 2, 1896, pp. 52–56). In the latter case the material was formed by solfataric action on rhyolite, in a small volcanic center, and the alunite made up a much smaller part of the rock than at Calico Peak.

BASIC DIKE ROCKS.

The geological maps represent a number of basic dike rocks occurring in various parts of the Rico Mountains, and a few others were observed in other parts of the quadrangle. These dikes are seldom more than a few feet in width and their length is apparently not great, though none of them has been accurately traced to its end. They are often irregular in course and are effectually concealed by slight coverings of débris.

The basic dike rocks of the Rico Mountains are closely related, as far as can now be ascertained, but few are fresh enough to allow an accurate determination of their original composition. The ferromagnesian silicates greatly predominate, common greenish augite being the most constant and abundant, with variable amounts of olivine, reddish-brown biotite, and brown hornblende. Magnetite is present rather sparingly. The feldspathic constituents are partly orthoclase, partly plagioclase, and analcite may have been present in some cases. The habit of the freshest rocks is decidedly basaltic, through the abundance and form of development of augite and olivine.

From the comparatively subordinate rôle ordinarily played by plagioclase, these rocks fall in the group of olivine-bearing augite-vogesites.

Rocks similar to these occur in the La Plata Mountains, in the Durango, Engineer Mountain, and Telluride quadrangles, and, in fact, all over the country adjacent to the San Juan Mountains, as far as it has been carefully explored. There is much more variety among these dikes than is represented at Rico, where one type prevails to an unusual degree. In spite of the variations, these rocks are apparently connected in origin with the intrusive sheets and stocks of monzonitic magmas described above. They cut all other rocks and are distinctly the latest igneous masses of the region.

GEOLOGIC STRUCTURE.

As has been stated in the general sketch of the relations of the Rico quadrangle to the surrounding country, that area lies in the zone where the nearly horizontal strata of the Dolores Plateau come under the influence of the San Juan continental uplift. The general distribution and attitude of the sedimentary formations which have been described are controlled by that fact until they come within the local domal uplifts of the Rico or La Plata mountains. The geological map and the profile sections of the structure-section sheet illustrate these conditions. It will be necessary to give some further attention to the San Juan and Rico structures, but the influence exerted by the La Plata dome within the Rico quadrangle is very small and is clearly expressed by section C–C and the geological map.

THE SAN JUAN STRUCTURE.

The San Juan Mountains are flanked on the south, west, and north by sedimentary formations dipping away from the central mountainous mass, which, beneath the surface volcanics, consists of granite, schist, and Algonkian sediments. On the east the relations are not well known, but so far as the evidence goes it indicates that such strata as escaped erosion prior to the volcanic eruptions dip toward the east, or that in their absence the surface of the granite upon which they once rested slopes in this direction. The structure is thus seen to be that of a broad quaquaversal fold. Its diameter in an east-west direction, along a line drawn through Rico and the central portion of the Needle Mountains to the Piedra River, is upward of 60 miles. The amount of arching along this line, estimated from a study of the present dip and strike of the Dakota sandstone and a hypothetical restoration to the domal position it occupied before it had been removed by erosion, is approximately 10,000 feet. This is equal to the total thickness of the Paleozoic and Mesozoic formations involved. On the Rico side this amount of depression of the Dakota below the apex of the former dome is reached between the two branches of the Dolores, but slight northwestward dips continue for many miles beyond this to the gently warped plateau region, which, as a structural province, must be separated from that of the San Juan Mountains in a somewhat arbitrary manner on some line of steeper dips.

This simple San Juan structure has been obliterated locally by the Rico and La Plata domes, and the relations of the various structures can best be considered after the local centers have been described.

THE RICO DOME.

Elements of the domal structure.—The structure of the Rico dome has been well exposed by erosion. Directly through its center the Dolores River has cut its course, dividing the mountains into eastern and western groups, which are further dissected by the tributaries of the master stream. From almost any commanding position within the central part of the area the strata may be observed to dip in all directions away from the center of the group.

Figs. 1, 2, and 5 of the illustration sheet show the attitude of the strata in accord with the dome structure on the slopes of Dolores, Blackhawk, Sandstone, and Telescope mountains. The general structure thus exhibited in a large way is found to hold also in detail except in the faulted area, where the dips are in various directions.

Were the whole of the deformation expressed by such quaquaversal dips the structure of the region would be comparatively simple, but this is not the case; the strata have also been faulted, and in such a manner that the dome effect is increased by the displacement of the faults. To the rule that the upthrow of faults is toward the inside of the dome there are only a few exceptions.

Still another factor in the deformation has been the intrusion of porphyry sheets at various horizons. Concerning these it has been noted that they are more abundant in the upper horizons of the Dolores formation than in any other part of the section, so that their effect has been greater on the higher formations now removed from the central portion of the mountains than on the lower strata which still remain.

The structure of the area, where it is not obscured by surface deposits, may be learned from the distribution of the formations, as exhibited on the economic sheet accompanying this folio. On this map strike and dip have been indicated by an appropriate sign—the strike by a line drawn in its direction and the dip by a shorter line at right angles to it, indicating the direction toward which the strata fall, the amount of deviation from the horizontal being indicated in degrees. Aside from this the manner in which the formation lines and the sheets which lie in the stratification cross the contours on the mountain slopes indicates clearly the general dip of the rocks. On the east side of the center the structure is well brought out by the lines bounding the Rico and the upper part of the Hermosa formation, together with the accompanying igneous sheets. On the west side these horizons are largely hidden, but the distribution of the porphyries shows the structure, as do also the tongues of the La Plata and McElmo formations on the main ridges.

A profile section of the dome is exhibited by section A–A on the structure-section sheet. The profile line passes a little south of the center of the dome, in order to avoid the larger faults and thus to bring out the amount of domal folding the more clearly. It shows the extent to which the formations of Eagle Peak take part in the structure, and the dome is specially brought out by the band representing the Rico formation. The flat position of the formations in the Dolores Valley is due to the strike being so nearly parallel to the course of the section.

The porphyry sheets of Anchor and Expectation mountains are represented as branches of one body to express the fact shown on the north face of the former summit. It may be that they are distinct on the line of the profile.

An arm of the monzonite stock is shown as cutting across the strata on the eastern slope of Expectation Mountain, for the reason that a tunnel nearly on the line of the section encounters that rock on penetrating the landslide débris of the shoulder projecting into Sulphur Gulch.

In the Rico report another section is given further illustrating the domal structure.

Deformation by folding.—The profile section gives a basis on which the amount of the Rico uplift can be approximately realized at a glance, but a more definite conception may be gained by restoring, in imagination, some particular stratum to the position it may be assumed to have occupied before erosion of the uplifted rocks.

The most comprehensive view of the Rico structure is to be obtained from a consideration of the La Plata sandstone. Before the dome was dissected the base of this formation over the summit was at least 4400 feet above the lowest rocks now exposed at Rico on the line of section A–A, and probably somewhat higher, since the above figure is estimated from the thickness of the Hermosa, Rico, Cutler, and Dolores formations and the

Newman Hill porphyry sheet, and takes no account of other probable intrusive sheets. The base of the La Plata on this estimate must have been at about the altitude of 13,200 feet—500 feet or more above the highest peak of the Rico district. It is plain that some of this elevation may be due to faulting, but it will be seen from the map that the uplift by dislocation is mainly north of the line of section A–A.

The amount of local doming which is thus indicated may be seen by comparing the position of the La Plata in the vicinity. About 5 miles north of Rico the base of the formation crosses the Dolores River at an elevation of 9300 feet, showing a fall from the restored position over Rico of 3900 feet, or nearly 800 feet per mile, independent of the influence of the porphyry sheet. Beyond this outcrop the northward dips are continued for only a short distance, so that here we have the full measure of the local deformation in this direction. In other directions the fall per mile is less, but the dips are continued for a greater distance. Thus from the northwest around to the south the average deformation or dip slope varies from 400 to 600 feet per mile for a distance of from 5 to 8 miles, beyond which it gradually lessens as the distance from the center increases. The diminished dips continue for many miles toward the west into the plateau region. Toward the south they fall at the rate of about 500 feet per mile, and are met by the structure of the La Plata Mountains at a distance of about 7 miles. Also to the southeast, though the La Plata is missing, the lower strata fall at a rate of 300 feet per mile for about 8 miles, where the local structure is completely neutralized by the contrary dips away from the Needle Mountains. Four miles to the east the base of the La Plata is 1700 feet lower than over the top of the dome and dips to the northeast, in which direction it continues to fall for several miles.

The attitude which the formations would now exhibit along the line of the Dolores Valley were it not for the Rico dome may be plainly seen from the areal maps of the Telluride and Rico quadrangles. In the southwest corner of the former, only 6 miles northeast of Rico, the Dolores flows in a canyon whose rim rock is the Dakota (Cretaceous) sandstone in almost horizontal position—the floor of the Dolores Plateau over large areas. As the valley of the Dolores leaves the Telluride quadrangle the formations rise rapidly under the influence of the Rico uplift, but at the mouth of Bear Creek, 12 miles below Rico, the stream is again coursing in a typical canyon of the plateau country, the Dakota sandstone reappearing as the floor of the mesas or plateau remnants on either side. But for the Rico uplift the Dolores would be flowing in a canyon like those referred to, along the stretch where the Rico Mountains now appear. East of the valley there would be remnants of the Dakota forming sloping mesas like those common in the Durango quadrangle.

Deformation by intrusion.—The additional deformation due to sheets and laccoliths can not be estimated except in a very crude way from the bodies which have escaped erosion. In the central part of the area the Newman Hill porphyry, the influence of which has already been mentioned in the preceding section, has a thickness of 500 feet, proved by the exposures and the drill hole sunk in the Skeptical shaft. Another important sheet near the top of the Hermosa formation has a maximum thickness of 250 feet where it crosses the river above Montelores, south of the area of the special map, but thins out as it rises with the dome, until it finally disappears entirely in Deadwood Gulch. Its distribution is such that it can hardly be supposed to have been present in the central part of the dome. Other porphyries in this formation, so far as they are exhibited in surface exposures, are of minor importance and could certainly in no single section aggregate more than 200 feet.

The Dolores and Cutler formations seem to have presented especially favorable conditions for sheet and laccolithic intrusions; and these are localized, with respect to the dome, on the eastern and western sides. The portion of the section in which they occur does not contain similar intrusions to the north or to the south, where cut by the Dolores Valley. Whether or not there were like intrusions over the central part of the dome can not be determined, but it would seem more likely that they did not exist from the fact that no central crosscutting bodies of porphyry which could have fed them are known; however this may have been, the porphyries which now remain reach locally an aggregate thickness of perhaps 600 or 700 feet, and by this amount must have augmented the arching of the La Plata and higher formations.

The formations above the La Plata doubtless suffered still more deformation from injected porphyry bodies, but large masses of igneous rock are at present to be seen only in the cap of Elliott Mountain and in the Flattop laccolith to the northeast, on the line between the Telluride and Engineer Mountain quadrangles. The former is immediately above the La Plata sandstone, while the latter lies on top of the Dakota and is capped by the shale of the lower Mancos formation.

The mass of monzonite which cuts through the sedimentary rocks on the west side of the dome has caused a considerable amount of metamorphism in the adjacent rocks, but there is no evidence that the strata have been turned up around its periphery. Its influence in modifying the dome must be compared to that of the block faults near Silver Creek, but there is no basis for measuring it.

Deformation by faulting.—In the process of uplift or deformation by which the Rico dome was produced the strata were no doubt fissured and fractured to a considerable extent. At the present time a great many old fissures may be detected. Most of them are filled by vein matter, partly ore bearing, partly barren; and in some cases the evidence is clear that the veins are lines of faulting. The displacement of the faults varies from more than a thousand feet to that which is scarcely measurable.

The supposition that the faults of the Rico Mountains are fractures contemporaneous with the domal folding, merely expressing relief of great tension by rupture of the rocks instead of further bending, seems in itself natural, but is opposed by the considerations connected with the intrusion of the igneous rocks. From the generally accepted theories in regard to the relations of igneous intrusion of laccolithic character to domal uplift it is necessary to assume that the porphyry sheets of Rico are contemporaneous with or later than the principal uplift. But these igneous bodies are cut by all faults observed to come in contact with them. No single instance was found of a porphyry dike ascending on a fault fissure. Further, the monzonite stock is traversed by many quartz veins, some of them bearing sulphide ores. It is therefore necessary to disconnect the fault phenomena of this region from the primary domal uplift, although it is of course possible, or even probable, that some unidentifiable portion of the folding accompanied the faulting.

In character the faults vary from clean-cut fissures to zones of sheeting or brecciation many feet in width. Extreme brecciation is well shown in various portions of the Blackhawk fault; in the veins of the Calumet, Zulu Chief, and several tunnels near Rico; in the "great vein" of the northern part of C. H. C. Hill; and in the boundary zones of the Algonkian quartzites in Silver Creek. Sheeting is also seen in most of these localities.

The distribution of the main faults is shown by the map. The greater dislocations are near the center of the dome, but a large number of lesser fractures occur in the circle of peaks about it. A glance at the map will show that there is no pronounced systematic arrangement of the faults. In certain localities the principal fissures may have a common trend, with minor zones intersecting at oblique angles. This is illustrated in the southeastern part of the region, in Silver Gulch, in the Dolores Valley near Burns, and in Newman Hill. As a rule the faults are nearly vertical, but dip at variable steep angles in some cases.

The displacement of the faults in relation to the dome structure is subject to a simple rule for nearly all of those found at some distance from the center. When even approximately parallel to the strike of the strata the upthrow is on the inside, or toward the center of the dome. The only important exception to this rule is the great fault of Telescope Mountain, which must be classed with the block faults of Silver Creek.

It is evident that all faults obeying the above rule have served to increase the uplift near the center of the dome. But it must be assumed that most of them die out gradually as they pass upward, and it may be questioned whether any of the dislocations of less than 300 feet in amount cut through the Mancos shale, assumed to have overlain the Dakota sandstone at the time of uplift. The Blackhawk and Nellie Bly faults are the important ones following this rule, and their effect at the horizon of the La Plata sandstone must have been still measurable by hundreds of feet. But if the lateral extent of these faults be compared with the diameter of the dome, as represented in the section, it will be realized that the modification of the dome by dislocations following the rule stated above was not great and was confined to the central portion.

The faults bounding the Algonkian schists and quartzites differ from most of the other faults in that they limit small blocks pushed up in the heart of the dome. So far as the fractures are known they are nearly vertical. The amount of upthrust is indeterminable, for no remnants of the Paleozoic sediments lie on the Algonkian blocks. These old rocks, then, represent plugs punched up through the strata and porphyry sheets without much, if any, visible disturbance of the adjoining beds at the horizons seen. These blocks are comparable to the monzonite stock in this respect, but from their small size the disturbance in the dome structure above them must have been much less than that above the stock, assuming that the stock magma did not reach to the surface. These fault blocks may perhaps be regarded as quite analogous to the stock eruption, in that both seem to be comparatively recent manifestations of an upward force suddenly exerted, producing vertical fissures rather than folding. If the fault blocks represented by the Algonkian rocks of existing exposures extended upward for some distance with nearly vertical walls, their disturbance of the dome structure may have reached to the upper shale series of the Cretaceous, but if they wedged out upward the faulting must have been resolved into local tilting of adjacent beds.

The great fault of Telescope Mountain is so hypothetical as to its course and in its relations to various other possible fissures that little need be said here as to its effect on the Rico dome. If a single fault, it must have materially modified the symmetry of the dome at the horizon of the La Plata sandstone.

Description of faults.—While the reader must be referred to the detailed report on the Rico Mountains for full descriptions of the many faults observed, a brief statement will be given here concerning each of the more important ones, with special reference to their structural significance.

The fault producing the greatest dislocation has been named the Telescope Mountain fault from its situation on the southeastern slope of that peak. Its actual location is not positively known and yet the faulting movement which has evidently taken place on the general line indicated amounts to nearly 2000 feet. The special map shows the relations of formations demanding the assumption of this great fault. The most striking facts to be explained are the apparent great thickness of the Cutler formation on the southeast face of Telescope Mountain, and the evident dislocation of beds, made plain by the distribution of the Rico formation, on the western slope. The Cutler appears to have almost doubled its normal thickness of about 1800 feet and that fact shows about where the fault must be if the dislocation is not distributed on several fault planes. A visible fault occurs at the right place to represent the one required and has been assumed to be in fact the fissure on which the great displacement has occurred.

The landslide area of C. H. C. Hill and Telescope Mountain conceals the western extension of the great fault, although certain isolated exposures shown by the map indicate nearly the line it must occupy.

The throw of the Telescope Mountain fault is up on the north or outer side of the Rico dome, making it the most important exception to the general rule of upthrow on the inner side.

The Blackhawk fault, named from a mine where the displacement seems at its maximum, extends in a northwesterly direction for several miles from Blackhawk Peak. It crosses several other faults and as the dislocation south of Silver Creek is much greater than to the north it seems plain that much of the faulting on the Blackhawk has been diverted to the east-west fissures, or vice versa. The relative ages of the various faults concerned could not be established.

The upthrow on the Blackhawk fault is on the southwest or inner side of the dome. It amounts to nearly 800 feet in the vicinity of the Blackhawk mine and diminishes to the southeast. On the northwest side of Silver Creek, beyond the Nellie Bly fault, the throw is only 85 or 90 feet. Its course is obscured by landslide material on C. H. C. Hill, but there are several veins in the strike, and the small faults crossing the Dolores River at Burns are believed to belong to it.

The Nellie Bly fault is an important east-west fracture crossing the southwest spur of Telescope Mountain known as Nigger Baby Hill. On the south of this fault the formations have been upthrown about 75 feet on the crest of the hill. Tilting of the block south of the fault causes rapid decrease in the displacement to the east. To the west the fault is obscured, but seems to be represented by the Aztec vein, west of the Dolores, where a large but unmeasurable dislocation has occurred.

Nearly parallel to the Nellie Bly occurs the Last Chance fault, crossing the lower slopes of Nigger Baby Hill. Forming the northern border of the Algonkian quartzite and schist area, this fault is clearly one of the most important, structurally, in the region, but it is obscured by surface wash in many places and its western portion, in particular, is concealed. Its displacement must be more than 1000 feet on the north side of the quartzites in Silver Creek and it may be even more to the west, although apparently divided among three or four fissures in a zone crossing the Dolores.

The extension of the Last Chance fault to the Blackhawk is not seen on the surface, but seems a natural assumption, since it provides an explanation for the sudden increase in dislocation on the latter fissure south of Silver Creek.

The Last Chance fault is regarded as one of several fractures bounding the small masses of Algonkian and early Paleozoic rocks which have been upthrust near the center of the Rico Mountains. Other named faults of this complicated area are the Smelter, South Park, and Silver Creek faults, in addition to which various transverse fractures divide the wedge-shaped blocks into smaller ones.

On the southern side of the central area are two notable faults named after Deadwood and Spruce gulches, which they cross. These fractures have a general northwest-southeast trend and the upthrow is in each case on the northeast, amounting to a maximum of 250 feet on the Deadwood and 400 feet on the Spruce Gulch fault. They die out to the southeast and pass into the landslide area on the west side of the Dolores.

Besides the major faults which have been mentioned there are many minor ones, some of which are shown by the map, while there are a multitude of still smaller fractures of no structural importance. It is a fact, discussed by Mr. Ransome under "Economic geology," that the numerous lodes of ore-bearing fissures of the region are rarely coincident with structural faults of importance, but seem to represent later fractures produced in adjustment of the rocks after the larger dislocations had occurred. Some of this adjustment has taken place parallel to the bedding planes of the sedimentary rocks and produced what were called "bedding faults" in the Rico report. As Mr. Ransome points out, some of the so-called "contact" ore deposits characteristic of important mines are intimately related to these bedding faults. This movement may have begun with the initial domal uplift, but proof of such origin is not now obtainable.

RELATION OF DOMES TO SAN JUAN STRUCTURE.

The Rico and La Plata secondary domes are probably genetically related to the broader San Juan structure, though how close the relationship may have been can not be determined, since the interconnection of igneous intrusion and continental and orogenic uplift of the Rocky Mountain type is not at present understood. In both

cases the preservation of the mountains as regions of high topographic relief is due to the presence of igneous rocks which have been more resistant to erosion than the sediments would have been alone. The intrusions are in the form of stocks, dikes, and sheets. To the latter, which may in some cases have sufficient thickness to be of the type known as laccoliths, a certain amount of the observed deformation of the stratified rocks is certainly due. In the La Plata Mountains the mass of intruded matter of this nature shown in the horizons exposed is comparable to the deformation which they have suffered over and above that affecting the lower formations, which are covered and therefore beyond observation; so that if the porphyry included in the hidden strata should bear the same proportion to the sedimentary rocks as in the observed section, the doming should be accounted for without additional uplift. At Rico the structure and make-up of the dome is much better exhibited, and though the theory that the observed structure might be due to a huge laccolith lying between the Algonkian and Paleozoic rocks was at one time entertained as a working hypothesis, it is now known that such a mass of igneous rock does not exist, and that the amount of deformation which the uppermost strata of the region underwent was several times in excess of the amount of igneous material which was intruded into the strata below them; that is, the formation of the Rico dome is mainly due to a central uplifting force, apart from any actual intrusions of liquid rock material. That such a force was also active in the La Plata uplift may well be believed, for there, as at Rico, the thickest laccoliths or sills occupy a zone, so far as the rocks now remaining are able to show, at a distance from the center of the dome, and it is on these peripheral intrusions that the estimate of the sufficiency of the porphyries to produce the observed structure was based.

THE RICO MOUNTAINS.

It has already been pointed out that there are three natural topographical and geological divisions of the Rico quadrangle, viz, the Rico Mountains, the Dolores Plateau, and the main Dolores Valley. The formations of the quadrangle and the general geologic structure determining their attitude and distribution having been discussed, it does not seem necessary to give further descriptive details concerning the plateau and valley areas, the geology of which is very simple. But the Rico Mountains are so complex in structure, igneous phenomena, and other respects that a résumé of their prominent features is desirable.

The Rico Mountains have been carved out of the domal uplift of several elements, already described. Naturally the peaks exhibit most clearly the formations taking part in the dome and their structure, while the deep dissection by the Dolores and its branches displays the features of the core of the uplift. The exhibition of the latter geologic detail is, however, greatly obscured by the superficial landslide materials, which assume a position of much local importance.

THE CIRCLE OF PEAKS.

The main summits of the Rico group arrange themselves in harmony with the domal structure in a circular zone. They are remarkably uniform in height, a dozen peaks exceeding 12,000 feet in elevation, while the highest, Blackhawk, is but 12,677 feet, or 4000 feet above the river at Rico. The Dolores River divides the group into two nearly equal crescents.

EASTERN SUMMITS.

Mountains south of Silver Creek.—While nearly all the peaks of the Rico group exhibit many characteristic features of the local geology, those lying to the south of Silver Creek are most noteworthy, because they show not only the domal structure, but the effects of faulting and igneous intrusion, and the sedimentary section is more completely displayed than elsewhere, on account of the comparatively insignificant development of landslide masses.

Fig. 1 illustrates many features of these peaks as seen from the west side of the Dolores, looking nearly due east. The prevalent dip to the southeast is particularly brought out by certain massive limestones of the upper Hermosa, which cross the slopes of Dolores Mountain seen in the central part of the view, and by many lines in the higher summits, due to stratification or to intercalated sheets of porphyry.

The higher portions of all these peaks consist of the red Cutler or Dolores strata with sharply contrasting grayish porphyries. Excellent sections of parts of the Cutler are to be found in several places, one on the slope of Whitecap Mountain being shown in the figure. The presence of a thin limestone conglomerate of the fossiliferous section of the Dolores very near the summit of Blackhawk Peak shows the projected horizon of the La Plata sandstone to be but a few hundred feet above that mountain.

The influence of faulting is not self-evident in this illustration, yet the magnitude of the displacement on the Blackhawk fault is really shown, for the prominent limestone band of the Dolores Mountain slope is dropped on that fault to a level too low to permit its appearing within the field of this view on the farther side of Allyn Gulch.

The faults of this area are clearly shown in many places by their dislocation of porphyry sheets, but the grassy or timbered slopes seen in fig. 1 often hinder a connected tracing out of some of them. The splitting of the Blackhawk fault and the gradual decrease of dislocation are plainly visible on the slopes of Blackhawk Peak.

It may be seen from fig. 1 how well the occurrence of intrusive porphyry masses is exhibited on Whitecap Mountain and the narrow divide at the head of Deadwood Gulch. There are numerous other points at which these relations can be seen to advantage. One of these is on the high northern spur of Blackhawk Peak, where a large sheet makes cliffs several hundred feet high, shown in fig. 1. This mass extends around the head of Silver Creek, covering a large surface, as shown in part by the special map. The crosscutting relations of these porphyries, as they pass more or less obliquely from one horizon to another, are very plainly indicated.

In the Rico report may be found several views which will assist the reader in comprehending the character of this portion of the mountains. One of these views presents the country lying east of Blackhawk Peak.

Telescope Mountain and vicinity.—The northeastern quadrant of the Rico Mountains is comparatively simple in its geologic structure and possesses but one mountain summit of prominence—Telescope Mountain. The Cutler red beds here assume almost exclusive surface importance, through their duplication by the Telescope Mountain fault. They are overlain by the Dolores formation at a short distance east of the area covered by the special map. The high divide running irregularly east from Telescope Mountain, which forms the watershed between the head of the Dolores River and Hermosa Creek, a branch of the Animas River, has many high points above timber line in which the several formations may be studied.

The Rico and upper Hermosa beds form a scarp facing the landslide area of C. H. C. Hill on the northwest ridge from Telescope Mountain as shown in fig. 5. The general structure of the mountain may also be seen in this view from exposures near the summit.

The minor faults of this region are conspicuous through dislocation of porphyry sheets, while the largest fault of the mountains is scarcely identifiable on the ground.

The porphyry intrusions of this section of the Rico Mountains are less in number and magnitude than in any other part, being limited to a few thin sheets and dikes in the upper half of the Dolores formation. It is worthy of note, however, that a large laccolith occurs just above the Dakota sandstone about one-half mile beyond the northeast corner of the area covered by the special map, on the farther side of Barlow Creek. This mass is the Flattop laccolith, a portion of which is situated in the Telluride quadrangle. It is not clear that this large intrusion has actual genetic connection with the Rico center, as will be explained in the discussion of the intrusions under "Geological history."

The landslide phenomena of Telescope Mountain proper are so clearly exhibited in fig. 5 as to require little further comment. The actual head of the slide area is on the ridge leading southwest to Nigger Baby Hill and less than 500 feet below the summit of Telescope Mountain. The entire area represented on the map as landslide territory exhibits the characteristic topographic detail. At the upper limit and on the southern border of the landslide tract seen in the view there is evidence of recent movement. In the Rico report may be found a picture of a tree split in two by movement now in progress, and even more convincing evidence is exhibited in the crushed or twisted timbers of mine workings throughout the tract.

Many small landslides have occurred on the northern slope of Telescope Mountain, but the blocks have broken up thoroughly in their fall and can scarcely be distinguished from ordinary avalanche débris.

WESTERN SUMMITS.

Mountains north of Horse Gulch.—The domal structure of the Rico Mountains, causing sedimentary beds to dip away from the center, is well shown in the high ridge leading from Sandstone Mountain through Elliott Mountain and northward across the quadrangle line. The general attitude of the strata on this line is represented in the view of Sandstone Mountain and the next higher point on this ridge, forming fig. 2 of the illustration sheet. The Jurassic and Dakota (Cretaceous) formations on the divides leading outward from Elliott, Sockrider, and Johnny Bull mountains exhibit the same structure.

Elliott Mountain is conspicuous in contrast to other peaks of the group by reason of the light-colored La Plata sandstone, which forms cliffs below the capping mass of porphyry.

The few faults of this area illustrate the lack of system in these fractures, and none of them produces results very marked in the present topography.

The porphyries of this district illustrate several intrusive relations of interest. The laccolithic form is fairly well shown in the mass of Elliott Mountain, the remnant of which is over 600 feet thick beneath the summit, while the porphyry is not present across the saddle north of the mountain. There are many sheets and small dikes and the forking or crosscutting of some of these bodies is clearly exhibited.

In one of the branches of Horse Gulch is very imperfectly exposed the rock of what may be one of the principal centers of eruption. The porphyry is here seen to cut across the sediments, sending off numerous dikes and thin sheets. It is full of apparent inclusions and is penetrated by many angular arms of the wall rock. Unfortunately there has been great decomposition here and in addition the extremely complex relations are obscured to a large extent by soil, forest growth, and wash, so that the representation of the map is in some degree diagrammatic. In spite of these conditions, this locality is an excellent one in which to study complex intrusive relations.

Eagle Peak.—The westernmost of the Rico Mountains exceeding 12,000 feet in elevation is Eagle Peak. It lies beyond the line limiting the distribution of visible porphyry masses and therefore presents in least distorted form the simple structural relations of the sedimentary rocks taking part in the domal structure. Passing from the peak along the ridge to the west one has excellent opportunity to examine sections of the La Plata, McElmo, and Dakota formations and to observe the change from the domal structure to that of the Dolores Plateau.

Calico Peak.—The variegated coloring exhibited by the decomposed rock of this summit at the head of Horse Gulch has led to the current name Calico Peak. The original porphyry of this peak has been almost completely altered to a mass of alunite, kaolin, and quartz, impregnated with pyrite, the oxidation of which has produced the vivid red and yellow colors now so striking. Apparently the rock occurs as a small stock, although its contacts are concealed by talus or slide. It is supposed that the rock was similar to the porphyry of large orthoclase phenocrysts, of which a long dike crosses the slope of Johnny Bull Mountain, and which occurs only in this vicinity.

The formation of alunite is referable to sulphurous emanations, either directly by gases or indirectly through waters which have absorbed gases. That such activity has been specially marked in this vicinity is shown by existing springs which give off strong odors of sulphureted hydrogen, near the head of Stoner Creek and on Johnny Bull Creek not far from Calico Peak.

The appearance of Calico Peak, with its talus heaps, less the vivid colors, is shown in Pl. VII of the Rico report.

Anchor and Expectation mountains.—Between the heads of Horse and Burnett gulches are two high peaks, Anchor and Expectation mountains, in which the crosscutting and branching of intrusive porphyry sheets is exemplified in many places. Indeed, so numerous are the visible forkings of the porphyry masses here that the conclusion seems by no means far fetched that all the more or less irregular masses shown by the map in the northwest-southeast zone from Johnny Bull Creek to beyond Landslip Mountain belong to one intrusion. The rocks are visibly different only in minor details of texture.

Peaks southwest of Burnett Gulch.—The southwestern summits of the Rico group exhibit the Cutler and Dolores red beds in their normal position dipping away from the center of the dome. On the ridge leading south from Storm Peak the La Plata and McElmo formations are seen in typical development. The porphyry bodies in the red beds have been referred to as probably connected with those of Anchor Mountain.

The most interesting local feature of this section is the landslide mass on the south slope of Landslip Mountain. This occurrence illustrates very well the various phases in the history of a landslide area, from the newly fallen blocks seen here adjacent to the summit of the mountain, through the older, partially disintegrated masses of the middle slopes, to the forest-covered débris near the stream below, where sinks and trenches still demonstrate the existence of slide masses.

Darling Ridge.—Between Horse and Sulphur gulches is a high tract cut almost in two by the head of Iron Draw. Here occurs the large stock of granular rock, quartz-monzonite, which appears to have been one of the later intrusions, if not the last, of the Rico center. The contacts of this stock are not well shown at any point, mainly on account of the shattered condition of the monzonite mass, which has resulted in talus or loose broken-rock piles, where larger landslides have not taken place. The metamorphosed condition of the sedimentary rocks on either side of the monzonite on Darling Ridge is everywhere evidence of the proximity of the contact.

Although the monzonite body is large and such massive rocks usually cause rugged topography, such is not here the case. This fact is probably due to the thoroughly shattered condition of the stock, leading to rapid destruction of prominences by frost. The large number of small knobs and knolls, often with pinnacled spurs or summits, situated on the north side of Darling Ridge, are plainly separated by zones of fracture and brecciation and are themselves crumbling to pieces under frost action. The assignment of these knolls to the landslide area will be discussed in the next section of the text.

THE INNER SLOPES OF THE MOUNTAINS.

From the preceding description of the domal structure of the Rico Mountains and of the circle of prominent peaks it will be plain to the reader that the outer slopes of the mountain group exhibit simple structural relations of sedimentary formations and that igneous masses are few. It does not seem necessary, therefore, to give further descriptions of the peripheral portion of the Rico dome. In the heart of the mountains, where the structural complexities are great, where several formations not occurring elsewhere in the quadrangle have been revealed by the deep erosion of the Dolores and its tributaries, and where many intrusive bodies appear, the case is quite different. Here, however, the phenomena of local interest are so numerous that the reader must be referred to the Rico report for the greater part of the detail; the present descriptions will be confined to certain of the larger features of importance. In fact, it is not the fundamental relations of the formations, but rather the way in which these relations have been obscured, which will receive most attention.

LANDSLIDE AREAS OF HORSE GULCH.

The map and figs. 3, 5, and 6 of the illustration sheet show how completely the normal structure

of the Horse Gulch slopes is concealed by landslide débris. This is all the more striking when compared with the cliff exposures of Sandstone Mountain at the mouth of the gulch.

Slope of Darling Ridge.—The formations of the crest of the ridge are obviously not derived by sliding from any other source, but they are in many places so shattered by important fractures running in all directions and the blocks bounded by these fractures are so plainly dislocated superficially that the whole mass is considered as broken and not strictly in place. The best illustration of the shattering is in the massive stock of monzonite opposite the head of Iron Gulch. By a glance at the map it will be seen that there are here a number of sharp pinnacles and knolls, to which one or two contours have been given. But a map of this scale fails to show the number of these knobs and the hollows, curving ravines, and irregular depressions between them, belonging to no drainage system. The rock of the knobs is often fresh, but much shattered, and the hollows between are rounded by the gravel of disintegration washed into them. This topographic detail, though on the top of the ridge, is similar to that on the landslide slopes. Below these pinnacles on the slope to Horse Creek are some other knobs of monzonite, and the surface is covered by talus and landslide heaps nearly all the way to the creek bed.

Eastward from the principal area of monzonite, along the crest of the ridge, the primary boundaries of the rock formations are more or less clearly exposed, but from the crest, or near it, down to Horse Creek the surface is a jumble of landslide blocks, large or small, intact or in process of dissolution, and geologic boundaries showing the original relations can not be traced.

The general topography of this ridge is seen in fig. 3. The main feature is the great number of trenches, most frequently parallel to the contours, or nearly so, yet often running diagonally across the slope. They are as a rule not persistent for long distances, being cut off by some other trench. A few of these lines are ravines of importance, shown by the maps, and at several places they run up to or cross the crest of the ridge.

Outside of the trenches are mounds, knobs, furrow-like ridges, or benches, and in these are not infrequent ledge outcrops which by various dips and strikes and the shattered conditions of the rocks add to the evidence of the landslide action. No regular drainage channel exists on the south side of Horse Gulch between the river and the ravine opposite Sinbad Hill.

It is probably true that in some cases, especially on the higher slopes, the dislocation of slide blocks is not very great, but it is sufficient to make correlation of different outcrops very uncertain except on a basis of exhaustive study of the whole ridge.

Landslide block at the Puzzle mine.—That there has been landslide action in Horse Gulch has been evident to all familiar with the ground about the Puzzle mine and with the experience of those who have tried to find the continuation of the ore body originally discovered in the Puzzle; but the extent of the slide has not been appreciated.

The ore body of the Puzzle mine, a replacement of a limestone stratum by galena, etc., was found in a ledge outcrop facing the stream. The strata of the ledge included crinoidal limestones typical of the middle division of the Hermosa (Carboniferous). The beds have a general dip downstream, but they are irregularly dislocated on fissures now open, and in places the dip is southerly at a low angle. The structure is at variance with that normal to the gulch, as seen on the north side.

The ore was traced under the bench, but it was soon cut off by breaks on the east, south, and west. A shaft sunk in the little trough at the base of the snow-covered slope, seen in fig. 3, passed into stream gravels at a depth probably less than 50 feet, proving that this ore-bearing block has slipped down from the slope above.

The workings on the original Puzzle ore body and the efforts to trace it beyond the breaks on all sides have not as yet indicated the depth to which this superficial dislocation extends, nor the position of the formation in place from which the ore-bearing block of the Puzzle mine was detached.

"The blowout."—Another locality in Horse Gulch worthy of special mention is the so-called "blowout," situated on the southern slope between 10,000 and 10,500 feet, and north of the monzonite pinnacles of Darling Ridge. The map shows closely spaced contours in a drainage channel at this point and a curving ravine above it, heading between the two monzonite areas of the ridge crest. In fact, this ravine heads on the flat top of the ridge, and is but one of several very marked landslide trenches in that neighborhood.

Western limit of the landslides.—The western limit of the continuous landslide area on the southern slope of Horse Gulch is rather indefinite, but lies on the east side of the south fork. It is here obscured by the presence of surficial materials of later origin, part of which are derived from the head of the south fork, while other portions are the result of disintegration of the landslide blocks.

The force by which the rocks of Darling Ridge were so shattered, producing the fissures which limit the main landslide blocks, was also exerted in less degree to the west, and landslides of small size have taken place in the angle between the south and west forks of Horse Creek, on the end of the ridge from Anchor Peak. The chief evidence of this action is in more or less distinct trenches of general east-west direction, below which the strata are broken up and disturbed in strike and dip.

North side of Horse Gulch.—The landslide area on the north slope of Horse Gulch is one of the most clearly defined of the region and has very characteristic details of topography.

The greater part of this slide area is now covered with grass or an aspen growth, and the direct evidence as to the character or attitude of the formations beneath is found in local outcrops, small slides of recent date within the main area, the prospect holes, or the topographic details found by observation to be characteristic of landslide surfaces. Along the landslide bank of the ravine coming down to Horse Creek just above the Puzzle mine, on the eastern border of the area and below the level of 10,050 feet, the loose materials have at several places been washed away, revealing ledge outcrops of greenish Hermosa sandstone. These exposures belong to different blocks, some of them 50 feet in visible length, the strike and dip changing abruptly from block to block, and never corresponding to the normal structure found on the east side of the ravine. Some of the blocks show a nearly vertical dip, while in others the beds dip 40° or more, usually down the slope.

This area serves to illustrate the manner in which the complex of a slide area gradually disintegrates still further, and must eventually lose all its distinctive surface features. Through the shattered condition of such landslides they become saturated with water, and at times different portions will slump away and break up into a mass of ordinary avalanche or landslide material. Each fresh break furnishes a point of attack for the elements of frost, rain, springs, snowslides, etc., and the destruction of the shattered mass goes on more rapidly.

All over the central part of this landslide area are very marked knolls and ridges, with shattered and irregular rock outcrops, back of which are the V-shaped trenches marking the fracture lines of individual slide blocks. Some of these features are illustrated in fig. 6.

The landslide area on this side of Horse Gulch ends upward in a point under the cliffs of red Cutler sandstones at about 11,400 feet. Chaotic slide blocks, which are rounded and more or less grassed over, cease at about 11,000 feet, and between this and the solid-cliff line there is a small area of more angular blocks of red sandstone and porphyry in which there is often a dip toward the mountain. Each of these blocks is clearly marked, and fissures of dislocation between them are like open faults with a measurable throw of 50 feet or less. Some of these blocks have fallen from the cliff in comparatively recent time, and fissures which may serve as boundary cracks of future slips are to be found here and there in the cliff.

RIDGE BETWEEN BURNETT AND SULPHUR CREEKS.

One of the largest landslide areas of the district is the broad ridge between Burnett and Sulphur creeks, extending from about 11,000 feet on the crest of the ridge down to the Dolores River, some 2400 feet below. In its present condition this area affords few localities where landslide phenomena are clearly exhibited, but on comparison with other areas the landslide evidence is still most convincing, and the ridge is of much interest as illustrating an advanced stage in the history of landslide areas, when the ordinary agencies of degradation have nearly completed their work of effacing the scars caused by the successive slips, leaving in the smooth slopes little evidence of the confusion existing beneath.

The upper limit of this area is a rather sharp line crossing the crest of the ridge almost from north to south at about 11,000 feet. This line is a well-marked trench of varying depth. On other sides the landslide has no close definable boundaries. The southwest slope of the ridge is smooth and rounded in features, entirely covered by grass or timber growth, and contrasts very markedly with the opposite side of Burnett Gulch, with its prominent cliffs of stratified rocks and porphyries. There are no outcrops of rock in place except at the head of the ridge and very near the bed of Burnett Creek, nor are there the usual broken ledges characteristic of landslide blocks. Instead of this, the few exposures where the character of the underlying materials can be seen and the scattered prospect tunnels reveal detrital matter of the texture of ordinary wash or slide rock. No prospect tunnel seen has penetrated to solid rock.

The physiographic detail of this slope is, however, most suggestive of landslides, especially when seen from Landslip Mountain. There are many projecting knolls and local benches, irregular transverse depressions belonging to no drainage system, and general lack of persistent drainage channels.

The most distinct evidences of landslides occur on or near the crest of the ridge leading from Expectation Mountain. For several hundred feet below the upper limit of the area the broad top of the ridge is characterized by rounded knolls with flat or shallow depressions between them. More or less distinct ledge outcrops of sandstone, shale, or porphyry are common on these knolls, but the greatest irregularity of dip and strike is found, and the most prominent beds are clearly not continuous. The dips observed in the mounds and knolls shown in this view are quite abnormal in most cases, being steep angles either down the ridge or to the east.

No geologic boundaries can be traced across this obscure area. From the known structure of adjacent areas it is plain that the massive limestones of the Carboniferous, the Montelores porphyry sheet, and the grits of the lower Hermosa must underlie this mantle of loose material.

C. H. C. HILL.

The triangular space between the Dolores River, the southwest ridge of Telescope Mountain, and the cliff line leading northwest is known as C. H. C. Hill. It is really a broad hollow on the slope of Telescope Mountain. Its character and relations are partially shown in fig. 5.

While landslide trenches, ribs, and knolls are very plain over nearly the entire area of C. H. C. Hill, the examinations have shown that the landslide phenomena are, on the whole, much more superficial than might reasonably be inferred from the physiography. The peculiar topographic features of the hill are principally due to landslides, but the ground, which has slipped in blocks, has been in part covered by avalanche débris and common talus. The disintegration of crushed rocks has yielded soil, and over much of the hill a growth of spruce and aspen conceals everything.

The part of the hill in which normal landslide phenomena are now most distinct is a broad band parallel to the cliffs on the northeast. The most pronounced trenches run in general parallel to these cliffs, and it seems probable that an observed sheeting of the strata in a northwest-southeast direction has caused not only the cliffs of to-day, but numerous fissures bounding thick plates or blocks of rock which have fallen en masse at various times. At one place observed the present cliff exhibits a very distinctly polished and striated surface, which may be due to landslip action.

Damming of Dolores River.—The bench between the wagon road and the river, extending from Burns to a point below the mouth of Horse Creek, is probably composed entirely of landslide material. As shown by the special topographic map, the river for some distance above Burns flows over a very flat, broad bottom. Immediately below Burns the stream passes into a little gorge, bounded on the western side by cliffs of limestone and sandstone and on the east by a steep bank made up of limestone, sandstone, and conglomerate in a wholly confused mass of coarse slide. No outcrops of rock in place occur on the eastern side along the face of this bench, and the railroad cutting reveals most clearly the chaotic mingling of various rocks. In Pl. XVI of the Rico report is an illustration of the abrupt ending of the flat at Burns against the bench of landslide material.

It seems necessary to assume that the present alluvial flat at Burns is due to the damming back of the river by the slide, and it is probable that before the slide the grade of the river was very even from McJunkin Creek to Silver Creek.

Recent slipping in C. H. C. Hill.—Evidence that motion is still in progress in the surface materials of C. H. C. Hill is abundant in the prospect tunnels and shafts of various localities, through the crushing or the twisting of timbers. Further proof and illustration of the character of this movement is seen in a crevice now gradually opening at the upper end of C. H. C. Hill. This crevice extends from an altitude of about 10,400 feet to 11,000 feet. It is most clearly shown at about 10,550 feet, below the trail leading from C. H. C. Hill to the Uncle Ned saddle in the ridge from Telescope Mountain, and on the north slope of the little spur indicated by the 10,650-foot and 10,700-foot contours on the map. The direction of the crevice is here nearly east-west, curving to the southeast in the upper part of its course.

Where most distinct this fissure occurs on a northerly slope which is rather thickly wooded, and several trees on its line have been split from the roots up to 2 or 3 feet above the ground, in the manner shown in Pl. XVIII of the Rico report. A stump of one tree cut off at about 2 feet above the ground has been split open since the tree was felled and the parts are now seen about 5 feet apart. The tree was probably cut about 1894.

It was stated in describing the faults of this district that the course of the Blackhawk fault seemed to be indicated by the Pigeon vein, or the "big fissure," and fig. 5 shows the prominent bench or depression marking the course of this fault in the midst of the landslide area. From various other evidences of the mines it is plain that the sliding movement has not greatly dislocated some of the adjacent blocks. Mr. Ransome's observations in the mines of C. H. C. Hill, recorded in his report and in this folio, lead him, however, to the general conclusion that even where ore bodies have been followed for some distances, it is doubtful if any ore has been taken from rock in place. His many observations of recent movement make it probable that nearly the whole area of C. H. C. Hill is affected by landslide action at the present time.

NEWMAN HILL.

The topographic relation of Newman Hill to Dolores Mountain is very similar to that of C. H. C. Hill to Telescope Mountain, but, while there is a deep mantle of wash, it does not appear that important landslides have occurred. The small landslides which have taken place on the western and southwestern slopes of Dolores Mountain have sent their débris in avalanche form down upon the upper part of Newman Hill. Local slips have also taken place in the wash of the hill, but no great movement of rocks has been detected. The wash covering of Newman Hill has been found to be several hundred feet deep in some of the shafts sunk near the steeper slope of Dolores Mountain.

The geologic structure revealed in the many miles of mine workings in Newman Hill is that to be expected so near the center of the dome. Low dips to the southeast prevail, with many small faults, most of which are of more recent date than the ore deposits, as is shown by Mr. Ransome in his report.

The lower Hermosa beds of Newman Hill are intruded by some porphyry sheets, the most important one, near the base of the hill, attaining a thickness of more than 500 feet, as shown by the boring at the Skeptical shaft. This mass

apparently splits into two or more small sheets before crossing the river, and many other irregularities may well be assumed to exist.

That this large porphyry body is in the main of laccolithic character is further indicated by the limited exposure of its base in the workings of the South Park mine in Silver Gulch. Several very small dikes or sheets of porphyry have been encountered in the mines of Newman Hill.

GEOLOGICAL HISTORY.

PRE-TERTIARY EVENTS.

Introductory.—The visible record of pre-Tertiary events in the geologic development of this area lies wholly in the sedimentary formations and their stratigraphic relations. From the discussion of the formations already given it appears that the section is nearly like that much better exposed, in its lower portions at least, in the Animas Valley. No marked local characteristic has been observed in the Rico formations of pre-Tertiary age, so that the course of events here can only be assumed to have been that of the surrounding province, an outline of which has been presented in the Telluride and Silverton folios. For the present folio it is considered sufficient to refer very briefly to the history preceding the continental uplift of the whole sedimentary section, in post-Laramie time.

Pre-Paleozoic era.—From the study of the Needle Mountains and the Animas Canyon sections it appears that the oldest rocks of this region are certain gneisses and schists, supposed to be of Archean age. The next younger series of rocks consists largely of igneous material, greatly metamorphosed and associated with some distinct sediments. Following the accumulation of this complex came a long period of sedimentation during which the Uncompahgre group of conglomerates, sandstones, and shales was deposited, in marked unconformity with the structures of older formations.

While the sequence of events is not wholly clear, it seems probable that great folding, faulting, and metamorphism of all the rocks as yet referred to was the next great step in the history of the region. The gneisses and schists are penetrated by a large number of granite masses, one known important body of gabbro, and many small dikes of diabasic rocks. Some of these rocks cut the Uncompahgre strata, and the comparatively unaltered textural condition of these intrusives appears to indicate that they are all later than the time of the above-mentioned folding to which the Algonkian sediments were subjected.

The presence of occasional fragments of granite or schist in the igneous intrusives of the Rico or La Plata mountains shows that these same old formations exist beneath later rocks in the country west of the Animas.

Paleozoic history.—Before the earliest Paleozoic sediments of the region were deposited there was a period of enormous erosion which appears to have affected the southern Rocky Mountain province and probably large areas of contiguous country. A peneplain of marked character was produced, which, on sinking beneath the later Cambrian sea, became the floor for the deposition of the Ignacio quartzite. If that formation is of Saratogan (Upper Cambrian) age, as now believed, it is reasonable to refer this great erosion to earlier Cambrian time.

As will be clear from the description of the Paleozoic formations, the epochs of sedimentation during the Ordovician, Silurian, and Devonian periods must have been almost insignificant compared with the intervals of nondeposition. The latter, however, were certainly not times of continental uplift to any great elevation above sea level, in this province at least, since the thin formations of the Ignacio, Elbert, and Ouray epochs, though separated by intervals representing long periods of land conditions, are preserved in almost conformable relations in the Animas Valley, a few miles east of the Rico quadrangle. A fuller discussion of this feature of Paleozoic history is given in the Needle Mountains folio.

Apparently the deposition of the Ouray limestone was continuous from late Devonian into early Carboniferous (Mississippian) time, and the succeeding elevation must have produced, as did the earlier ones, a land surface near sea level, because the erosion of the interval was nowhere sufficient to wholly remove the Ouray limestone at any point observed on the southern slopes of the San Juan region. As stated in a preceding section the absence of the Ouray limestone in the valley of Silver Creek, near Rico, is supposed to be due to erosion of this interval. That is, however, the only point adjacent to the San Juan Mountains as yet found where the Ouray is lacking at its appropriate place in the section. It may be that the area of greatest elevation and consequent erosion, of the time in question, was west of the San Juan area, in what is now the plateau district.

The Pennsylvanian sedimentation was of very different character from any that preceded it in the general area of southwestern Colorado. A long-continued oscillatory movement of the earth's crust caused frequent recurrence of conditions favorable to the deposition of limestones, shales, and sandstones, forming the complex called the Hermosa formation. Without visible break the Hermosa beds grade into those of the Rico (Permo-Pennsylvanian) and those into the overlying Cutler red beds, here assigned to the Permian.

The character of the Cutler formation is in general much like that of the lower portion of the "Red Beds" in many other places where no stratigraphic break separates them from strata containing a Pennsylvanian fauna. The fact that a break is now known to exist above the Cutler beds renders it impossible to assume that the Paleozoic section of the San Juan region is complete. There may have been deposited in this district a considerable thickness of Permian strata now entirely absent, owing to the pre-Dolores erosion.

Pre-Dolores uplift and erosion.—The angular unconformity at Ouray between the Dolores and older formations testifies to important uplift affecting the entire known Paleozoic section. The geographic extent of this uplift remains to be determined. The Cutler beds were sharply folded in the Ouray district, but apparently the region of maximum disturbance lay to the north and east of the San Juan, since on the south and west no relations of marked unconformity exist between the Dolores and Cutler formations.

The epoch of uplift and consequent erosion under discussion was followed by the deposition of the fossiliferous Dolores strata, but until the horizon within the Triassic system represented by those beds has been determined it is premature to assign the orogenic movement to late Paleozoic rather than to early Mesozoic time.

Mesozoic history.—Evidence that the Dolores formation is of Triassic age has been given. In the upper Dolores Valley, as in the San Miguel to the north and the Animas to the east, the Triassic strata are overlain with apparent conformity by the La Plata formation, yet on the northern side of the San Juan the La Plata transgresses the edges of older sediments and in places rests on the Archean, demonstrating that a period of continental uplift and great erosion intervened between the Dolores and La Plata epochs. Similar relations are known elsewhere in Colorado.

Whatever decision may ultimately be reached as to the relations of the Gunnison group as a whole, it is true that the upper of the assumed Jurassic formations, the McElmo, bears such strong lithologic resemblance, in some of its upper sandstone members, to the Dakota sandstone of the Cretaceous that it would be natural to assume that both formations belong to one epoch of sedimentation, rather than that there was a great stratigraphic break between them, involving the whole of Lower Cretaceous time.

The Upper Cretaceous section formerly present in the Rico region was doubtless like that which has been mentioned as present south of the La Plata Mountains. The alternation of shales and sandstones, with numerous coal beds, testifies to general conditions similar to those prevailing in the Rocky Mountain province, but differing somewhat in detail.

Post-Laramie uplift and erosion.—That the domal folding of the entire Paleozoic and Mesozoic section about the San Juan center occurred in the interval succeeding the Laramie epoch has been clearly established and is discussed at some length in the Telluride folio. The local uplifts of the Rico and La Plata mountains are imposed upon that older structure and to some extent obscure it.

Through the San Juan uplift a large area was elevated far above sea level and has never again sunk below it. Erosion became active and degradation of the land area continued until it was reduced to a peneplain, possibly with a small mountainous island rising above it to which the Needle Mountains area belonged. The peneplain in question is that upon which the Telluride conglomerate (Eocene?) rests in the western San Juan and San Miguel mountains.

That this post-Laramie peneplain extended over the Rico quadrangle is evident. The nearest point at which it can now be seen is beneath the Telluride conglomerate in Mount Wilson, about 5 miles north of the northeast corner of the Rico quadrangle, at an elevation of 12,000 feet. In Sheep Mountain, 6½ miles to the northeast, the same horizon is shown. The general position of this plane in the Telluride quadrangle is represented and its significance is discussed in the Telluride folio.

TERTIARY PERIOD.

No surface rocks of the Tertiary period now exist in the Rico quadrangle, but it is necessary to refer to rocks of that age which formerly covered the area, in order to discuss intelligently the history of the Rico Mountains.

ACCUMULATION OF THE TELLURIDE CONGLOMERATE.

When the peneplain produced by erosion following the post-Laramie uplift had reached a certain stage of development the local conditions changed, so that a great amount of débris from the ensuing further erosion of the adjacent mountain masses was deposited upon it as a conglomerate. This formation, originally called the San Miguel conglomerate and afterwards renamed the Telluride, acquired a rapidly increasing thickness westward from its border in the Silverton quadrangle to the San Miguel Mountains. On its border it is 50 feet or less thick and is a coarse conglomerate. In Mount Wilson, a few miles north of Rico, it is about 1000 feet thick and consists of fine conglomerate, sandstone, or shale, the transition in texture and thickness being clearly exhibited in the intermediate area.

While much of the Telluride formation is well stratified and apparently of subaqueous origin, it seems possible that the whole may have been of fluviatile origin. In any case it is probable that the conglomerate was deposited over the Rico area with a texture and thickness corresponding to that exhibited in the San Miguel Mountains.

No fossils have been found in the Telluride formation, hence its exact age is unknown. Its relation to the San Juan volcanic deposits shows it to have immediately preceded them and at present it is assumed to be of early Eocene age, although there are some reasons for thinking that the Telluride conglomerate may be correlated with the Arapahoe formation of the Denver region, assigned to the Post-Laramie part of the Cretaceous on paleontologic evidence. A full discussion of this question is given in the Telluride and Silverton folios.

SAN JUAN VOLCANIC ERUPTIONS.

The volcanic complex of the San Juan region is known to be the result of outbursts of various kinds and with various products, extending through Tertiary time. The earliest eruptions must have followed the deposition of the Telluride conglomerate very closely, and it is probable, from the considerable thickness of tuffs and lava flows above that formation still remaining in the adjacent San Miguel and San Juan mountains, that the lower volcanics extended over the Rico area, with a thickness perhaps of several thousand feet. This question is particularly referred to in the Telluride folio, while the explanation of the absence of the volcanics in the Rico summits is presented below, in the discussion of the origin of the Rico domal uplift.

IGNEOUS INTRUSIONS OF THE RICO AND LA PLATA MOUNTAINS.

While no surface volcanics are now preserved in the Rico quadrangle, the numerous intrusive rocks which have been described belong undoubtedly to the Tertiary period. It is, indeed, possible that the monzonite or syenite stocks of the Rico and La Plata centers may represent channels through which extensive outpourings of lava took place. Be that as it may, there is every reason to correlate the igneous phenomena of these local centers in a general way with similar occurrences of the San Juan area. Porphyritic diorite, monzonite, or granite intrusions are known in the Telluride and Silverton quadrangles, and in some cases proof exists that they are later than some of the surface volcanics. The epoch of intrusion is, however, not at all clearly determinable with reference to the general time scale. The stock eruptions of the Telluride and Silverton areas are later than any known lavas of those districts, and as the Rico and La Plata stocks cut the laccolithic intrusions of similar magmas, it may well be that all eruptions of this type can be referred to the same epoch in the latter part of the Tertiary.

It has been pointed out that the Rico Mountains belong to the laccolithic group of the Henry Mountains type, in spite of local structural features not commonly supposed to exist in some of the similar centers of intrusion. These general considerations as to the time of the Rico intrusions have undoubtedly a bearing on the question as to the age of all the laccolithic groups of the plateau province. The conclusion reached here is in accord with that derived from the examination of the Elk Mountains, Colorado (see Anthracite-Crested Butte folio).

UPLIFT OF THE RICO DOME.

It was brought out in describing the structure of the Rico dome that three elements enter into its constitution, namely, domal uplift by folding, igneous intrusion, and faulting. Whether or not these are all resultant phases of the action of one great force is a question of far-reaching importance. The evidence to be found in the Rico Mountains is manifestly inadequate for the solution of this problem. It is clear, however, that the various manifestations of deep-seated forces at this point belong to different epochs and seem in some particulars independent of each other.

Quaquaversal folding.—It is believed that the quaquaversal folding which seems to have been the principal factor in the elevation of the Rico dome took place after the accumulation of a considerable thickness of volcanic rocks from San Juan eruptions—that is, in the Tertiary period and possibly in the Eocene epoch soon after the formation of the San Juan tuff. The erosion which produced the Telluride peneplain would surely have truncated the dome had this structure been of Mesozoic age. That plain is, however, nowhere seen in the Rico Mountains, although Blackhawk Peak still rises more than 600 feet above the level at which it appears in Mount Wilson, a few miles to the north.

The greater part of the uplift which has taken place has affected the whole Paleozoic section and the underlying Algonkian rocks and thus the small Rico dome comes to show close relationship with the much broader San Juan uplift. As has been stated already, the most prominent structure in the San Juan region is pre-Tertiary in origin, but there was also uplift in Tertiary time, and it is possible that the Rico dome is synchronous with the later elevation and a result of the same force. The same is true of the La Plata Mountains. But until the structural history of the San Juan region has been studied in much greater detail the relation between the local uplift of the Rico and La Plata mountains and the more nearly continental movements of the San Juan region can not be thoroughly discussed.

Age of the laccolithic intrusions.—The dikes, sheets, and small laccoliths of porphyry in the Rico Mountains belong to the group of diorite-, monzonite-, and granite-porphyries which are so widespread in the laccolithic mountain groups of the plateau country and also in the mountains of Colorado. That these rocks are in all these instances of approximately the same age is a natural conclusion in harmony with all known facts, although the definite evidence of Tertiary age is found in but few localities.

Evidence at Rico bearing on this question is limited to the general considerations above stated as to the age of the domal uplift. In the adjacent Telluride and Engineer Mountain quadrangles there are large laccolithic bodies of porphyries very similar to rocks of the Rico Mountains, and some of these are intruded into volcanic rocks, proving their Tertiary age. But no evidence has been found to indicate the particular epoch of this period in which the intrusions took place.

Stock eruptions and faulting.—In considering

the nature of the forces which have produced the Rico uplift, it is apparent that there is a close analogy between the two phases of intrusive action and the two phases of structural uplift. The primary upward pressure at this center was one to which the whole section of Paleozoic and Mesozoic strata accommodated itself by folding, stretching, and no doubt by minor fissuring. It would appear to have been a gradually exerted pressure, of the kind assumed to have forced the magmas of laccoliths and analogous sheets between the strata of a sedimentary complex. Corresponding to this idea, it is found that the distinct porphyry sheets of the Rico Mountains are the earliest intrusions.

The fault blocks of the heart of the mountains, made up, at the exposures now seen, of Algonkian schists and quartzites, have been thrust up through the folded strata with little or no evidence of contemporaneous folding of the adjoining beds. This is also the relation of the Darling Ridge monzonite stock, as far as can be seen, and also of the similar stocks of the La Plata, Telluride, and other neighboring quadrangles. Such fault blocks and such masses of igneous rocks seem alike due to forces suddenly exerted, producing vertical fracture instead of doming. With such an analogy in mind, the suggestion naturally arises that a mass of magma, forming a stock in greater depth, may have followed the upthrust blocks now revealed. Such a hypothesis requires the assumption of very direct connection between the propelling forces of magmas and those of structural uplift.

Connection between folding and intrusion.—If folding and intrusion at the Rico center be referred to the action of the same great force, it is difficult to explain why larger amounts of magma were not intruded into the strata of the Rico dome, in view of the large porphyry masses of probably contemporaneous origin occurring near at hand in comparatively undisturbed beds. The Flattop mass of porphyry, exceeding in bulk all the sheets of the Rico Mountains put together, occurs just at the northeast base of the dome, but similar large bodies occur on the San Miguel River in the Telluride quadrangle, 20 miles from the Rico uplift, and another occurs in Hermosa Peak, a few miles to the east. The stocks of the Telluride quadrangle appear likewise to be distributed without visible relation to any structure of the sedimentary formations. In other words, it appears to be the case that, while laccolithic intrusions and stock eruptions have occurred at the Rico and La Plata centers, both forms of intrusion have also taken place not far away in much greater volume, at points seemingly independent of such centers. It is to be hoped that more extended studies of the San Juan and adjacent regions may throw light on the relations of these various phases of intrusion of magmas to structural movements of the earth.

PHENOMENA CONNECTED WITH IGNEOUS INTRUSION.

Aside from the mechanical features of intrusion, which have been referred to, the principal phenomena connected with the igneous intrusions of the Rico Mountains are those of contemporaneous metamorphism and of solfataric exhalation which appears to have continued down to the present time.

Contact metamorphism.—Contact metamorphism of the calcareous strata adjacent to the monzonite stock is very pronounced at nearly all places where these rocks are exposed in the vicinity of the intrusive. The character of the alteration is such as might be expected from the action of mineralizing agents, as chlorine, fluorine, and heated water carrying those gases and perhaps others in solution. The metamorphism referred to consists in the formation of garnet, pyroxene, vesuvianite (?), and possibly other silicates of alumina, with magnesia, iron, and lime, and in the deposition of specular iron in scales, either impregnating the rocks or, more commonly, in thin crusts in fissures. Such alteration of the calcareous strata may be seen on the north side of Darling Ridge, near the blowout in Horse Gulch, and down near Piedmont. If the metamorphosed stratum is a limestone the matrix for the silicates named is usually white crystalline marble.

The great metamorphism of the Devonian limestone in the Dolores Valley at Rico is so clearly of the kind described that it is considered probable that this change is also due to the monzonite intrusion. The eastern end of the monzonite is just above the street in Piedmont, and there must have been fissures traversing the strata in the prolongation of the principal axis of the stock. These may have given heated solutions the necessary access to the limestone at the places now seen. So far as observed, such contact metamorphism is confined to the zone about the stock, with the exception of one place in the shattered zone, between the forks of the Blackhawk fault, where garnet masses and specular iron occur near a small porphyry dike.

Solfataric action.—While no evidence can ever be discovered proving that the surface phenomena ordinarily known as volcanic attended the deep-seated intrusions in the Rico dome, certain processes which are generally supposed to characterize zones near the surface have been active in the horizons now revealed by erosion. One of these processes is the decomposition of rocks by sulphurous vapors or by solutions that have absorbed those vapors, and the production of alunite. This substance is formed at the surface in the crater of Solfatara, near Naples, and is a common product of the sulphurous emanations of volcanoes known from this locality as solfataric exhalations. But the process is not necessarily connected with solfataras of typical volcanoes, and the term has been gradually extended to cover the metamorphosing action often consequent on eruptions which have been accompanied by mineralizing agents of sulphurous character, even when taking place in depth.

The orthoclase-bearing porphyry mass of Calico Peak has been almost wholly decomposed by such agents, alunite and kaolin being the principal products.

Existing sulphur springs.—It is especially noteworthy, in connection with the evidence above given of former intense solfataric action, that there are numerous springs of water heavily charged with sulphureted hydrogen issuing to-day from the slopes of Stoner and Johnny Bull creeks and of other tributaries of the West Dolores north of Johnny Bull Creek. The waters of these springs are surface waters, as they are influenced directly by the rainfall of the season and dry up at times, but the sulphurous gases escape continuously. The exclusive presence of these springs on the west side of the dome, extending from the immediate vicinity of the solfataric center at Calico Peak toward the West Dolores, suggests that these exhalations really belong to a later solfataric period of this eruptive center.

ORE DEPOSITION.

After the uplift of the Rico dome, the intrusion of the igneous rocks, and at least a portion of the fault fissuring there was a period of extensive ore deposition in the rocks now forming the Rico Mountains. While the age of the ore deposits can not be closely determined, it is in every way probable that they correspond in time to the deposits of the La Plata Mountains and that they belong to the great epoch of ore deposition which succeeded the early Tertiary igneous intrusions or more typical volcanic eruptions in many parts of the Rocky Mountains. Apparently the more typical laccolithic mountain groups of the plateau country to the west do not contain ore deposits in an abundance at all corresponding to their development in the La Plata and Rico mountains, but whether that fact is connected with their situation remote from the great centers of eruptive activity or with local causes can not now be determined. It would, however, appear natural that more extensive deposition of ore minerals should occur in a center like the Rico Mountains, where there has been so unusual an amount of fissuring, affording channels for the circulation of metal-bearing solutions.

EROSION OF THE RICO DOME.

General statement.—The San Juan and adjacent country appears to have been a continental tract during the whole of Tertiary time. Erosion must, therefore, have been continually in progress during that period. The work of degradation was repeatedly interrupted and in great measure undone by vast volcanic accumulations in several different epochs. Further, the erosive power of streams varied greatly, according to the alternating elevation or subsidence of the region, which probably continued during the period in question. Naturally the work of distinct epochs of Tertiary erosion can not be recognized in the Rico district, and the present discussion is, therefore, directed to the local problem as to the sculpturing of the Rico dome. This erosion began with the rise of the dome, at some unknown time in the Tertiary period, and has continued to the present day, although discussion is here confined to pre-Glacial erosion. The glaciation here referred to is that of which evidence is observable, and is not necessarily the earliest of the region, as will be explained in a later paragraph.

Sculpturing of the dome.—At the inception of the Rico dome the volcanic rocks which covered the San Juan country were being attacked on all sides by streams whose positions were probably determined by the distribution of the volcanic materials. So long as eruption continued the stream courses were constantly liable to alteration by lava flows, but with the temporary cessation of volcanic activity each stream would maintain the course it then held, deepening its channel and sapping at its head to extend its canyon into the central mountainous region. It seems probable that the Dolores River had assumed its present course previous to the formation of the Rico dome, since, supposing that the surface at the time the dome was formed was sufficiently smooth for the development of consequent drainage on its slopes, it is difficult to understand how one of the radial streams thus resulting could have gained so distinct an advantage over the others that it would finally cause their complete diversion. The relations of hard and soft rocks in the region to the north of the dome are such that it seems as if diversion of the radial streams on the northern slope must have been accomplished by the western branch of the Dolores River long before any stream originating on the southern slope of the Rico dome could have cut its valley backward through the hard core of the group to the north side of the dome structure.

The actual amount of erosion since the Rico uplift can not be estimated, since its effects are not separable from those of the epoch preceding. It is believed, however, that the volcanic rocks had not been removed entirely and that, as in Mount Wilson, to the north, sediments above those now exposed were present, up into the Mancos shale, at the time of uplift.

Whether the Dolores was flowing in a shallow valley or deep canyon previous to the domal uplift at Rico can not be surmised, but before the completion of the structure the stream had doubtless cut a deep trench well down toward the base of the volcanic rocks which are supposed to have covered the region, and possibly into the Mesozoic sedimentary rocks, upon which they probably rested. This erosion belonged to the epoch of deformation. It was succeeded by continued erosion of the present epoch as arbitrarily limited by the completion of the distinct uplift.

With the downward cutting there has doubtless been concomitant elevation, but of this there is no evidence in the immediate vicinity of Rico, though some 10 miles or so to the south there are gravel beds about 400 feet above the present valley floor, showing the former position of the stream bed and indicating an uplift since their deposition. The effect of erosion within the mountains has been as if the river had cut its way at once to the present position and then side streams and gullies had completed the grading of the slopes. It is believed, however, that several distinct uplifts have occurred, but the pauses between them left no records because of the fact that the river was cutting its channel and not at any time widening its valley, so that the valley was successively deepened, and under conditions of heavy precipitation the slopes of the valley walls were gradually reduced without the production of terraces.

The softer rocks have been carved away, leaving the more indurate as cliffs or steep slopes between more gentle acclivities and determining the positions of the main mountain masses. The rocks which have been sufficiently massive to form mountain caps are mostly intruded porphyries, though the La Plata sandstone always rises as a knob above the general level of the adjacent ridges. Of the few high peaks capped by other sediments than La Plata, Telescope Mountain is the only one not protected by a very massive sheet of porphyry lying within 100 to 200 feet of the top.

The monzonite stock on the west side of the river has been sufficiently resistant to form a ridge both south of Aztec Gulch and in the main divide south of Horse Gulch, though in neither place does it reach to as high an elevation as the porphyries of the adjacent peaks.

The distribution of the laccolithic porphyry masses in the upper part of the Dolores formation has determined the zonal grouping of the principal mountain peaks about the center of the dome structure. In fact, it is to these porphyries that the Rico Mountains owe their existence. Had they not been encountered by the streams, the latter in dissecting would have given to the dome a molding scarcely different from that which they have impressed upon the adjacent areas of sedimentary rocks; the concentric outcrops of the harder beds would be expressed in knolls or curving ridges, but the general elevation would have been much less than at present.

GLACIATION OF THE RICO MOUNTAINS.

It is known that the higher portions of the San Juan region were practically covered by an ice sheet during a late stage of the Glacial epoch. It is, therefore, not strange to find evidence of recent local glaciers in the Rico Mountains. Reasons exist for believing that the San Juan Mountains were also glaciated in an earlier portion of the Glacial epoch, but evidence bearing on this question is found in the Rico district only in certain high-level gravels of the Dolores Valley.

Evidence of recent glaciation.—The record of glaciers in the Rico Mountains is seen in certain topographic forms, in rock scoring, and in accumulations of débris, but none of these is strikingly prominent or characteristic, from which it appears that because of their somewhat lower altitude and their isolation the Rico Mountains were not so completely dominated by the ice as were the higher mountains adjacent. They formed a local center of accumulation, and though the basins at Rico were probably deeply buried in snow there were but few places in which the accumulation became sufficiently deep for the consolidation of the snow into true glacial ice.

That glaciers were not prominent for any great length of time seems clear from the absence of marked glacial cirques or amphitheaters in the higher mountains. The basin at the head of the small gulch next east of Allyn Gulch, in the eastern part of the group, is the only one of the region which strongly resembles a typical cirque. It is also noteworthy that the side gulches of the mountains seldom possess the profile outline characteristic of valleys filled by glaciers, the only two exhibiting the U-shaped form being Silver and Horse gulches, the largest and deepest of the group.

Striated or grooved rock faces have been noted in several places, notably in Deadwood and Silver gulches and near the head of Johnny Bull Creek, west of Calico Peak.

Glacial débris retains distinct morainal form only on the southeastern slopes of the mountains, at the head of two branches of Scotch Creek, in the Engineer Mountain quadrangle. These were deposited by short glaciers of small dimensions. In other places the gravels supposed to be of glacial origin are mingled with avalanche, landslide, or wash débris, and could not be shown on the map. They occur on various ridges or mountain slopes and in certain gulches, and details of their observed distribution were given in the Rico report.

The rounded ridge at the entrance to the valley of Silver Creek has an external appearance similar to that of kames or eskers, but it is really composed of sedimentary rocks and intrusive porphyry and is merely capped by gravels. It is consequently a form of erosion rather than of construction.

Collectively the phenomena observed are believed to warrant the conclusion that true glacial streams at one time existed on the southeastern slopes of the mountains, in the valley of Silver Creek and its tributaries, and in Deadwood Gulch, and that in the upper part of Horse Gulch there were important accumulations of ice which may or may not have reached into the lower part of the valley. If others existed, their marks have been obscured by surface materials of another origin or by recent erosion.

Valley gravels related to glacial deposits.—A group of gravel deposits which may be tentatively referred to the close of the recent (Wisconsin) stage of glaciation occurs in the Dolores Valley at many points from the Rico Mountains downward. These gravels are seen in the terrace upon which the town of Rico is partly built, and on the similar and probably corresponding bench which occurs about 40 or 50 feet above the river bed north of the mouth of Sulphur Creek. The gravels are best exposed in the cutting for the roadway to the railroad station at Rico, but are known to form the edge of the terrace for nearly half a mile to the south. Occasional remnants of corresponding gravel benches occur down the Dolores River as far as the mouth of Bear Creek. South from Montelores the bench is from 10 to 30 feet above the present stream, and it seems to slope down the valley at a slightly greater grade than that of the Dolores River. This bench is not entirely depositional, since occasional exposures show rock in place. Just north of the mouth of Ryman Creek the inclined and truncated edges of the Cutler beds are shown to be covered by a thin capping of gravel, and east of Montelores the eroded surface of the porphyry is but partially concealed.

Less conspicuous remnants of a gravel terrace occur along the Bear Creek flat. This terrace is at about the same elevation above the present stream as the Dolores terrace and seems to be closely related to it genetically. At the angle of the union of the streams a terrace remnant appears to be common to both. The terrace gravels of Bear Creek came, of course, from the La Plata Mountains. West of the mouth of Bear Creek this bench is inconspicuous or wanting. It seems probable that these Dolores Valley gravels represent the scanty morainal materials of the Rico glaciers transported and deposited. The amount of stream cutting below the gravel-covered terraces is consistent with this idea.

Ancient glacial (?) gravels.—Coarse gravel or bowlder beds, which from their position suggest a considerable former extent of such materials, occur at numerous points in the Dolores Valley at several hundred feet above the present stream. The most northerly of these observed occurrences is on the ridge south of Aztec Gulch, near Rico, where, at an elevation of 9500 feet, or about 700 feet above the river, an excavation in the wooded surface reveals a mass of very round bowlders lying in fine gravel. Among the rocks represented are blue limestone, greenish sandstone, and vein quartz. The bowlders are very unlike the angular fragments which are sparingly scattered about the surface. These angular blocks, often 3 feet or more in diameter, seem to have come from up the river, for red Dolores sandstone is common among them. Bowlder gravels have also been exposed at a lower level on this same ridge in prospects near the line of the Calumet vein, about 300 feet above the river.

On the slope below the tufa bench south of Sulphur Creek, southwest of Rico, at about 300 feet above the river, there are several patches of coarse gravel beds. Among the fragments noticed here was one block, nearly 3 feet in diameter, of the peculiar hornblendic porphyry known only in dikes in the Algonkian schists above Rico.

Farther down the Dolores Valley other similar gravel patches occur at this general level of 300 feet above the river. They are especially well shown on the west side of the river between Snyder's ranch and Rio Lado and have been noted also near the mouth of Bear Creek. Possibly they occur in small remnants much farther down the river. A specially good exposure was noted near the mouth of Tenderfoot Creek, where the pebbles average about 4 or 5 inches in diameter, though some reach 8 or 9 inches. Among the rocks represented here are porphyries, sandstone, limestone, quartzite, vein quartz, and shale.

These high-level bowlder beds are considered as mere remnants of important deposits belonging to the epoch when the floor of the valley was 300 feet or more above its present stream bed. From the evidence, common in southwestern Colorado, of slight stream erosion since the last Glacial epoch, it would seem necessary to conclude that the gravels under discussion are older than the recent (Wisconsin) stage of glaciation. But the waterworn character of the bowlders and the meager evidence concerning their origin scarcely warrants the assumption of any particular relation to more ancient glaciation. Gravels of high level are abundant on all sides of the San Juan, and in the forthcoming Ouray folio strong evidence indicating a pre-Wisconsin glaciation will be given.

LANDSLIDES.

The landslide areas of the Rico Mountains, which assume unusual importance, have been described as to their character and local distribution, and it remains to refer briefly to their age and the evidence of their origin. A much fuller treatment of the subject is given in the Rico report.

Age of the landslides.—The epoch of the Rico landslides may be said to extend backward from the present day to their beginning, at a remote period not accurately determinable. From the great number of the slides in this limited region and the conditions of their distribution it must be assumed that they are primarily due to some very unusual force, shattering the rocks to a remarkable degree and principally exerted at the beginning of the landslide epoch. It is therefore of prime interest to ascertain when these slides began.

Of all the phenomena of Quaternary age in this region there is none affording definite proof as to the remoteness of the time at which the fracturing of the formations took place. The principal changes in the topography since the landslides began have been caused by the slides themselves. There has been practically no erosion in the Dolores Valley or in the more evenly graded reaches of its local tributaries in the landslide epoch. All the distinct alluvial formations, as flood plains and the fans or aprons at the mouths of streams tributary to the Dolores, are referable to activities during the landslide epoch. Even the glacial deposits seem to afford little evidence as to the age of the first landslides. The main traces of glacial deposits are in the eastern portion of the Rico Mountains, where landslides have not occurred; and the gravel deposits, which seem to be of glacial origin, have in most cases been more or less rearranged, so that little weight can be placed on conclusions drawn from their present position. The landslide period was apparently contemporaneous with the glaciation, or nearly so.

Relations to topography.—From the details regarding the various slide areas which have already been given and from the illustrations, it is evident that the topography of the Rico Mountains had acquired almost the detail it now exhibits when the landslides began. The only considerable modification of that topography in the intervening time to the present has come directly from the landslides or indirectly through the rapid breaking down of the principal slide areas. The valley of the Dolores, at the foot of C. H. C. Hill, must have been of the exact type now seen above Marguerite Draw. The stream bed of Horse Creek has plainly been interrupted by the Puzzle slide.

The primary conditions for a landslide may be generally stated as a thoroughly fractured state of the rocks on steep slopes, permitting the force of gravity to cause the fall; and were all the rocks of a mountain district to be uniformly shattered the mountains of most precipitous and irregular form would naturally experience the most extensive landslide action. But in the Rico district some of the most rugged mountains have undergone no visible degradation by landslips, even in the heart of the area most affected. Sandstone Mountain is the most striking instance of this immunity.

Relations to other Quaternary phenomena.—The ordinary processes of degradation operative in the high mountain regions of Colorado have of course been active in the Rico Mountains during the long epoch of landslide action, and it scarcely need be pointed out that all the destructive agencies must have been especially effective within the landslide areas. The shattered landslip blocks themselves have been in high degree vulnerable to the attacks of solvent waters, frost, etc., and have in many cases rapidly disintegrated. The whole slope of Darling Ridge, as of other landslide areas, is practically without surface drainage channels, so permeable is the mass beneath to the rain that falls upon it and to the snow water.

One effect of this saturation by circulating waters has been to keep the fracture lines of attrition matter and many layers of crushed sandy shale in a soft condition, favorable to the slipping of more or less extensive masses whenever the support weakened sufficiently. Secondary slides of this sort must have been frequent ever since the original shattering of the formations, and they are still taking place.

The more exposed and isolated landslide blocks, if prevented from further slipping en masse, break up gradually, while a talus slope or an avalanche track often denotes the course of the more rapid disintegration.

Origin of the landslides.—The immediate cause of the Rico landslides is manifestly the very unusually shattered condition of the rock formations on steep slopes, and the discussion of origin must be directed to the seat and nature of the force to which the intense shattering is due. The evidence concerning this force contained in the observations which have been recorded may be summarized as follows:

1. The principal landslides are confined to a small circular area in the heart of the Rico uplift, but do not cover all of that area.
2. The slides are more recent than the topographic details of the mountains and valleys, except only some recent and minor features.
3. The shattering of the rock varies locally in degree.
4. The shattering is independent of lithologic character and structural attitude of the formation, and there is nothing in either of these conditions especially favorable to landslides.
5. The principal landslide slopes are in the courses of many known faults, but several intensely faulted areas of rugged topography do not exhibit landslides.
6. Many fault veins seem to have been opened again by the shock producing the shattering of the formations.
7. The shattering extends below the surface zone of actual sliding and to unknown depths.

The consideration of all observed facts leads to the comprehensive statement that in geologically very recent time a part of the central portion of the Rico Mountains suffered a severe shock, shattering the rocks at the surface and to unknown depths. As a result of this shattering many landslides have occurred where other conditions were favorable. This shock must have had its source in greater or less depth, and may be referred to as earthquake shock.

Two important sources of earthquake shock are specially recognized, viz, that originating in the relief of tension arising from structural movements of the earth's crust, and that connected with volcanic phenomena. The Rico Mountains represent a center of upheaval and intense faulting, and of igneous intrusions of a nature not strictly volcanic. It seems natural to suppose that seismic disturbances must have taken place at the surface of the Rico dome during the periods of faulting and during the intrusion of at least the monzonite magma in the channels represented by the stocks of to-day. But those disturbances took place at so distant an epoch that the connection of the shocks now under discussion with either of them is not plausible.

RECENT GEOLOGICAL HISTORY.

Many of the features of post-Glacial geology at Rico are inseparable in origin from similar features of Glacial and earlier time, since in those parts of the area that were not covered by ice similar processes of general erosion and of local deposition were active throughout the Glacial stage. For this reason, in referring to certain phenomena as Recent, there is no intention of limiting their age to the post-Glacial, but rather to indicate that certain conditions have continued down to the present time. The Recent phenomena of the Rico region are mainly erosion and deposition. The latter includes landslides, talus, and avalanche materials, river gravels, and spring deposits, which have been described as formations. The processes of their formation are so commonly known that but little further reference to them seems necessary.

Post-Glacial erosion.—If the gravels occurring at an elevation of 700 feet above the Dolores River on the northern edge of the monzonite arm from Darling Ridge are of Glacial origin, they indicate a much greater accumulation of such débris in the valley than would be suggested by any other occurrences. But even if they are Glacial, the recent work of the river seems to have been largely the removal of the gravels, with little cutting into the underlying rock. In Deadwood and Allyn gulches the streams have cut down through the unconsolidated gravels of Glacial origin, but this is a task which they could have easily accomplished in a short time. Similar indications of the small effect of post-Glacial bed-rock erosion are seen in Silver Creek, where the stream has locally excavated narrow canyons in the wider valley of Glacial origin, but these canyons have in no instance exposed the bed rock to a depth of more than possibly 20 feet, and in many places the stream is working on débris of very recent origin, which has been thrown into its channel from the side gulches and ravines. All the evidence serves to point to the recency of the Glacial occupation and to the small amount of erosion which has since ensued. The present topography is in no essential feature different from what it was previous to the accumulation of the ice. Before that the streams had found their present courses and had practically assumed their present grades.

In the higher parts of the mountains, however, the ordinary atmospheric agencies have been active and large amounts of talus and slide rock are seen on many of the steeper slopes.

Modification of topography by deposition.—The greatest change in the topography of the region since the great erosion has been effected through the agency of landslides. Throughout the larger tracts which are shown on the map the landslides have modified the form of the ridges and mountain slopes and have to some degree filled up the valley bottoms, especially of the Dolores opposite C. H. C. Hill and of Horse Creek. Apparently the streams in their lower courses have not as yet been able entirely to remove this landslide débris.

In the valley of the Dolores there are various deposits of stream gravels, and the map shows the distribution of the more recent deposits. Remnants of terraces in several places indicate former deposits, but these are not always clearly distinguishable from débris of other origin.

While the lateral tributaries of the Dolores have no bottom deposits of importance, several of them have built up very decided alluvial cones at their mouths. The more important of these are represented on the map.

Small deposits of calcareous sinter or tufa have been noted at various points on the banks of the Dolores, and several of them are shown on the map. At a number of these points the spring waters are still highly charged with carbonate of lime and deposition is still going on.

It will be noted that the effect of nearly all of these recent agencies is to modify the form of the mountains existing before the Glacial epoch and the beginning of the landslides, by producing gentler forms of the ridges and by filling up in some degree the various valleys.

Gas springs.—Emanations of carbonic acid gas and of sulphureted hydrogen accompany many springs of water in the Rico region. The former is continually escaping in large quantities in the central part of the area, while the latter is noted in many places on the west side of the mountain group in the drainage of Stoner and Johnny Bull creeks. Both gases doubtless have their origin in chemical changes which are going on at a greater or less depth beneath the surface, and the waters with which they are associated may or may not be of deep-seated origin. In some cases they certainly are not, for at the sulphur springs the water increases and diminishes with the humidity or dryness of the season, and at certain times the flow of water ceases entirely, while the gas continues to escape. It appears that in such instances the gases have found the same channels along which the waters are circulating and that the two mix and escape together. In the section on "Economic geology" Mr. Ransome tells of the frequent appearance of carbonic acid gas in mine workings.

June, 1904.

ECONOMIC GEOLOGY OF THE QUADRANGLE.

By F. L. Ransome.

INTRODUCTION.

The principal ore deposits of the Rico quadrangle are confined to its northeast corner, and are included within the area of about 35 square miles covered by the Rico special map. The mining district is nearly coextensive with the isolated group of peaks which have been described in the foregoing pages as the Rico Mountains. Rico, a town of a few hundred inhabitants and the seat of Dolores County, lies nearly in the center of the district, on the Dolores River, which traverses the area from north to south. The Rio Grande Southern Railway connects the town with the Denver and Rio Grande system at Durango on the south and at Ridgeway on the north.

The following general account of the ore deposits is for the most part condensed from a report entitled "The Ore Deposits of the Rico Mountains, Colorado," published in the Twenty-second Annual Report of this Survey in 1902. To that report the reader is referred for detailed descriptions of individual mines.

HISTORY OF MINING DEVELOPMENT.

Records of the discovery and early development of the Rico ore deposits are fragmentary and often conflicting. The first recorded attempt to prospect the region was in 1861, when Lieutenant Howard and other members of John Baker's expedition into the San Juan region made their way over the mountains from the east. Eight years later Shafer and Fearheiler built a cabin on Silver Creek, near its junction with the Dolores River, and located several claims. One of these, the Pioneer, subsequently gave its name to the mining district.

In 1872 R. C. Darling and others erected an adobe furnace and attempted to smelt ores from what are now known as the Atlantic Cable, Aztec, Phoenix, and Yellow Jacket claims. They were unsuccessful, and it was not until 1877 that active prospecting was resumed in the Pioneer district.

In 1879 rich oxidized silver ore was discovered on Nigger Baby Hill, and the future productivity of Newman Hill was foreshadowed by the shipment to Swansea of some ore from the Chestnut vein. The town of Rico at once sprung into existence.

In October, 1887, the largest and richest of the blanket deposits on Newman Hill was discovered by David Swickhimer in the Enterprise shaft, at a depth of 262 feet, and shortly after ore bodies were found in the Blackhawk, Logan, and Rico-Aspen mines.

The Enterprise mine was sold in 1890 to a Pittsburg company, and the same year saw the advent of the Rio Grande Southern Railway. Vigorous exploitation was continued in various parts of the district until 1895, when mining activity showed signs of abating.

Since 1895 the output of the Pioneer district has decreased. The large bodies of rich "contact" ore have been mined out, and many of the veins have been worked down to a depth at which the ore no longer pays for shipment. Masses of ore often proved to be curiously limited, owing to various conditions that are characteristic of the region and that will presently be described.

The decline in the price of silver has had a depressing effect on this as on other districts where this metal forms a large part of the output. But nearly all the important ore bodies formerly exploited were sufficiently rich to be workable to-day had they not been exhausted. In 1900 the only ore being shipped from the district was an occasional carload taken out by leasers working small areas of unexplored ground in the larger mines.

In 1902 practically all the important mines in the district were consolidated under the name of the United Rico Mines Company and although no material increase of production has yet resulted, the new company has devoted itself with considerable success to the development of the Atlantic Cable mine and to the experimental treatment of the sphaleritic ore there found.

PRODUCTION.

The total production of the Pioneer mining district can be only roughly estimated. According to the reports of the Director of the Mint, the output from 1879 to the end of 1903 has been about 73,000 ounces of gold and 9,000,000 ounces of silver. The value of the entire product, including the base metals, probably lies somewhere between $8,000,000 and $10,000,000. By far the greater part of this has been silver. Present developments indicate that the district may soon produce considerable zinc and lead.

PRELIMINARY OUTLINE OF THE ORE DEPOSITS.

The ores of the Rico district show unusual variety in their occurrence, as regards both form and genesis. It is proposed in this report to treat the deposits under four general heads, namely: (1) Lodes, (2) blankets, (3) replacements in limestone, and (4) stocks. This is confessedly and obviously a rough grouping for convenience and clearness of treatment, and is not intended as a scientific classification.

Under the first head will be described simple or complex veins, usually nearly vertical, which when they occur in the sedimentary formations cut across the planes of bedding. They are fractures or fissures in the rocks, which have been afterwards filled with ore or valueless vein matter.

Under the second head will be treated various deposits usually more nearly horizontal than vertical, and lying parallel to the planes of bedding or to the surfaces of intruded sheets of igneous rock. These are the deposits locally known as "contacts." This term, used in a sense that has no necessary connection with its true geological meaning, has unfortunately found its way into literature and has been so universally adopted by the miners that it is difficult to altogether avoid its use. Wherever employed, however, the word will be placed in quotation marks, indicating its true standing as miners' vernacular.

Under the third head will be considered those deposits, often irregular in form, which have resulted from the metasomatic replacement of limestone by ore.

Lastly, under the fourth head, will be noticed a few small ore bodies, often referred to as "chimneys," of which the Johnny Bull is the principal example in this region.

No sharp distinction exists between these various deposits. Lodes of flat dip may pass into bedding faults along weak strata, producing breccias which, when mineralized, are classed as blankets. The mineralization of such a breccia, particularly if the material be calcareous shale, is likely to be largely by metasomatic replacement, producing a deposit closely akin to those resulting from the simple replacement of limestone. Moreover, the ore bodies grouped under the second and third heads are always intimately connected with fissures or lodes which may or may not be themselves productive.

The greater part of the product of the district has come from the blankets. Some of the lodes have proved rich, but their value has invariably fallen below the limit of profitable working at a remarkably shallow depth, which generally bears a constant relation to some overlying blanket with which the lode or lodes connect. Some important bodies of ore have also been formed by direct replacement of limestone.

The bulk of the ore has been found in the Carboniferous sedimentary series, particularly that portion of it known as the Hermosa formation. This is nearly equivalent to saying that most of the ore has come from the central portion of the district, in the heart of the dome-like uplift of the Rico Mountains.

The ores consist primarily of galena—often highly argentiferous and associated with rich silver-bearing minerals—sphalerite, and pyrite, with various gangue minerals. In many deposits more or less complete oxidation of the primary ores has taken place, resulting in pulverulent earthy ores, often very rich in silver.

DISTRIBUTION OF THE ORES.

In all probability more than half of the ore produced in the Rico district has come from Newman Hill. This name is applied to the slopes immediately south and east of Rico, constituting the western flank of Dolores Mountain. Newman Hill may be considered as bounded on the north by Silver Creek, on the west by the Dolores River, on the south by Deadwood Gulch, and on the east by the cliffs formed by the massive bed of limestone characteristic of the medial division of the Hermosa. On this slope, which is deeply covered with surface wash, are the Enterprise, Rico-Aspen, Newman, Union-Carbonate, and other mines, in which the ore occurred partly in lodes and partly in blankets. Of the latter the principal one is locally known as the Newman Hill or Enterprise "contact."

Also on the east side of the Dolores River, but north of Silver Creek, is Nigger Baby Hill, a spur of Telescope Mountain. This hill has produced ore since 1879. The ore occurs in oxidized form in lodes, which in their upper portions possess so flat a dip as to constitute essentially blanket deposits.

C. H. C. Hill lies immediately north of Nigger Baby Hill. It is a landslide area, honeycombed with workings from which much ore has been taken. The ore, largely oxidized, occurs in blankets, the continuity of which has been greatly broken by landslide movements.

From the three hills mentioned has come the greater part of the Rico ore. There are, however, several important outlying deposits. The most prominent of these is that of the Blackhawk mine, between Silver Creek and Allyn Gulch, where the ore occurs oxidized in a lode and as sulphide replacement deposits in massive limestone. Another example is the Puzzle mine, on Horse Creek, about three-fourths of a mile from its mouth, where the ore also occurred replacing limestone. The Johnny Bull mine on Johnny Bull Mountain, near the head of Horse Creek, has also produced some ore.

The entire basin of Horse Creek and the eastern slope of Expectation Mountain are dotted with prospects, many of which have produced small quantities of ore, but nearly all are now abandoned.

Another deposit of considerable interest and prospective value is that of the Atlantic Cable mine, on the north side of the town, in which galena, sphalerite, and other minerals occur as replacements of the Devonian limestone.

By reference to the geological map the preponderance of the important ore bodies occurring in the Hermosa, particularly in the lower and middle divisions, will be evident. Near the periphery of the dome, where the Permian, Triassic, and Jurassic sediments now constitute the surface, no large ore bodies have been found. The Johnny Bull, it is true, occurs in Dolores rocks, but the ore body, although at one time giving rise to considerable excitement, proved to be little more than a pocket.

MINERALOGY OF THE ORES.

The ores of the Rico district present few noteworthy or peculiar mineralogical features, and need receive but brief treatment under this head. They may be roughly divided into (1) pyritic ores, usually of very low grade, and (2) argentiferous galena ores, sometimes with rich silver minerals and often containing much sphalerite. The pyritic ores constitute the characteristic vein filling of most of the lodes and occur in many of the blankets and other deposits. The galena ores form the workable ore bodies, deposited under various favorable circumstances of concentration. The two kinds of ore are not capable of sharp mineralogical or commercial distinction, and are not necessarily of different age.

The principal minerals occurring as a direct result of the general processes of mineralization are as follows:

Pyrite.—This is by far the most abundant sulphide in the district. Associated with quartz and small amounts of chalcopyrite, sphalerite, and galena, it constitutes the practically worthless filling of most of the lodes. It is found in large blanket-like masses, free from gangue, in C. H. C. Hill. In similar masses, but usually in more solid condition, it is found as a replacement of limestone. This is the mode of its occurrence in the Blackhawk mine, where it is frequently associated with fluorite and grades by increase of chalcopyrite and galena into workable ore. Although commonly containing small quantities of silver and gold, the pyrite has hitherto proved too low in grade for successful treatment. Rickard records that the pyrite from the northwesterly lodes in the Enterprise mine usually afforded on assay from 4 to 8 ounces of silver and traces of gold. In the Gold Anchor prospect in Bull Basin a large body of pyrite was found which is said to have indicated, in single assays, as much as 90 ounces of gold per ton, but which as a whole did not pay the cost of extraction.

Galena.—This very important ore mineral occurs abundantly in the Enterprise blanket and in most of the bodies of unoxidized ore that have been worked in the district. It is always argentiferous, but apparently does not constitute rich ore unless accompanied by argentite, tetrahedrite (freibergite?), proustite, or polybasite, as is the case in the Newman Hill mines. On the other hand, it nowhere occurs in sufficiently large masses, unless possibly in the Atlantic Cable mine, to be workable for its lead alone. It presents no unusual peculiarities in this region and is, as elsewhere, nearly always accompanied by sphalerite.

Sphalerite.—Zinc blende is an abundant constituent of the rich ores of Newman Hill, which sometimes contain over 15 per cent of zinc. Its common associates in these ores are galena, chalcopyrite, rhodochrosite, and quartz, and it occurs both in the northeasterly lodes and in the blanket. It is also found in massive granular form, associated with a little chalcopyrite, galena, and fluorite, in the Blackhawk mine, where it makes up a considerable part of the large replacement bodies in limestone. In the Atlantic Cable claim it occurs in coarsely crystalline nodular masses, associated with chlorite, specularite, chalcopyrite, and galena, in limestone. This sphalerite is dark brown, while that in the Newman Hill veins is usually rosin colored. It is also abundant in the Sambo mine and in the Bancroft and Lily D. prospects, associated with galena. The occurrence of sphalerite has until recently been purely an objectionable feature in the ores, owing to the penalty attached by the smelters to ores containing over 10 per cent of zinc. But in 1900 experiments were begun to determine the feasibility of working some of the sphalerite ores for zinc. At the present time zinc ore is extracted in commercial quantities from the Atlantic Cable by the United Rico Mines Company and treated in a small stamp mill. The galena is saved on vanners and the sphalerite concentrated by a magnetic separator. Some shipments have been made, but the plant is essentially experimental.

Chalcopyrite.—This mineral is not very abundant in the Rico district, although nearly always present with galena and sphalerite in the workable ores. Associated with pyrite, fluorite, and some finely granular galena and sphalerite, it formed some of the best ore in the Blackhawk replacement bodies, where it often occurred in fine concentric or irregularly curved, narrow bands. It is present in small quantity in the blanket and lode ores of Newman Hill, in the Silver Swan, Aztec, and Atlantic Cable prospects, and in many other lodes and blankets throughout the district.

Tetrahedrite.—Gray copper ore occurs in the

rich blanket ores of the Enterprise and Rico-Aspen mines and in some of the northeasterly lodes. It is a valuable constituent on account of its argentiferous character. It is here associated with sphalerite, polybasite, galena, rhodochrosite, and quartz. It also occurs in these mines in ore that has replaced gypsum, the gangue in such cases being partly the transparent crystalline form of gypsum known as selenite. Small amounts of tetrahedrite are found as a replacement of sandstone in the Gold Anchor prospect in Bull Basin. It is probably present also in the Aztec lode, with chalcopyrite, and may have formed part of the Johnny Bull ore. A small pocket of tetrahedrite was extracted from the Iron lode, but the mineral apparently does not occur in the replacement deposits of this mine. A little occurs also, with quartz, in the Eureka, a prospect near the head of Iron Draw. It is nowhere abundant, and its presence is generally indicative of high-grade ore, although not necessarily in large amount.

Enargite.—This mineral, a sulpharsenate of copper, occurs at the head of Horse Creek in the Johnny Bull mine.

Specularite.—The crystalline variety of hematite occurs abundantly in several mines and prospects in the metamorphosed Devonian beds near Rico. Among these may be named the Iron Dollar, Eighty-Eight, Atlantic Cable, Shamrock, and Smuggler. It is closely associated with chlorite, epidote, garnet, and wollastonite (and perhaps vesuvianite), as well as with galena, sphalerite, and chalcopyrite, and its formation was evidently connected with the general metamorphism of the Devonian limestone. It is of no value as an ore in this region, but has been sometimes mistaken for sphalerite.

Magnetite.—This mineral has been mined in small amounts for fluxing purposes from the Magnet prospect on the north side of Darling Ridge and from the Eagle prospect near the head of Sulphur Creek. It occurs massive, with a little chalcopyrite, replacing limestone. It may contain half an ounce of silver and $2 in gold per ton.

Argentite and other silver-bearing minerals.—Argentite, proustite, polybasite, and perhaps stephanite occur in the rich blanket and lode ores of Newman Hill. They were evidently among the last ore minerals to form, and to them are mainly due the richness of these deposits. They are almost invariably found in vugs in the more solid ore, and when present in the lodes occur along the medial plane of the vein in the spaces left by the comb structure of the quartz and other minerals. Argentite is found in rounded masses, suggestive of particles of shoemaker's wax which have softened and fitted themselves to the interstices between the earlier crystals. Polybasite and proustite also occur in vugs, but in implanted crystals of the forms characterizing these minerals. Stephanite was not identified at the time of visit, but its occurrence has been reported by Farish, who also mentions pyrargyrite. These rich silver-bearing minerals were not seen elsewhere in the district in 1900; but argentite is said to have occurred in the Puzzle mine, in a quartzose gangue, replacing limestone.

Silver.—Native silver is reported from the Enterprise and Puzzle mines, but none was seen in 1900. It was probably a product of oxidation.

Gold.—Free gold is rarely detected in the Rico ore deposits. Some is said to have been found associated with sphalerite and chalcopyrite in the Enterprise mine, and some embedded in rhodochrosite in the Eureka vein of the same mine. A little free gold has also been found in prospects near Calico Peak, but none was seen in place. The ore of the Johnny Bull mine contained considerable gold, with tellurium and traces of bismuth, but it is not known whether any of the gold occurred native. Gold, associated with a little molybdenum, occurred in the Uncle Remus mine, but whether free or not can not now be ascertained.

Copper.—Native copper was noted only in the California prospect, near the head of Iron Draw, as small crystalline sheets or skins in the country rock.

Quartz.—This is by far the most abundant gangue mineral in the region. It is nearly always associated with pyrite, and constitutes the common filling of the lode fissures. Although usually present in the workable ores, it is there associated with other gangue minerals. The lode quartz shows no special features peculiar to this region, and requires no detailed description. In the form of jasperoid (a cryptocrystalline aggregate commonly associated with replacement deposits) quartz occurs in the Blackhawk mine and in the blanket of the Sambo mine. In the former mine, also, are found spongy, cavernous masses of rusty quartz, apparently due to the removal of limestone, by solution, from a network of quartz stringers. Quartz is abundant in some of the blanket breccias as a replacement of the brecciated material. In the case of the nearly black Hermosa shales, many of the fragments are still recognizable as dark patches in the white quartz, although the microscope shows that they have been altered to cryptocrystalline quartzose aggregates. In the main blanket of the Union-Carbonate mine fragments of monzonite-porphyry have been more or less completely transformed into very spongy masses of white quartz, sometimes containing pyrite. A somewhat similar silicification of porphyry has taken place alongside the lode fissures of the Mohawk and Marriage Stake prospects in Horse Gulch. In these cases, however, the resulting siliceous skeleton still preserves, in a measure, the original porphyritic appearance of the rock.

Rhodochrosite.—The carbonate of manganese is present in the rich upper portions of the northeasterly lodes of Newman Hill and in the Enterprise blanket. Its delicate pink color makes it easily recognizable, and it is important in these mines as a rough indication of good ore. It occurs massive, often irregularly but beautifully banded with the quartz and ore of the lodes. It does not, as far as known, occur in this region in the large, well-formed rhombohedral crystals which characterize this mineral in some other localities. A little residual rhodochrosite was noted in the oxidized Little Maggie vein, at the Blackhawk mine, but it is not generally abundant outside of Newman Hill. Some of the "spar" veins in other portions of the region have a slight pinkish tint, however, and decompose in part to black oxide of manganese, showing either that some of this mineral is present or that the "spar" is manganiferous.

Calcite.—This mineral, the common "spar" of the miners, is abundant only in the veins of Nigger Baby Hill, where it takes the usual place of quartz as the principal gangue mineral. It is generally finely crystalline, more or less impure, and often resembles ordinary limestone. It is always manganiferous, and readily undergoes decomposition, whereby the calcium carbonate is largely removed and a soft black mass of oxidized manganiferous ore left behind. Calcite is naturally often present as gangue in the replacements of limestone by ore.

Fluorite.—Fluorspar is not of widespread occurrence in the Rico ore deposits, but is abundant in the displacement ore bodies of the Blackhawk mine and in the Fortune and Duncan prospect north of Silver Creek. In the Blackhawk it forms the gangue of pyrite, chalcopyrite, sphalerite, and galena in the large pay shoot outcropping at the surface near the bunk house. It is pale lilac or colorless and is easily recognized by its hardness and cleavage. In the Fortune and Duncan it constitutes the gangue of a low-grade pyritic ore occupying a breccia zone between quartzite and limestone. It is nearly colorless, with slight pinkish and greenish tints, and forms with pyrite and chalcopyrite a friable crystalline aggregate. A small quantity of fluorite also occurs in the Hibernia tunnel.

Gypsum.—The hydrous sulphate of calcium occurs as a gangue mineral, as far as observed, only in those ores which have replaced massive gypsum in Newman Hill. A portion of the gypsum has in such cases recrystallized as transparent plates of selenite.

Barite.—Heavy spar, or the sulphate of barium, is not known in this region as the gangue of any workable ore body. It occurs, however, on a claim adjoining the Aztec mine, in a vein supposed to be the same as that worked in the latter mine.

Chlorite.—This mineral occurs abundantly as a gangue for sphalerite, chalcopyrite, and specularite, in the Atlantic Cable and other prospects in the Devonian limestone. It is cryptocrystalline and massive.

Garnet, epidote, pyroxene, and wollastonite.—These minerals, all characteristic of contact metamorphism, occur in the altered Devonian limestone of the Atlantic Cable and adjacent claims.

Kaolinite and sericite.—These minerals are not abundant in this region and can scarcely be considered as gangue minerals. Some kaolinite, however, occurs associated with the ore in the Johnny Bull mine, and sericite is found in connection with the C. H. C. Hill blanket.

Paragenesis.—By paragenesis is here meant the association of the various ore and gangue minerals, with special reference to the mode and order of their formation.

Although these minerals, as indicated in the preceding section, are commonly found in more or less characteristic association, no constant and regular order of deposition has been discovered. Careful study of the banded veins of Newman Hill has failed to show that this banding can be explained by any simple depositional sequence of the component minerals. Each mineral has evidently been developed at many different times during the whole period of mineralization. The only generalizations which it appears safe to make are that in Newman Hill the rich silver ores proustite, argentite, and polybasite were the last ore minerals to form in the northeasterly lodes and in the Enterprise blanket, and that there was deposition of practically barren quartz and a little pyrite, which was also subsequent to the formation of the galena, sphalerite, and rhodochrosite. Whether this barren veining preceded, followed, or coincided with the deposition of the rich silver minerals is not known. It is supposed to have followed it.

Products of oxidation or weathering.—The access of surface waters to the upper portions of many of the lodes and to some of the blankets and replacement ore bodies has resulted in a variety of products, many of them earthy and of obscure mineralogical character. The rather thorough oxidation of the shattered pyritic blankets of C. H. C. Hill has given rise to great masses of limonitic iron ore, sometimes containing gold and silver, but usually of no value. Associated with this are earthy lead sulphate, pulverulent hydrous silica, jarosite (hydrous sulphate of iron and potash), sericite, halloysite, gypsum (derived from limestone by sulphate solutions from oxidizing pyrite), silver in unknown combination, and probably many other minerals. In Nigger Baby Hill the decay of the calcitic veins to a depth of some 200 feet has resulted in soft, black earthy ores consisting largely of hydrous oxides of manganese and iron, obscure hydrous compounds of alumina, carbonates of copper in small amounts, and silver, lead, and zinc in unknown conditions, probably in part as carbonates. Similar products have resulted from the alteration of a bed of impure limestone in the Forest-Payroll mine. In the Puzzle mine the argentite is stated by Purington (unpublished MS.) to have been partly altered to native silver and to embolite, the chlorbromide of silver; and on the M. A. C. claim, adjoining the Puzzle, in a shaft now inaccessible, was found a soft mass of pale-blue allophane (hydrous silicate of alumina) and kaolinite in a cavity, dissolved in the limestone.

Although not strictly a product of oxidation and weathering, it may be well to mention in this place the pulverulent gray mixture of dolomite and celestite which has remained as a residue after the solution of the gypsum of Newman Hill.

OCCURRENCE OF THE ORES.

DEFINITIONS.

It is essential to clearness that the usage of such terms as are employed in the description of the Rico ore deposits should be plainly understood. The following definitions are intended to make clear the terminology adopted in this folio, and need have no currency outside of its pages.

A *fissure vein* is the filling of a fissure. *Lode* is applied as a more comprehensive term, and may mean either a simple fissure vein or a complex assemblage of closely spaced veins or stringers, often including a certain proportion of mineralized country rock occurring alongside of and within the fissure zone. A lode is roughly tabular in form, and when occurring in sedimentary rocks cuts across the beds at an appreciable angle. It is usually more nearly vertical than horizontal. That portion of a vein or lode which consists of workable ore is termed a *pay shoot*.

The word *blanket* is used to designate a zone or lens, composed of mechanically or chemically disintegrated material, lying parallel to the bedding of the sedimentary series within which it is inclosed. Such a mass is always referred to as a "contact" by the miners of Rico. In contradistinction to a lode, a blanket is usually more nearly horizontal than vertical. It is normally composed of soft material as compared with the rocks which immediately overlie or underlie it, and is in most cases a breccia.

Blankets are frequently mineralized and contain bodies of ore which may or may not be coextensive with the blanket itself. Such ore bodies will be termed pay shoots, as in the case of lodes.

Replacement ore bodies in limestone require no special definition. They embrace those ore masses, often of irregular form, which have molecularly replaced the limestone through the process known as metasomatism.

Stocks are those ore bodies commonly referred to as "chimneys." They are more or less solid masses of ore, roughly circular in plan, with their longest dimension nearly vertical. Their formation, while usually initiated by two or more intersecting fissures, is accompanied by considerable metasomatic replacement of the country rock.

LODES.

Fissure systems.—Partly on account of the oxidation of their upper portions, but more largely through the concealment of their outcrops by landslides and wash, the lodes of the Rico district are very poorly exposed on the surface. Their distribution is closely connected with the general geological structure of the district. They are most abundant in the central portion of the area and decrease in number and importance toward the periphery of the dome-like uplift of strata from which the Rico Mountains have been carved. The most important group of fissures is undoubtedly that of Newman Hill. Second in number and productiveness are those of Nigger Baby Hill. Other notable fissures are connected with the great dislocation known as the Blackhawk fault. Some of these seem to have played an important part in the mineralization of C. H. C. Hill, but they are so disturbed and buried by landslide material that thorough study of them is impossible. Many other lode fissures occur in Horse Gulch and on Expectation Mountain, but they are poorly exposed and none of them have proved of much economic importance.

The principal fissures of Newman Hill fall into two classes, distinguished by their strikes or trends and by the characters of the veins which fill them. The fissures of the more important class are characterized by strikes varying from about N. 25° E. to N. 65° E. They are locally known as "verticals" or "pay veins," but will be referred to in this folio as *northeasterly* fissures. These are occupied by the ore-bearing lodes, such as Swansea, Kitchen, Enterprise, Songbird, Hiawatha, Eureka, Jumbo No. 2, Jumbo No. 3, Chestnut, Klingender, Montezuma, Selenide, Star, and other veins.

The lode fissures of the second class are characterized by strikes ranging from nearly north and south to about N. 45° W. They correspond to the "barren veins" or "cross veins" of the Newman Hill mines, but will be referred to in this folio simply as *northwesterly* fissures. They are not themselves ore bearing, although they exercised an important influence on the deposition of ore in an overlying blanket.

The northeasterly fissures are usually simple fractures, nearly vertical or dipping southeasterly at high angles. They range in width from a mere crack up to 2 or 3 feet; but a width of 18 inches is rare, and the average is probably not much over 6 inches. They traverse sandstones, shales, and limestones belonging to the lower division of the Hermosa. These beds dip somewhat east of south at a general angle of from 10° to 15°. The fissures were originally opened by normal faulting, of which the known throw has in no case exceeded 10 feet and is usually much less.

The fissures are limited above by the main Newman Hill blanket, commonly known as the "contact." Some are known above the blanket,

but they contain no ore, and can not be individually correlated with those below it.

The conditions which limit the northeasterly fissures in length are not well known, as apparently none of them have been worked to the point of disappearance. Toward the southwest some of the more continuous ones probably reach and are cut off by the Deadwood fault. Toward the northeast it is probable that the prominent northeasterly fissures known in the Enterprise, Newman, and Rico-Aspen mines do not persist across the thick intrusive sheet of monzonite-porphyry which rises up over the northern slope of Newman Hill. They either die out before reaching it or are deflected into other courses.

None of the northeasterly fissures have been explored to great depth, but the section afforded by the Lexington tunnel, about 450 feet below the Newman Hill blanket, shows that they are smaller at this depth than in the workings above.

The northwesterly fissures of Newman Hill are more abundant than the northeasterly; but as they contain no workable ore, they are seldom drifted on and are consequently not so well exposed as the latter. Their dips range from vertical to about 40° and may be northeast or south, the former being more common. The average dip is lower than that of the northeasterly fissures. They vary greatly in width, from a mere crevice up to 3 or 4 feet. Although often simple fractures, they very frequently show more complex form. They appear to have been opened by normal faulting, and in some cases are reported to have faulted the overlying blanket to the extent of 25 feet throw. Vertical displacement to this amount is, however, rather exceptional. Moreover, as will be seen later, the structure of the northwesterly lodes shows that a considerable part of the observed faulting may have taken place since the fissures were first formed.

In the Union-Carbonate mine, on the northern spur of Dolores Mountain, the fissures show few resemblances to those of the more southerly portion of Newman Hill. The productive northeasterly fissures are not developed. Numerous other fissures are found striking from N. 60° W. to N. 75° W.—that is, more westerly than the northwesterly veins of the Enterprise mine. Fissures of this general trend are dominant on the northern slope of Dolores Mountain, as shown in the Union-Carbonate and Forest-Payroll workings.

Outside of Newman Hill, northeasterly fissures are of small importance. Several have been worked at the eastern base of Expectation Mountain, between Sulphur Creek and Iron Draw, in the N. A. Cowdrey, Tomale, Argonaut, and Bancroft mines. The strikes of these fissures range from N. 40° E. to N. 60° E. They are fairly abundant, but small, rather irregular, and apparently not very persistent.

On Nigger Baby Hill the economically important fissures are northwesterly in trend. Such are the Hope, Cross, Grand View, Phoenix, and Butler veins. Near the top of the hill and on the western slope the average strike is N. 30° W. and the average dip northeasterly at about 25°, although the Cobbler vein is steeper. As these fissures are followed downward, their dips are found to increase. The Phoenix vein, with dips sometimes as low as 15° in the upper workings, steepens to 45° in the lower tunnels, on the southern slope of the hill. The strike of the fissures is also found to be more westerly as they are followed southeast, toward Silver Creek.

The Iron lode, on the southeastern slope of Nigger Baby Hill, strikes N. 16° W. and dips easterly at about 75°. Its trend is thus more northerly than the majority of the lode fissures on the hill.

The Hope, or Grand View, Cross, Phoenix, and Nellie Bly fissures are notable from the fact that their strikes are very nearly parallel to those of the beds which inclose them, while their dips, though generally slightly steeper in angle, correspond in direction to those of the strata. Consequently these fissures cross the bedding planes at a very acute angle, causing the lodes, particularly in the upper part of the hill, to closely resemble the form of deposit that has been termed a blanket.

The main fissure, on which are located the Blackhawk, Argentine, and Uncle Ned mines, has a general course of N. 40° W. and dips northeast at angles varying from 50° to 80°. The geological work of Cross and Spencer has shown that this fissure is part of a pronounced zone of faulting which they have called the Blackhawk fault. The same fissure passes under the landslide of C. H. C. Hill and probably corresponds to the Pigeon lode, or so-called "big fissure" of that hill, and to the C. V. G. lode at Burns. It is quite possible, also, that the A. B. G. lode, on the west side of the river, is on a branch of the same fault, for, as the geological map shows, it occupies a fault fissure. Details of the Blackhawk fissure are difficult to obtain. It is the largest and most persistent in the region, attaining in places a width of over 40 feet. It is not likely, however, that an open space of this width existed at any one time. The great width of the lode at certain places is due to the passage of a simple fracture into a sheeted zone, and also to repeated reopenings and fillings along the same zone of fracture.

Intimately connected with the Blackhawk fissure are several fissures striking about N. 70° W. and falling into the main fissure on its northeast side. Such are the Little Maggie and Allegheny veins, the former dipping northeast at about 60°, while the latter dips southwest at about 70°.

On the northwestern slope of Telescope Mountain and north of C. H. C. Hill are several northwesterly fissures, usually with steep southwest dip. The two on which are located the Golden Rod and Leap Year claims are strong and persistent fractures.

Northwesterly fissures also prevail in Horse Gulch, but they are poorly exposed and not at present producing ore. Such are the fissures of the Mohawk, Christina, Belzora, Caledonia, Utah, and other unworked prospects. They are prominent also in the Little Leonard mine, in monzonite, on the eastern slope of Expectation Mountain.

In addition to the Nellie Bly lode fissure (not the Nellie Bly fault) on Nigger Baby Hill, which has a low northerly dip, nearly east and west, approximately vertical fissures are known in the Lily D. mine, on C. H. C. Hill; in the Calumet mine, north of Piedmont; in the Aztec mine, in Aztec Gulch; in the California and Zulu Chief mines, near the head of Iron Draw; and apparently also in the Eighty-Eight mine, on Silver Creek.

It appears from the foregoing that the northeasterly fissures which have proved so productive in Newman Hill are characteristic of but a small part of the district, comprising roughly the southern half of Newman Hill and that part of the base of Expectation Mountain lying between Sulphur Creek and Iron Draw. Fissures of general northwesterly course, on the contrary, are abundant, not only in Newman Hill, but over the entire central portion of the area. Between northeasterly fissures and northwesterly fissures the separation is fairly definite; but between northwesterly fissures, on the one hand, and east-west fissures and in a few cases north-south fissures, on the other, the distinction is less sharp. In the main the fissures are simple and of small or moderate size. With a few notable exceptions they either show no evidence of having been opened by appreciable faulting or else the throw of the fault is small. Thrust (i. e., reversed) faults of importance are not known, and the prevalent dislocation has plainly been normal in character.

Structure and material of the lodes.—The northeasterly fissures of the southern half of Newman Hill are usually occupied by simple veins of banded ore, confined between sharply distinct walls of sandstone or shale. The vein filling consists of quartz, rhodochrosite, sphalerite, galena, chalcopyrite, and pyrite, together with argentite, proustite, polybasite, and other highly argentiferous minerals. These various minerals have been so deposited within the fissure as to give a pronounced but rather irregular banding to the veins. Along the middle of the vein there is usually a zone of comb structure, or vugs, consisting largely of quartz and of the high-grade argentiferous minerals. The last are particularly abundant in the quartz vugs, which nearly always occur along the medial plane of the vein, and sometimes along planes near the wall.

In most cases the filling of the northeasterly fissures from the walls to the medial zone of vugs appears to have been a continuous process; but in other instances the fissure, after having once been filled, has been slightly reopened along one or both walls and the resulting space freshly filled, usually with practically barren quartz.

Though the northeasterly lodes of Newman Hill are characteristically simple fissure veins, yet they occasionally split up into more complex forms, such as sheeted zones or stringer lodes. The transformation of the veins to masses of small, irregular stringers, near their junction with the Newman Hill blanket, has already been referred to.

Toward the north the material of the Newman Hill northeasterly veins changes. Such veins as have been followed to the vicinity of the Laura shaft show a notable diminution in the value of their contents. Immediately north of the Laura shaft the veins have not been much explored; but a little farther north, in the Pro Patria, Fickle Goddess, and other tunnels, the only northeasterly veins found carry little but quartz and pyrite and are usually of too low grade to pay for working.

The northeasterly veins exploited in the Cowdrey, Tomale, Argonaut, and Bancroft mines, on the west side of the Dolores River, differ materially in their filling from those in Newman Hill. They contain low-grade argentiferous galena, with much sphalerite and pyrite. The gangue is quartz, with no rhodochrosite. These veins are generally small and adherent, or "frozen," to their walls. They frequently split into small, irregular stringers which die out in the country rock. The striking banded structure of the Enterprise lodes is lacking in these veins of like trend on the west side of the river.

The northwesterly lodes of Newman Hill form a notable contrast to those of northeasterly trend. They are filled with white quartz, sometimes containing pyrite, but never any ore in commercial amounts. As opposed to the usual solidity of the northeasterly veins, the northwesterly lodes are crushed and accompanied by seams of gouge. The result of this crushing, in extreme cases, is a loose mass of quartz and clay that can be excavated with pick and shovel.

In the Newman mines, where the northwesterly lodes are better exposed and often less shattered than elsewhere, they frequently show rather complex structure, and many of them are, properly speaking, stringer lodes.

In the northern part of Newman Hill and on the northern slope of Dolores Mountain the more westerly lodes, which there predominate in the Union-Carbonate and Forest-Payroll mines, show less crushing or shattering. They have also furnished a little ore. The Forest lode is composed of about a foot of quartz and low-grade sphaleritic ore. The latter occurs only in bunches.

On the northern spurs of Blackhawk Peak the Little Maggie and Allegheny lodes, which also have a northwesterly course, are simple veins, but so deeply oxidized that their original filling and structure can be only surmised. The Blackhawk lode itself is difficult to describe or define, as it apparently consists of several nearly parallel veins of quartz, forming part of the Blackhawk fault zone. These veins are composed of practically barren massive quartz, showing no peculiarity of structure. There are no other accessible workings on this lode until C. H. C. Hill is reached, where its probable extension, the Pigeon lode, is encountered in the Logan and Pigeon mines. Here it greatly resembles the northwesterly lodes of Newman Hill, but is on a much larger scale. Where seen in the Pigeon mine it shows a width of 40 feet and consists of several stringers of quartz and pyrite separated by sheets of country rock. The whole lode is greatly shattered and is accompanied by much soft gouge. In the Logan workings the lode shows a width of 12 feet and contains masses of soft, crumbling pyrite. Neither the Blackhawk nor the Pigeon lode carries any workable ore as far as known, although some appears to have been extracted from that portion of the fissure which traverses the Uncle Ned ground, on Telescope Mountain.

The C. V. G. lode, at Burns, not now accessible, is probably the same as the Pigeon. The A. B. G., on the west side of the river, is a strong vein up to 6 feet in width, carrying streaks of galena, sphalerite, and pyrite in a gangue of quartz and calcite.

On Nigger Baby Hill the northwesterly fissures are distinguished by an entirely different type of vein from those on Newman Hill. They are filled by simple veins of moderate size. In their upper portions these veins have undergone decomposition of a kind to be more fully described hereafter, but in their deeper, unoxidized portions they contain a relatively low-grade sphaleritic ore in a calcite matrix or gangue. Quartz is either wholly lacking or is very subordinate in amount. The bulk of the ore from Nigger Baby Hill has been obtained from the decomposed upper portions of these relatively low-grade calcitic veins.

Little can at present be learned concerning the structure of the numerous northwesterly lodes of Horse Gulch, owing to the abandonment of most of the workings on them. The lodes of the Mohawk, Zenith, and Marriage Stake claims contain practically no vein filling, but are zones of silicification and of impregnation by pyrite along fissures in monzonite-porphyry. The dump of the Lackawanna shows that this prospect followed a lode containing abundant manganiferous carbonate. Most of the Horse Gulch lodes evidently contained much pyrite, in association with which occurred bunches of salable ore.

The structure and filling of the nearly east-west lodes of the Nellie Bly vein, on Nigger Baby Hill, are in every way similar to those of the northwesterly veins on the same hill, such as the Hope or Grand View. The Last Chance lode, lower down on the south slope of the hill, is an irregular vein between walls of altered porphyry impregnated with pyrite. The vein itself is composed of quartz, pyrite, and chalcopyrite. The Aztec lode, supposed to be on the line of the Nellie Bly fault, consists of banded quartz about 3 feet in width, accompanied by much crushed and mineralized country rock on each wall. In the Zulu Chief mine, near the head of Iron Draw, is a lode exhibiting a similar structure to that of the Aztec. It is likely that the two occupy the same fissure. The Calumet lode, supposed to correspond to the Last Chance fault, is a large, irregular vein up to 5 feet in width, filled with quartz containing bunches of pyrite. There are no regular walls to the fissure and the country rock is much decomposed. The whole lode is crushed and disturbed by recent movements.

The foregoing description shows that, taking the region as a whole, fissures of like trend are not necessarily characterized by similar ores or by corresponding structures. The miners who first worked in Newman Hill were naturally struck by the contrast between the local richness of the northeasterly veins and the poverty of the northwesterly fissures. They distinguished the two as "pay veins" and "barren veins," and this terminology has obtained a certain currency throughout the district. The adoption of richness and poverty as criteria for classifying the lodes of the region is misleading, particularly as different portions of a single lode would thereby frequently be placed in supposedly distinct classes.

Changes in the ore with increase of depth.—There are few more striking features connected with the Rico ore deposits than the very limited vertical range of their ores. With the exception of the Little Maggie and Allegheny veins and those of Newman and Nigger Baby hills, none of the lodes in the district has produced much ore or has been explored to any considerable depth. Such ore as has been found occurred in isolated pockets, or is so low in grade that the various spasmodic attempts to work it have been successively abandoned. Low-grade pyritic ores extend to greater depths than are anywhere reached in the mines, but no success has yet attended attempts to exploit them. In the cases of the Little Maggie, Allegheny, and Nigger Baby Hill lodes, the lower limit of the workable ore has thus far been found to correspond to the bottom of the zone of oxidation. The rich ore is here due to purely secondary processes.

In the northeasterly lodes of Newman Hill, however, there is a decided change which antedates all superficial oxidation. Unlike secondary enrichments due to ordinary oxidizing processes, the depth at which the Newman Hill veins change their character bears no relation to the topographic surface, but is more or less constant with reference to an overlying blanket. For a maximum distance of about 150 feet below this blanket, the northeasterly lodes contain pay shoots of rich ore. Below

this depth the valuable silver minerals disappear; galena, sphalerite, and rhodochrosite vanish; and the veins, which above produced ore carrying many hundreds of ounces of silver per ton, become practically barren quartz and pyrite. So far as their material is concerned these lower portions are indistinguishable from the northwesterly veins. In the Lexington tunnel, which crosscuts the Newman Hill veins at depths varying from 350 to 550 feet below the blanket, they are small and practically barren, consisting of quartz and a little pyrite.

Oxidation of the lodes.—In the southern part of Newman Hill, as no lodes are worked above the Newman Hill blanket and as the latter is protected from the free access of surface waters by an impervious layer or "roof" of shale, oxidation has played but a minor part in the development of the ore bodies. In the Union-Carbonate mine some oxidized ore was mined from a northwesterly fissure. This ore was near the surface, and extended to a depth of 30 or 40 feet below an overlying blanket, also oxidized. On Nigger Baby Hill, however, and in the Little Maggie and Allegheny lodes, descending surface water has been the effective agent in producing workable deposits of ore.

The depth to which oxidation has penetrated in Nigger Baby Hill is apparently variable. Owing to the steep sides and faulted structure of the hill the permanent ground-water surface is low, and oxidation has probably nowhere extended down to it. The process has been irregularly limited by very local physical and chemical factors and by time. From the extent of the old stopes it appears probable that complete oxidation extends for about 200 feet from the present surface of the hill near its summit, growing less on its flanks.

The process of decomposition was undoubtedly greatly facilitated by the fact that the veins contain a calcitic and not a quartzose gangue. The impure calcite is dissolved and carried away, leaving behind a sooty residue, consisting chiefly of hydrous oxides of manganese and iron, with some silica and alumina. This soft black or brown material is sometimes rich in silver.

The alteration of the upper portions of the Little Maggie and Allegheny veins is somewhat similar to that described. The Little Maggie vein, however, seems to have contained more copper than is present in the Nigger Baby Hill veins, and some residual kernels of pink rhodochrosite were noted.

Relation of the lodes to faults.—The relation of the lode fissures to the important structural faults established by the geological mapping is neither so close nor so obvious as on a priori grounds might be expected.

Productive lodes do not occur in the fissures of considerable faults. Out of the 50 or more fault fissures drawn on the geological map, not one has been shown to contain any large bodies of ore. The Blackhawk lode, which does not itself contain workable ore as far as known, is close to a large fault, but it is by no means certain that it fills the actual fault fissures. The same may be said of its probable continuation, the Pigeon lode, in C. H. C. Hill. The A. B. G. lode, at Burns, is possibly on a branch of the Blackhawk fault. It contains some low-grade ore, which, however, has never been worked on a commercial scale. The Nellie Bly fault certainly does not coincide with the Nellie Bly vein, but appears as a close, inconspicuous fissure a few feet south of the vein. It is possible that the western extension of this fault passes through the Aztec and Zulu Chief lodes, but these properties can scarcely be classed as productive. The Last Chance fault, although taking its designation from a prospect of that name, is certainly not identical with the Last Chance lode fissure. It is shown on the map as passing through the workings of the Calumet, an unproductive prospect on the west side of the river.

The question of the coincidence of faults and lodes may be justly summed up in the statement that the most productive lode fissures of the district show very little faulting along them, while fault fissures of sufficient extent to be structurally important contain little or no ore. It is but fair to remark, however, that the fault fissures have been scarcely prospected.

Considerable structural faults may also be important in displacing lodes which they cross. It is highly probable that the Deadwood fault, south of Newman Hill, cuts off the Newman Hill blanket and lodes, throwing their southern continuation downward and westward. A zone of faults passing down the west slope of Dolores Mountain, past the Laura shaft, has probably offset the lodes on the north. Neither of these points, however, could be determined underground at the time of visit.

The Nellie Bly fault, which passes over the end of Nigger Baby Hill and brings the massive limestones of the medial division of the Hermosa formation up on the south until they abut against the Rico beds on the north, passes through the workings of the Grand View and Iron mines, without, as far as can be seen, interrupting the Phoenix, Grand View, or Iron veins. It seems necessary to conclude that these veins are of later origin than the fault.

Relative ages of the lodes.—The question of the relative ages of the northeasterly and northwesterly lodes of Newman Hill is of theoretical and practical importance. The observed phenomena that bear on the question may be briefly summarized as follows:

(1) The lodes of the two systems are distinctly different in trend.

(2) The northwesterly lodes are practically barren, whereas the northeasterly veins usually contain rich ore to a depth of about 150 feet below the Newman Hill blanket.

(3) The northeasterly veins sometimes show a later generation of quartz and pyrite.

(4) The northwesterly veins, when not too much crushed, usually show banding due to repeated openings and fillings.

(5) The northeasterly veins are solid and often adherent to their walls; the northwesterly lodes are almost invariably crushed and accompanied by gouge.

(6) The northwesterly fissures generally cross the others without being themselves deflected.

(7) In some cases the northwesterly fissures fault the northeasterly lodes, but more commonly they pass through the latter without offsetting them. Marked changes in the value of the ore are said to occur at such crossings.

(8) A northeasterly vein is sometimes lost at the crossing of a northwesterly vein, as was the case with the Hiawatha on the 100-foot level of the Enterprise mine and the Chestnut and Newman veins in the Newman mines. It has been commonly assumed in such cases that the northeasterly vein has been faulted and offset for distances up to 175 feet. It is to be noted that the northeasterly vein is not always sharply cut off at the supposed fault, but small stringers are sometimes present, continuing beyond the latter. Furthermore, the supposed offset of any one of the northeasterly veins cut by a northwesterly fissure is not always comparable in amount with the offset of neighboring veins cut by the same fissure.

(9) Northeasterly veins sometimes contract or divide into small stringers on approaching a northwesterly lode.

(10) None of the lode fissures displace the overlying blanket more than 25 feet, most of them much less than this.

(11) In one case (that of the Jumbo No. 3 vein, Enterprise mine) a northeasterly vein is known to turn into a northwesterly fissure for a short distance and then resume nearly its normal course. The deflected portion of the vein has been brecciated, and subsequently healed by white quartz, which was later shattered in its turn. In a few rare instances small northwesterly fissures have been observed containing the characteristic filling of the northeasterly lodes.

(12) The Eureka vein pursues a nearly straight course through the principal Newman Hill workings, without being offset by the northwesterly fissures which cross it and which are commonly supposed to have offset neighboring lodes, in some cases as much as 175 feet.

It is believed that the hypothesis which best reconciles the various observed facts is one which supposes the initial fractures, both northwesterly and northeasterly, to have been formed at practically the same time. Studies of vein structure in this and other regions show that lode fissures may not open to their full width until some considerable time has elapsed after the production of the first fracture. It is probable that in the network of intersecting and partly incipient fractures in Newman Hill the northeasterly fractures were as a whole the first to open sufficiently to allow of vein deposition. If the northwesterly fissures are entirely of later date than the northeasterly veins, it is impossible to account for the fact that the latter occasionally follow the former for short distances, and that they sometimes die out or divide into stringers just as a northwesterly fracture is approached. That the ore changes abruptly in value at the crossing of northwesterly fissures, even where no faulting is perceptible, is strongly insisted on by the miners. It is best explained by supposing that the northwesterly fractures existed when the ore was being deposited in the more open fissures. If the northwesterly fissures were of altogether later date and simply faulted the northeasterly veins, it should be possible to consistently match the faulted lodes on opposite sides of the dislocation. In many cases this is utterly impossible; for whereas some lodes are found to be slightly displaced and can be recognized and followed, others have no continuation beyond the fissure. Attempts to find and identify such continuations have led to absurdities, such as supposing that a fracture which throws the overlying blanket less than 24 feet and does not perceptibly offset the Eureka lode can offset one lode 175 feet and another, but a few feet away, only 20 feet.

On the other hand, unless it be allowed that the principal opening and filling of the northwesterly lodes was later than the ore deposition in the northeasterly lodes, it is impossible to account for the fact that the former cross the latter, and no good reason appears why both should not have been equally filled with ore. The opening and filling of the northwesterly fissures may in part correspond to the slight reopening and filling with barren quartz and pyrite observed in connection with the northeasterly lodes.

Finally, the shattered nature of most of the northwesterly lodes and their constant accompaniment by seams of gouge show that they have continued to be planes of more or less movement up to recent times. It is consequently impossible to determine how much of the observed moderate faulting along these fissures took place prior to their complete filling with quartz, and how much has taken place during the subsequent crushing of their veins.

It has been assumed in the foregoing discussion that lodes of like trend and similar character are of practically the same age. It is possible, however, that some of the northwesterly lodes may be earlier and some later than the northeasterly veins. While it would be difficult to disprove this latter view, it is not considered probable.

Beyond the bounds of Newman Hill, it is found that the same age relationship exists between the northeasterly and northwesterly lodes on the west side of the Dolores River, between Sulphur and Iron creeks. In other portions of the district, however, there is scant opportunity for determining the sequence of lode fissures of different trend. As already noted, the northeasterly lodes are absent or insignificant.

BLANKETS.

Of the various blankets occurring in the Rico district, the so-called Newman Hill or Enterprise "contact" is most important. This is, for the most part, an unconsolidated breccia occurring nearly midway between the top and bottom of the series of sandstones, shales, and limestones which make up the lower division of the Hermosa. It underlies the southern half of Newman Hill, but its extent is only approximately known. On the west it should outcrop along the hillside above the adits of the Rico-Aspen, Newman Hill, and Enterprise mines, were it not for the thick cloak of wash which conceals the rock in place. On the east it conforms to the general southeasterly dip of the beds (about 15°) and passes under Dolores Mountain. On the north it has not been followed far beyond the Laura shaft.

Other blankets occur to the north in the Union-Carbonate mine, but none of them has been identified as the Enterprise "contact." On the south the blanket is cut off by the Deadwood fault. As it approaches the latter it turns down with a rapidly increasing southerly dip and passes out of reach of the present workings.

The blanket has been extensively exploited by the Enterprise, Newman, Rico-Aspen, and other mines and is estimated to have produced at least one-third of the entire output of the district. At present very few known bodies of ore remain, and the labyrinth of contact workings has been allowed to cave in.

The blanket rests everywhere upon a bed of limestone, familiarly known as "short lime," but which may here be conveniently referred to as the *blanket limestone*. This bed varies in thickness from a few inches to about 2 feet.

Below the limestone are usually found 5 or 6 feet of dark shales alternating with very thin lenses of sandstone. Under these is generally a second bed of limestone similar to that above, and below this limestone come sandy shales and sandstones, the latter predominating with increasing depth. The blanket resting upon the blanket limestone varies in thickness from 2 to 20 feet; the average is perhaps 6 feet. It is overlain by fissile black shale, which, as far as known, is never absent and performs an important function in keeping out by its imperviousness the abundant surface waters. Above the shale are beds of sandstone and sandy shale, all more or less fractured and soft, which extend up to the loose surficial material covering the hill.

As a rule the breccia constitutes but the upper part of the blanket. The lower part, resting directly upon the blanket limestone, is commonly a gray, soft, silty material, frequently showing a laminated structure suggestive of a water-laid origin. This deposit varies in thickness and in its upper part is mingled with fragments of shale. Wherever ore occurs in the blanket it is usually as a replacement of this material.

The foregoing description applies to the typical and usual appearance of the blanket, but in some places considerable bodies of gypsum occur above the blanket limestone, occupying space usually filled by the blanket. Such a mass occurs in the Enterprise mine south of the Group tunnel and extends toward the southeast in the direction of the Vestal and Aspen shafts. Another large body occurs in the Rico-Aspen mine, near the Silver Glance shaft. The maximum thickness of the gypsum is not now revealed, but it probably exceeds 10 feet. It sometimes rests directly upon the blanket limestone, but in other places the two rocks are separated by a varying thickness of the gray, silty material already described as a characteristic constituent of the lower portion of the blanket. Wherever this occurs, however, the under side of the gypsum shows evident signs of solution. This is well shown in the Rico-Aspen mine, near the Silver Glance shaft.

The gypsum is pitted with rounded, pothole cavities, up to 8 feet in diameter. Lying upon the limestone under these cavities is always more or less of the silty material, which chemical analysis shows to be a mixture of dolomite and celestite—about 56 per cent of the former to about 37 per cent of the latter.

The Newman Hill gypsum was originally a bed laid down with the Hermosa shales, sandstones, and limestones. There are good reasons for supposing that it was lenticular in form and may not have extended far beyond the present bounds of Newman Hill.

The gypsum is in process of solution and this solution is accompanied step by step by the accumulation of the silty residue of dolomite and celestite. The residual gypsum masses show characteristic cuspate solution forms on their peripheries. The blanket breccia, closely following up the process of ablation, crowds snugly against the wasting gypsum. The gypsum not only once possessed a greater horizontal extent than at present, but was probably at one time coextensive with what is now known as the Enterprise "contact," or blanket. The recognition of the fact that the present gypsum masses are mere waste remnants of the continuous bed that once occupied the entire space is of more importance for an understanding of the genesis of the ore deposit than is the distinct question of the origin of the gypsum itself.

The blanket as thus far described, consisting of shale breccia and of pulverulent dolomite and celestite, has been locally modified through processes connected with ore deposition. The results of these processes may be classed as (1) silicification and (2) deposition of ore. Both of these modifications are directly connected with the lode fissures and occur where the latter meet the blanket. Workable ore is sometimes associated with such a silicified blanket, but more often as silicification becomes prominent the ore vanishes, or vice versa.

The blanket ore occurs chiefly as a replacement of the pulverulent lower part of the blanket above both the northeasterly and northwesterly lodes, but it sometimes extends up into the breccia, where it may, perhaps, have formed partly as the filling of interstitial spaces as well as by replacement. It often partly replaces the blanket limestone, particularly where the latter is brecciated.

In the vicinity of the Vestal shaft and in portions of the Enterprise mine ore occurred in the gypsum itself. It was found as irregular bunches in the lower part of the bed, having metasomatically replaced the gypsum. Such ore has a gangue of quartz, rhodochrosite, and selenite.

The usual blanket ore of the Enterprise and Rico-Aspen mines is similar to that of the northeasterly lodes, but presents certain differences which are always sufficient to identify it. It is usually less solid and shows less regular banding or none at all. It consists of galena, sphalerite, and one or more silver-bearing minerals in a quartz and rhodochrosite gangue which is often subordinate in amount. Rhodochrosite is not so abundant as in the lodes. With the foregoing minerals are often associated small amounts of chalcopyrite and sometimes argentiferous tetrahedrite. Common pyrite is apparently very subordinate in the rich blanket ore. The rich silver-bearing minerals which have been identified include polybasite, argentite, proustite, and probably stephanite.

Many other blankets occur in the Rico Mountains, some ore bearing and some not. Most of them are in rocks belonging to the lower division of the Hermosa, and some of them occur at the same stratigraphic horizon as the Enterprise blanket; but certain conditions entered into the formation of the latter which increased its ore-bearing capacity and which appear to have been absent in the formation of all other blankets examined.

A small blanket, of limited horizontal extent, is known in the Enterprise workings from 100 to 150 feet below the main "contact." It is a breccia of dark shale which carried a little ore alongside of the Enterprise vein.

Still lower in the stratigraphic series and fully 400 feet below the main Enterprise blanket is the blanket of the New Year mine. This is a strong zone of brecciated shales resting upon an intrusive sheet of porphyry and overlain by soft shales. It is partly silicified and contains some low-grade ore.

On the west side of the Dolores River "contacts" occur in the N. A. Cowdrey, Bancroft, Little Maggie, and Silver Swan mines. These are all in lower Hermosa rocks, but occur at various horizons. The Cowdrey blanket consists of two members of disturbed black shale, separated by a bed of limestone about 3 inches thick. The entire blanket is underlain and overlain by massive sandstones. Some low-grade ore occurs near the bottom of the lower shale, at its intersection by a lode. The Bancroft blanket consists of soft shale breccia, mixed with clay, which rests upon massive sandstone and is overlain by shale. It is from 2 to 3 inches in thickness. In the Silver Swan mine a blanket consisting of about 6 inches of soft black clay or gouge passes upward in an unknown thickness of brecciated black shale. In the Little Maggie the principal blanket consists of dark shale breccia resting upon a bed of limestone and overlain by shale. It more closely resembles the Enterprise blanket than do the breccia zones of the other mines, but none of the powdery mixture of dolomite and celestite was observed. This breccia contains small bunches of low-grade ore that has been but little explored.

In the Union-Carbonate mine, on the north spur of Dolores Mountain, several blankets are known, none of which, in spite of their proximity and the fact that they occur in lower Hermosa rocks, can be correlated with the Enterprise blanket. The principal ore-bearing "contact" of this mine is composed of a zone of breccia resting upon a sheet of intrusive porphyry. It is sometimes overlain by porphyry and sometimes passes upward into relatively undisturbed shales. It has a thickness of 4 to 5 feet and in its less altered condition consists of some of the mineralized fragments of shale and porphyry; but where certain fissures intersect the blanket it is entirely replaced by masses of quartz and pyrite containing bodies of low-grade ore.

Below the blanket just described occur several smaller and less important ones of different character. These are found in beds of dark shale, particularly in thin beds lying between relatively massive beds of sandstone or sheets of porphyry, and consist of plastic yellow clay. The clay is an alteration product of the shale in place, and often preserves traces of the original shaly lamination. These clayey zones sometimes contain bunches of oxidized ore near intersecting vertical fissures.

In the Forest-Payroll mine, about 1000 feet northeast of the Union-Carbonate, there are two blankets from 30 to 50 feet apart, neither of which has as yet been correlated with any of those in the Union-Carbonate mine, although, like the latter, they lie in strata belonging to the lower division of the Hermosa. The lower blanket is about 5 feet in thickness. It is a breccia of shale mingled with yellow clay and resembles some of the blankets of the Union-Carbonate mine. It is underlain by sandstones and overlain by shale. This blanket contains some rather low-grade ore where intersected and slightly faulted by nearly vertical northwesterly fissures. A little galena is found, but the ore is usually oxidized. The upper blanket is 5 or 6 feet in thickness and rests sometimes on shaly, calcareous sandstone, sometimes on a sheet of porphyry. It is overlain by disturbed and broken shales. In its appearance this blanket is similar to the lower one, but it contains irregular masses of limestone which bear much the same relation to the blanket that the gypsum bears to the Enterprise "contact." The limestone has been irregularly dissolved, leaving behind a black, sooty residue consisting largely of hydrous oxides of manganese and iron, with considerable magnesia and alumina in unknown combinations. The ore of the upper blanket consists mainly of galena in various stages of alteration to cerussite and anglesite. It occurs in small bodies at the intersection of the blanket by northwesterly fissures. It is not known to occur as a direct replacement of the limestone.

The South Park mine, at the northwest base of Newman Hill, was unfortunately not accessible in 1900. The ore is reported to have occurred partly in a blanket of dark shales. If this is true this blanket is the lowest known in Newman Hill, since it occurs below the gray sheet of monzonite-porphyry, while all the others lie above it.

In C. H. C. Hill there is apparently one extensive blanket which has been exploited in the Princeton, C. H. C., Wellington, Logan, and Pigeon mines. All of the blanket thus far explored lies in a great landslide and is consequently much broken and disturbed. Owing to this fact, coupled with the caving of most of the old workings, it is impossible to be sure that the principal blanket worked in the above-named mines is continuous and identical throughout. It certainly presents a more varied character and is less open to a simple explanation than those thus far described. The blanket is thought to lie between beds of the upper division of the Hermosa, but this is by no means certain. It is usually 5 feet or less in thickness and rests in some places upon sandstone and in others upon limestone. It is overlain by sandstone or shale. It is most commonly composed of limonite, sometimes as a fairly firm, cavernous mass, but often as a loose, yellow, earthy material, which falls to powder between the fingers. In certain portions of the blanket the limonite passes into masses of crumbling iron pyrite, from which mineral it was undoubtedly formed by oxidation. Ore, when present, occurs in the lower part of the blanket and is almost without exception completely oxidized.

In the Princeton mine workable ore occurs as a soft, banded stratum, in which are layers of an ocherous, yellow powder containing a considerable proportion of silver, alternating with bands of impure, sandy sulphate of lead and streaks of a white material which proved on chemical analysis to consist of about 83 per cent of silica, 5 per cent of water, and 9 per cent of lead sulphate. The silica is probably in the opaline form.

The main blanket of C. H. C. Hill is associated with considerable alteration of the rocks between which it lies. The limestone which usually underlies the blanket has been extensively attacked and removed by chemical processes, with the formation of small quantities of gypsum, halloysite (an amorphous hydrous silicate of alumina), and other obscure products. The sandstone, unlike the limestone, is not directly soluble or convertible into soluble substances. The change in this case involves the removal of some of the quartz, with the accumulation of much sericite and small quantities of limonite, anglesite, and some hydrous magnesium mineral.

In addition to the main blanket of C. H. C. Hill, several blanket-like masses of pyrite occur at other horizons in the stratigraphic series. Three such bodies of crumbling pyrite, inclosed in shales and aggregating over 50 feet in thickness, were passed through in the Crebec shaft before reaching the main ore blanket. Although nearer the surface than the latter, the pyritic bodies show almost no oxidation and are too low in grade to be worked under present conditions. Similar but smaller bodies were noted in the Logan mine, extending into beds of shale on the southwest side of the Pigeon lode.

As a whole, the blankets of C. H. C. Hill present a striking contrast to that of the Enterprise mine. The persistent shale breccia, passing below into the silty mixture of dolomite and celestite, is absent in C. H. C. Hill, where the blankets appear to have been originally sheet-like or lenticular bodies consisting chiefly of pyrite. The Enterprise "contact" is practically unoxidized, while the main blanket of C. H. C. Hill is almost wholly transformed to secondary products and its earlier history thereby obscured. Without such oxidation and secondary enrichment, however, the ore would probably have been too poor to mine.

On the west side of the Dolores River a small blanket occurs in the A. B. G., a prospect at Burns. This is composed of partly oxidized, crumbling pyrite, about a foot in thickness, lying between the beds of the lower Hermosa on the southwest side of the A. B. G. lode.

Two blankets are known in the Great Western prospect, on the north side of Horse Creek, in rocks that probably belong to the middle division of the Hermosa and dip 15°, to the north. The upper "contact" is a soft, dark breccia of crushed shale, sandstone, and limestone, lying between two massive beds of limestone. The lower blanket is about 6 inches thick and consists of brecciated shale lying between shaly limestone below and shaly sandstone above. It is apparently of no great horizontal extent. Neither of the blankets has produced much ore.

The Sambo blanket, on the northeastern spur of Expectation Mountain, occupies a bedding fault in lower Hermosa rocks, between black shales below and gray calcareous shales above. A zone of brecciation is replaced by quartz and ore for a width of about 30 feet on the southwest side of a northwesterly lode. The Sambo has produced considerable rather low-grade ore.

Lastly, an unimportant blanket is known in the Montezuma mine, near Piedmont, consisting of crushed rock, gouge, and ore, resting partly on quartzite and partly on intrusive monzonite-porphyry. It is overlain by shales and sandstone. This is apparently a bedding fault along a bed of limestone which has been fractured and partly replaced by low-grade pyritic ore.

RELATION OF LODES AND BLANKETS.

As far as mining developments have shown, ore occurring in a blanket is always directly connected with some lode. The nature of the connection, however, is not always the same.

In the Enterprise, Newman, and Rico-Aspen mines, in Newman Hill, the northeasterly and northwesterly lodes, as they approach the blanket from below, split up into innumerable small stringers. These stringers are particularly numerous and noticeable in the blanket limestone and the shales which underlie it. They commonly consist of barren white quartz, although the stringers above some of the northeasterly veins contain rich ore. The aggregate result of these small fractures is to slightly fault the overlying blanket, and in the case of the northwesterly lodes there is usually also a fault plane of more recent date, defined by a seam of gouge, which may pass upward through the blanket.

In the blanket itself all the lodes, as far as could be seen or learned, entirely disappear, but their existence below is indicated by the occurrence of the blanket ore, which caps them. These flat ribbons of ore, which follow the courses of the lodes beneath them, attain a maximum width of 40 feet and a maximum thickness of 3 feet, being usually larger over northwesterly than over northeasterly lodes. Above the intersections of two or more lodes the blanket-ore body is often much more extensive.

With one or two possible exceptions, which are no longer open to examination, the lodes of Newman Hill do not extend above the blanket. The overlying rocks are much fractured and contain some unimportant veins, which may have been formed at the same time as the lodes beneath the blanket, but there is no good reason to suppose that they were ever continuous with the latter. The upward limitation of the lodes by the "contact" is a natural consequence of the slight faulting which accompanied the opening of their fissures and the yielding, fissile character of the beds in which the "contact" lies. If the lodes continued in full strength up to the blanket and were there abruptly cut off, it would be natural to suppose that they once extended to the surface and that their upper portions had been displaced by faulting. But not only do they practically die out, as lodes, before the blanket is reached, but the relations of the blanket ore to the lodes and of the blanket to the gypsum and the nature of the blanket itself all support the view that the latter has not been a plane of extensive or general faulting.

In the Union-Carbonate and Forest-Payroll mines the blanket ore is connected with northwesterly fissures which apparently pass through the blankets without interruption. Whether or not the fissures are slightly faulted as they traverse the blankets could not be satisfactorily determined with the available exposures. The prevalent oxidation in these mines and the recent slipping along the lodes, as attested by the presence of gouge, tend to obscure the original relationship between lode and blanket.

In C. H. C. Hill the mineralization of the main blanket and of most of the smaller ones has plainly emanated from the great Pigeon-Blackhawk lode. Here, too, subsequent movement and oxidation have obscured the details of original connection. In this case the blanket is without much doubt considerably faulted by this lode, but it is impossible to say how much of the faulting took place before and how much after mineralization. All the ore so far extracted from the blankets of C. H. C. Hill has occurred on the southwest side of the Pigeon-Blackhawk lode. On the northeast side of the lode the blanket horizon was probably dropped by the original fault; but how far its position has since been changed by later movement, including landsliding, is not known.

The blanket ore of the C. V. G. mine, at Burns, is evidently connected with the northwesterly lode lying northeast of it, but the connection is not exposed.

In the Sambo mine the blanket is continuous with a lode which faults the lower Hermosa beds to the extent of at least 4 feet. The ore occurs on the southwest side of the lode and extends into the blanket for a maximum distance of about 30 feet.

REPLACEMENTS IN LIMESTONE.

The principal examples of ore deposition by replacement are found in the Blackhawk, Iron, and probably, also, the Puzzle mines. The Atlantic Cable and other prospects in the Devonian limestone north of Rico must also be placed in the same category.

In the Blackhawk the replacement ore bodies occur on the northeast side of a lode belonging to

the Blackhawk fault zone. They have irregularly replaced a bed of massive limestone, belonging near the top of the middle division of the Hermosa, and dipping away from the lode to the northeast at an angle of about 25°. They attain a thickness of more than 15 feet and extend to a maximum distance of 50 or 60 feet from the lode. These bodies are composed in great part of massive pyrite, of no present value, in which lie irregular bodies of workable ore. The best of this ore consists of fine-grained galena, chalcopyrite, and pyrite, in a gangue of fluorite. Such ore passes toward its periphery into lower-grade ore, large quantities of which are still standing in the mine. This is composed of massive compact sphalerite and galena, with a little chalcopyrite, and practically no gangue. This ore in turn passes into enormous masses of nearly pure, worthless pyrite, or is directly inclosed in limestone. As a rule there is no sharp boundary between limestone and ore. The latter sometimes penetrates the white granular limestone in small bunches, but more often the limestone next the ore is changed to jasperoid.

Similar in character is the occurrence of the ore in the Iron mine. Here middle Hermosa limestone is partly replaced by ore on both sides of a lode which does not noticeably fault the beds. In this mine the workable ore extends less than 12 feet from the lode, except in some cases where replacement has worked out along minor fissures in the limestone. The ore, which is of low grade, is usually massive, consisting chiefly of pyrite and chalcopyrite, with more or less calcite and quartz as gangue. It has replaced the limestone directly, with little or no formation of jasperoid.

The mode of occurrence of the ore in the Puzzle mine is at present not directly determinable. It appears, however, to have been an irregular replacement of limestone by a siliceous ore containing argentite or other rich silver minerals. The ore occurred in a landslide block.

In the Atlantic Cable and neighboring prospects the Devonian limestone has been most irregularly replaced by more or less isolated bunches of ore. It is reported that one of these bodies, discovered since the time of visit, has been followed for some distance southward under the town of Rico. The deposition of this ore was closely connected with a metamorphism of the limestone, giving rise to chlorite, epidote, garnet, and wollastonite. The ore consists chiefly of sphalerite, chalcopyrite, and galena, associated with much specularite. It is not visibly connected with any parent lode or fissure.

STOCKS.

The only examples of stocks known in the Rico district are in the Johnny Bull and Gold Anchor mines, at the head of Horse Creek. These, however, are individually of small importance and but poorly represent a type that finds much better exemplification in the stocks of the Red Mountain district, in the San Juan Mountains.

The Johnny Bull stock had a diameter of 10 or 15 feet and a depth of about 120 feet. It was inclosed in fine-grained sandstone of the Dolores formation, which is here cut by several dikes and irregular intrusions of porphyry. The ore, consisting of enargite, pyrite, free gold, and probably other minerals, was deposited largely by replacement of the sandstone, which is silicified and impregnated with pyrite in the vicinity of the former ore body.

A similar, smaller stock, consisting chiefly of pyrite, occurs at a lower level in the Gold Anchor mine, nearly under the Johnny Bull.

GENESIS OF THE ORE DEPOSITS.

General relation to geologic structure.—If the preceding account of the ore deposits of the Rico district has succeeded in clearly and truthfully sketching their essential features, the statement that they are genetically connected with the present geologic structure of the region requires no further demonstration. But it remains to investigate this general and fundamental connection more closely in order properly to discriminate and distribute the various effects traceable to one common source—the geologic revolution through which beds once nearly horizontal have been elevated into a fissured dome and subsequently carved by erosion into the topographic forms known as the Rico Mountains.

The vertical extent of the original Rico uplift is estimated by Cross and Spencer at about 4500 feet. A minor part of this elevation, at least 800 feet, is connected with the intrusion of sheets of porphyry between the beds of the sedimentary series. But the major part of the uplift was subsequent to these intrusions and was associated with profound faulting, showing "the action at this center of a powerful vertical upthrust which is not demonstrably connected with igneous intrusion."

That the ore deposition is chiefly connected with the later phases of uplift is shown by the fact that the intrusive porphyries are themselves traversed by lodes and are invariably mineralized when occurring in contact with ore bodies.

Origin of the blankets.—Study of the Enterprise blanket has shown that it is essentially due to the removal, by solution, of a massive bed of gypsum which may have been from 15 to 30 feet in thickness. As the gypsum has not dissolved at an equal rate throughout, and has been largely attacked from below, with the consequent formation of caverns, the overlying beds must have subsided unevenly as the gypsum was removed, and were probably often let down abruptly by the enlargement and final collapse of caverns of solution in the under side of the bed. Nearly all stages of the process may yet be seen in the Newman Hill mines, from the usual "contact," with no remaining gypsum, to a thick bed of gypsum showing (at least on its under surface, which alone is visible) places where solution has not yet been active. This irregular subsidence, proceeding at different rates at different times throughout the area now occupied by the blanket, is amply sufficient to account for the brecciation of the overlying shale and for the generally shattered character of the rock up to the base of the wash covering Newman Hill.

That more or less movement has taken place in the mass of shale breccia precipitated upon the soft, pulverulent residue of the gypsum is well shown by the occurrence within it of irregular seams of gouge. Such movement is probably still in progress, but it is chiefly local in character, owing to varying adjustments, under gravitative stress, within the plastic mass. It can not be ascertained that any general faulting has taken place along this soft and structurally weak zone.

As the gypsum was deposited in Carboniferous time, its solution may have begun at an early date. But it was probably much accelerated, if not initiated, by the original doming of the rocks coincident with the intrusion of sheets of porphyry between the beds. The later fracturing, which was associated with the final stage of uplift, must have still further hastened the process of removal by allowing to underground waters, heated by the intruded masses of igneous rock, a more active circulation.

The upper blanket of the Forest-Payroll mine is somewhat analogous in origin to that of the Enterprise. It is due in great measure to the local solution of a bed of limestone and the consequent letting down of the overlying shales. In this case the residue of the limestone is a sooty material containing much oxide of manganese. Owing to the prevalent oxidation in this mine, it is impossible to determine whether the ore was originally deposited in the limestone before its solution. Apparently it was not.

Of still different origin are certain of the lesser "contacts" studied in the Union-Carbonate mine. In these the process has been purely chemical. Certain beds of shale have been wholly or partially altered to a soft, ferruginous, clay-like mass containing some oxidized ore. The fact that some of these soft zones are cut by dikes of porphyry (intruded prior to the alteration) which have not been fractured or displaced shows that the formation of the zones is not connected with faulting along planes of bedding.

The genesis of the main blanket of C. H. C. Hill is not perfectly clear, owing to later oxidation and disturbance. It was evidently once a large body of low-grade pyrite, which later underwent oxidation and a concentration of its valuable constituents. This pyrite apparently occurred in large part as a replacement of shale, limestone, and sandstone; but whether this replacement was preceded by brecciation is not known.

There are, however, a number of blankets in the district, such as those found in the Sambo, Great Western, Bancroft, Silver Swan, Little Maggie, and New Year mines, and probably the main "contact" of the Union-Carbonate mine, which seem to owe their existence chiefly to bedding faults. It can not be positively affirmed, however, that all of the blankets named are purely fault breccias. It is quite possible that some of them may have been initiated by the solution of gypsum, as in Newman Hill, and that the traces of such genesis have been obliterated by subsequent movement.

The stratigraphic conditions under which, in this region, such brecciation has taken place are fairly constant. The fissile black shales of the lower Hermosa are the rocks usually involved, not only by reason of their intrinsic weakness, but on account of their present distribution with reference to the center of orographic movement. Such shales are particularly susceptible to brecciation near their contact with some more rigid member of the lithological series, such as a sheet of porphyry or massive beds of sandstone or limestone. When the bed of shale is relatively thin and is inclosed between two massive strata, it is frequently reduced entirely to breccia. That the actual relative movement of the stronger beds need not be very great to produce brecciation in the shales between them is well illustrated in the Rico-Aspen mine, near the Silver Glance shaft. Some of the shales below the blanket limestone, lying between thin beds of sandstone, are here locally folded and crumpled to the verge of brecciation, while the thin beds above and below them are undisturbed and the crumpling itself has no great horizontal extent. Similar incipient "contacts" in various stages of development were noted in the Little Maggie and other mines, often dying out within a short horizontal distance and plainly formed by only slight movements along planes of bedding.

A part of the necessary movement probably took place at the time of the initial doming of the beds by laccolithic porphyry intrusions. But the greater part, and obviously that which produced brecciation along the contacts between porphyry and shale, must have been effected when the final elevation was given to the dome by upthrust and faulting.

Origin of the lode fissures.—It is to this general period of later orogenic movement that the present fissure systems of the region belong. Such earlier fractures as may have resulted from the first relatively gentle doming were probably superficial in character over the central region of the dome and have been largely removed by erosion. The more deep-seated fissures which presumably opened beneath the flanks of the uplift were in all likelihood filled with dikes at the period of laccolithic intrusion. It is to the later fractures, which traversed the solidified masses of monzonite-porphyry and which served as channels through which ore-bearing solutions could penetrate to the blankets, that the ore deposits are really due.

That the fissuring did not all take place at one time is shown by the facts that many of the lodes, particularly northwesterly lodes, show evidence of repeated opening; that the northwesterly fissures of Newman Hill, although probably initiated at the same time as the northeasterly fissures, subsequently faulted the former in several instances; and that the fissures of the Phoenix and Iron veins are apparently younger than the Nellie Bly fault.

One of the striking generalizations afforded by the study of the district has been the lack of coincidence between those fault fissures of such extent as to appear as "structural faults" and the lode fissures. That some faulting has taken place along lodes, both before and after their filling, is of course undeniable. But the great fault fissures of the district, numerous as they are, apparently nowhere carry workable bodies of ore and are certainly only to a minor extent coincident with veins. The northeasterly veins of Newman Hill and, less certainly, the northwesterly veins of Nigger Baby Hill show that the favorable channels for ore deposition were not the great fault fissures that gave the district its final structure, but were clean-cut, open fractures of but slight tangential displacement. Such fissures show no clear evidence of horizontal, compressive stress. They are, so far as faulting has taken place, in the main normal faults. It is believed, although this belief is not entirely demonstrable, that they represent the relatively slight readjustment, chiefly subsidence, necessary to restore the rocks to gravitative equilibrium after the greater faults had determined the main structure of the region. They are a record of the final settling down of the region under gravity after an episode of vigorous faulting and uplift.

Pay shoots.—The superficial character thus far shown by the pay shoots is one of the most interesting phenomena of the Rico district and vitally concerns the permanence of its mining industry. As pointed out in the preceding sections, only a relatively small number of the lodes have been themselves productive, and those to a comparative slight depth. In the case of the Nigger Baby Hill, Little Maggie, and Allegheny veins, the most important falling off in value takes place at the passage of oxidized into unoxidized vein matter. These veins thus owe their workable portions to a process of enrichment which is of common occurrence elsewhere, is wholly secondary, and is well understood in its general features. Below this zone of oxidation the veins have not been successfully worked, and it is not certainly known whether the value of the primary ore suffers a still further diminution with increasing depth. This, however, seems probable.

The rather abrupt falling off in value of the northeasterly veins of Newman Hill, at a depth of less than 200 feet below the blanket, is not so readily explained. It will be recalled that both the northeasterly and northwesterly lodes are capped by pay shoots in the Enterprise blanket, those over the northwesterly lodes being usually the larger and richer bodies. So far as can be determined, the blanket ore over the northeasterly lodes did not differ mineralogically from that over the northwesterly lodes. Furthermore, at a depth below the blanket greater than 200 feet, the contents of the two sets of lodes are mineralogically identical. It thus appears that the mineralogical difference between the northeasterly and northwesterly lodes, which is so striking a feature in certain of the mine workings, is not, after all, so great as might at first be supposed if their comparison were confined to one level. The contrast is one brought about mainly by the difference in depth to which the ore extended in each case.

Various hypotheses have suggested themselves in explanation of this difference. Evidently difference in the country rock can not be appealed to, since both sets of lodes traverse the same beds. For the same reason, differences in pressure and temperature can scarcely have been important factors. If, however, the northwesterly lodes are in the main later than the northeasterly, it is inevitable, from what is known of its origin, that some change in the overlying blanket must have taken place in the interval, and it is possible that this change may have been of a character to influence ore deposition.

It is suggested as a first hypothesis that at the time the northeasterly lodes were being formed the gypsum may have been only in small part dissolved. In such case the blanket ore may have been originally deposited chiefly as a replacement of gypsum (a process which is known to have operated in some portions of the blanket zone). The ore-bearing solutions, checked by the gypsum overlying the lodes and not finding in the slow process of metasomatic replacement sufficient opportunity for the deposition of their metalliferous contents, may have encountered in the upper portions of the fissures conditions favorable to the deposit of ore. One such general condition of ore deposition is believed to be sluggishness of circulatory motion in the ore-bearing solutions.

If mineralization through the northwesterly fissures was of later date, it is conceivable that the more complete removal of the gypsum may have given all of the ore an opportunity for deposition in the unconsolidated blanket material.

If the foregoing hypothesis is correct, some structural evidence for it might be expected in the ore of the northeasterly pay shoots of the blanket. Unfortunately, however, all of the known ore has been mined out.

It has been previously pointed out that some grounds exist for supposing that the northwesterly fissures, while initiated at substantially the same time as the northeasterly fissures, did not gape open until a later date, and that such opening was gradual and intermittent. This suggests,

as a second hypothesis, that the blanket ore may have all been formed at the same time, before the full opening of the northwesterly fractures, and that the nonoccurrence of ore in the northwesterly fissures is due to their contracted openings at the time of ore deposition.

Of the two hypotheses advanced, the second (not the "former," as was inadvertently stated in the preceding report on this district) is regarded as the more probable; but whichever one is accepted requires to be supplemented by further considerations relating to the chemical causes of precipitation before it can be regarded as complete.

The view that those ore bodies showing a marked decrease in available sulphides with depth and passing finally into practically barren pyrite are due to the action of both ascending and descending solutions has come to be widely accepted. The Newman Hill pay shoots appear to constitute striking examples of ore bodies due to the mingling of solutions. That the purely ascending solutions rising through the fissures of this region have normally deposited only low-grade pyritic ores is abundantly exemplified throughout the district. But such solutions ascending in the fissures under the Enterprise blanket not only found their upward progress barred by the impervious shales above, but entered a markedly porous, unconsolidated zone traversed by laterally moving solutions which must then, as now, have carried considerable calcium sulphate in solution. Too little can be learned of the chemical nature of the fissure solutions to determine whether the calcium sulphate acted as the precipitant, but that the precipitation was due, at least in part, to mingling solutions and not entirely to metasomatic replacement within the blanket is indicated by the fact that the ores extend below the blanket for over 100 feet in the northeasterly lodes. It is thus seen that the depth to which deposition of pay ore extended in the lodes may have been determined by the equilibrium between the ascending solutions in the lode fissures and the lateral descending solutions in the blanket. Evidently if the lode fissures were small and filled with solutions moving upward under considerable head all the ore would be deposited in the blanket.

None of the other known blankets in the district have contained such large and rich pay shoots as the Enterprise blanket. With the exception of an oxidized zone in the Union-Carbonate mine, the fissures through which the mineralization of these blankets has taken place are barren or contain only a little low-grade ore. It is evident that the conditions for ore deposition in the Enterprise blanket were usually favorable and were determined in varying degree by the following peculiarities, which are not found associated together in any other blanket known in the district: (1) The underlying blanket limestone; (2) the gypsum and its pulverulent residue; (3) the overlying, nearly impervious bed of black shale; and (4) the upward termination of the lodes at the blanket horizon. But although no one of the other blankets possesses all these advantageous attributes, yet they illustrate the general fact that in this region, replacement deposits in limestone being for the present ignored, large bodies of workable sulphide ores occur only where the solutions in the lode fissures have had opportunity to mingle with laterally moving solutions in a blanket. The extent and richness of the deposit depend largely upon the number of the above-enumerated favorable conditions which are present in any one case.

A similar statement may be made with regard to replacement deposits in limestone. Lode fissures, which ordinarily carry pay ore, are frequently connected with bodies of workable ore in limestone, as in the Blackhawk and Iron mines. In such cases the concentration which has enabled solutions ordinarily capable of depositing only low-grade pyritic ore to form relatively rich sulphide masses has been effected not so clearly by mingling of solutions as by the process, probably in large part selective, of metasomatic replacement.

Sources of the ores.—The ores of the Rico district were carried in aqueous solutions and were concentrated under the conditions already described. In this, as in many other regions, stratigraphic disturbance, igneous intrusion, and ore deposition have been genetically connected. The ore-bearing solutions undoubtedly owe much of their efficiency in gathering, transporting, and depositing the ore constituents to heat derived from igneous activity. That some of this heat still remains is indicated by the thermal character of the water issuing from the west face of Nigger Baby Hill.

It is possible that pneumatolytic emanations (that is, gaseous products given off at high temperature) from deep-seated cooling masses of intrusive monzonite-porphyry may have mingled with underground meteoric waters and contributed largely to their mineral contents. But the known porphyry masses had certainly solidified and probably lost much of their initial heat before the ores were deposited. The deposits that most strongly suggest pneumatolytic cooperation are the exceptional ore bodies in the Atlantic Cable and neighboring claims. These have the characteristics of contact deposits.

The actual chemical character of the ore-depositing solutions is not readily determinable. Their action on the sedimentary rocks which usually form the walls of the fissures is, with a few exceptions, inconspicuous and often obscured by secondary alteration. The presence of abundant calcite in the lodes of Nigger Baby Hill and of rhodochrosite in the upper part of the northeasterly lodes of Newman Hill indicates that the solution contained carbonates—possibly alkaline carbonates.

Equally impossible of definite answer is the question as to the particular rocks and the precise depth from which the ores were derived. But it is probable that all the rocks, particularly from the top of the Rico formation down, have contributed some metalliferous constituents to the ore bodies, not by the narrowly confined, academic process known as "lateral secretion," but by the concentration in favorable localities of materials widely drawn from the rocks of the disturbed region and often reaching the point of their final deposition after a roundabout journey to depths far below any ever likely to be reached by mining operations.

The formation of the ore of the Atlantic Cable and neighboring claims is evidently connected with intense contact metamorphism, as shown by the close association of the ore minerals with garnet, wollastonite, vesuvianite, pyroxene, chlorite, and epidote. The character of this metamorphism is such as to suggest the possibility of substantial pneumatolytic contribution to the solutions that deposited the Rico ores. The cause of the metamorphism is not evident. It may be due to the intrusive mass of monzonite between Iron Draw and Aztec Gulch, or more probably to some igneous mass which has not been exposed by erosion.

GEOLOGICAL AGE OF THE ORE DEPOSITS.

The age of the ore deposits can not be determined from a study of the Rico district alone. They are plainly subsequent to the doming and faulting of the region, but no definite date is assigned to these structures by Cross and Spencer. A tentative conclusion, however, may be drawn from the similarity in character between the monzonite of the Rico district and that of the Telluride and Silverton regions. It may be assumed as probable that the monzonitic intrusions of the San Juan Mountains and those of the Rico Mountains, only a few miles apart, belong to the same general period of igneous activity. In the San Juan the monzonite stocks cut the Telluride conglomerate (Eocene?) and the overlying volcanic series. Their intrusion probably took place in late Tertiary time. This relation indicates that the ore deposits of Rico are roughly of the same age as those of the San Juan Mountains—probably late Tertiary and possibly extending into the Pleistocene.

VALUE OF THE ORES.

Most of the ore produced in the Rico district has been shipped crude or smelted in Rico without previous mechanical concentration. Consequently the ore handled has been of rather high grade. Ore worth $20 a ton, such as was produced from the Union-Carbonate mine, is considered "low grade." The ore of the Enterprise and Rico-Aspen mines varied widely in value, but was usually rich. Thus during one year the average of the Enterprise was 200 ounces of silver and 2 ounces of gold per ton. One carload from this mine (about 10 tons) was valued at $8000. The general range, however, appears to have been as follows: Gold, from 0.2 to 1 ounce; silver, from 100 to 200 ounces; lead, up to 10 per cent; and zinc, up to 15 per cent.

Some of the oxidized ore from Nigger Baby Hill was rich in silver. In 1900 ore containing over 300 ounces of silver per ton was being shipped in occasional carloads.

The ore of the Puzzle mine is reported to have been rich, but in general the replacement bodies in limestone, such as those of the Blackhawk and Iron mines, are of relatively low grade. That from the Blackhawk contained from 10 to 30 ounces and that from the Iron mine from 20 to 40 ounces of silver.

An attempt was being made in 1900 to rework the dump of the Enterprise mine, by concentration.

Recently the United Rico Mines Company has succeeded in concentrating and separating the ore from the Atlantic Cable mine into three products, namely, sphalerite concentrates containing from 46 to 53 per cent of zinc, galena concentrates with about 45 per cent of lead, and pyrite concentrates containing 59 per cent of iron, with some gold and silver. The sphalerite concentrates bring $25 a ton, while the galena and pyrite concentrates are disposed of on favorable terms to the smelters. The Pro Patria mine in 1902 was producing concentrates containing 54 per cent of zinc, from the veins of Newman Hill, particularly the Jumbo No. 3 vein.

MINOR DIFFICULTIES IN MINING.

Carbonic acid gas.—Prospecting within the Rico district is often much hindered by the abundance of carbonic acid gas which issues from nearly every fissure traversing the rocks in the central portion of the dome. The gas is particularly troublesome in shafts, which become entirely filled by it. It occurs in the Lexington, Mediterranean, and Syndicate tunnels to such an extent as to render them inaccessible unless artificially ventilated, and a stream of this heavy gas was noted issuing from a fissure in the Blackhawk mine. But it is in the immediate vicinity of Rico that the evolution of the gas is most abundant. On the west bank of the Dolores River, on the Riverside, Smuggler, and Shamrock claims, gas issues in many places with a bubbling noise loud enough to attract the attention of the passer by, and in such volume as to suffocate birds and small animals that venture too near, attracted by the water through which the gas escapes. About 300 feet upstream from the Piedmont bridge the water of the river is kept in a state of violent ebullition by the escape of gas, apparently from an east-west fissure. A similar copious evolution constantly agitates the water in the bottom of the so-called "gas shaft," a shallow prospect on the southwest slope of Nigger Baby Hill. As shown by bore holes on the Atlantic Cable claim and in the Rico-Aspen mine, underground reservoirs of gas exist under considerable pressure. In fact, there is scarcely an opening in the ground near Rico that does not fill up with gas, and not a stretch of the river between the mouths of Sulphur and Horse creeks where bubbles of carbon dioxide may not be seen rising through the water.

LANDSLIDES.

These are of later date than the period of ore deposition, but have an important economic bearing on account of the hindrance which they impose upon successful exploitation. This is well illustrated in the case of the Puzzle mine, where a body of rich ore occurred in a landslide mass which has slipped down from Darling Ridge and buried the former channel of Horse Creek. All attempts to find the source of this block and the continuation of the ore body have failed. The difficulty of the problem is apparent on referring to the geological map, where it is seen that the whole northern slope of Darling Ridge is covered with landslide material. The depth of this material is often several hundred feet, and rock in place can be reached only by tunneling. There is no means of knowing how far the Puzzle mass has slid. Even if the original source of the block should be found after tedious and expensive prospecting, it is by no means certain that there would be any ore there.

Similar difficulty is encountered in the landslide of C. H. C. Hill, which, as shown by the various mine workings, has a maximum thickness of several hundred feet. In this case also all of the ore thus far found has been in landslide material, and the main ore horizon has never been found in rocks in place. Even if discovered, it is by no means certain that it would contain workable ore.

Like conditions of obscurity obtain over a considerable area north of Horse Creek and on the southeast spur of Expectation Mountain. Prospecting undertaken in these areas without some realization of the nature of the disturbance which they have undergone will almost inevitably result in disappointment.

MISCELLANEOUS MINERAL RESOURCES.

Coal.—The shaly layers of the Dakota formation, as Mr. Cross has pointed out, usually carry some thin seams of lignitic coal of poor quality. Some of this coal was formerly mined on the west side of the Dolores River a few miles north of Rico, to supply the local demand. But it has been supplanted by the better coal now brought in by the railroad, and is not likely to become economically important.

Building stone.—The La Plata sandstone and the thicker beds of the Dolores and Cutler formations offer an abundant supply of fairly good stone, for which, however, there is no demand. Some of the Dolores sandstone was formerly quarried alongside the railroad near the western edge of the quadrangle; but the quarry has been abandoned, as the quality of the stone was not sufficiently good to compensate for the long haul to the nearest market.

Limestone.—Material suitable for flux or for lime is abundant in the Ouray and Hermosa formations near the town of Rico.

WATER RESOURCES.

The quadrangle is well watered by the Dolores River and its tributaries. The river supplies power for lighting Rico, and undoubtedly it and the smaller streams in the quadrangle might be much more extensively utilized for the generation of electricity for mining purposes.

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Leadville limestone and other correlated horizons in Colorado and the West, and in the lower beds of the Mississippian series in the Mississippi Valley. Some of the characteristic species are:

Schuchertella inæqualis.	Spirifer centronatus.
Chonetes Illinoisensis.	Eumetria Marcyi?
Productella concentrica.	Camarotœchia metallica.
Productus parviformis.	Straparollus Utahensis.
Productus lævicosta.	

CARBONIFEROUS SYSTEM.

SECTION OF SOUTHWESTERN COLORADO.

According to the usage of the Geological Survey the Carboniferous system is divided into three series, namely, the Mississippian (Lower Carboniferous), Pennsylvanian (Upper Carboniferous), and Permian. Of these the Pennsylvanian series has long been known as represented in a large assemblage of limestones, sandstones, and shales grouped in the Hermosa formation. At the time the report on the Rico Mountains was issued it was supposed that the Hermosa beds rested directly on the Ouray limestone, throughout southwestern Colorado, making a stratigraphic break where the Mississippian beds should appear. This gap has been partly filled by the discovery, already mentioned, that the upper part of the Ouray limestone contains Mississippian fossils. It is, however, impracticable in any region thus far examined to distinguish the Carboniferous portion of the Ouray as a separate formation.

It has also been found that in most localities where the narrow zone between the Ouray limestone and the lowest limestone of the Hermosa complex is well exposed there is a thin, reddish, calcareous or sandy formation containing many chert pebbles, in some of which are Mississippian fossils. These include the forms known in the uppermost portion of the Ouray, as well as others, and it seems clear that the cherts were derived from eroded parts of the Ouray. Thin limestones of this reddish formation contain fossils known in the Hermosa limestones and a few other forms of the Pennsylvanian fauna. This lithologically peculiar formation, representing the earliest sediments of the Pennsylvanian in this region and containing evidence of a preceding erosion interval, was called the Molas formation in the Silverton folio. It is distributed through the Animas Valley, but neither its characteristic red strata nor the thin chert conglomerates were observed at Rico, possibly because of metamorphism or poor exposures in the very limited area where it must occur, if at all. Despite its omission from the Rico map it is possibly present.

Above the Molas formation comes the succession of strata grouped as the Hermosa formation, the Pennsylvanian age of which is amply demonstrated by an extensive invertebrate fauna.

Succeeding the Hermosa formation comes the great series of sandstones, grits, etc., known as the "Red Beds," variably referred, on scanty evidence, to the Carboniferous or to the Trias. The Rico district yielded the first definite evidence, in the form of invertebrate fossils, that any portion of the "Red Beds" of the San Juan region belongs to the Carboniferous. This lower fossiliferous part of the "Red Beds," locally some 300 feet in thickness, has been called the Rico formation.

Following the Rico beds comes a series of unfossiliferous "Red Beds," which were assigned to the Triassic in the Rico report, but are here grouped as the Cutler formation and referred provisionally to the Permian series. The ground for separating the Cutler formation from the overlying Triassic strata is the existence of an extensive angular unconformity between these divisions of the "Red Beds," shown in the Uncompahgre Valley at Ouray. This unconformity was discovered in 1904, in the work of mapping the Ouray quadrangle, and soon afterwards the boundary line between the Cutler and Dolores formations was traced through the Rico quadrangle by Mr. W. H. Emmons.

PENNSYLVANIAN SERIES.

HERMOSA FORMATION.

Definition and name.—The Hermosa formation is lithologically complex, consisting of interbedded limestones, shales, and sandstones, reaching a maximum thickness of about 2000 feet in the Animas Valley. Individual beds of different lithologic constitution are too thin and too variable in development to deserve special representation on the map, and groups of strata change so greatly in character from place to place that horizons can not be definitely recognized in localities separated from one another by more than short distances. The base of the Hermosa is conformable with the Molas, the line between these formations being that of a change in lithologic character, as has been stated. Its upper boundary is in general the base of the "Red Beds" of the region and is more accurately defined at Rico by the lowest fossiliferous layer of the Permo-Pennsylvanian. The geologic unity of the Hermosa is shown by the invertebrate fauna which characterizes many of the limestones and calcareous shales from the bottom to the top.

The name Hermosa is derived from a large creek entering the Animas River in the Durango quadrangle, and was given to the formation in the Rico report, in a chapter by A. C. Spencer.

General description.—Lithologically the Hermosa is composed of limestones, shale, and sandstone, but all of these strata are more or less calcareous throughout. The limestones are of a blue-gray color, rather dense in texture, and usually very fossiliferous. They are frequently more or less bituminous, sometimes so much so as to afford a distinct odor when struck with a hammer. The shales vary from black bituminous clay shales, rather fissile, to sandy shales and sandstones of an olive-green color. The sandstones are also of a greenish color, and under the microscope are seen to have an amorphous green cement. The sandstones are composed mainly of quartz, but feldspar and mica are common. The cementing material is largely calcite. Sandy beds vary in grain from fine to coarse, and some are conglomeratic.

The strata of the Hermosa formation form the western wall of the wider valley of the Animas outside the canyon, from Hermosa Creek to Engineer Mountain, and thence, still northward, their outcrops may be traced nearly to Silverton. In this distance of 25 miles the variable and inconstant character of the formation is well exhibited. The fossiliferous limestones which occur at the base are found throughout this extent, but the strata above them change greatly from place to place. Near Hermosa Creek the lower part of the formation above the limestones is made up of green sandstones and shales with some bands of gypsiferous shale; the middle and upper parts show fossiliferous gray limestones in beds from 1 to 20 feet in thickness, interbedded with shales and sandstones. Gypsum occurs locally, but has not been found north of the Durango quadrangle. In the region farther north the limestones become more massive and the intercalated shales and sandstones less important, so that for some distance south of Cascade Creek the limestones of the middle section are very prominent, forming the upper scarp of the valley wall. Between Lime Creek and Molas Lake the Hermosa formation exhibits a distinct phase, since the blue fossiliferous limestones are less massive than to the south and are distributed throughout the entire thickness of the formation.

Development at Rico.—At Rico the Hermosa formation has about its normal development, since it reaches a thickness of 1800 feet or more. It shows an unmistakable general correspondence to the Animas section, and in particular has a development similar to that in the adjacent portion of the Animas region, where the limestones in the medial portion of the formation are massive and conspicuous. At Rico, however, the gray or blue limestones are even more closely segregated in the middle third of the formation, and are of rare occurrence in the upper and lower portions. This is doubtless entirely a local facies of the formation, as may be inferred from the facts observed in the Animas section, but it makes it possible to divide the Hermosa, as shown at Rico, into three approximately equal parts, and this division will be followed in the description. On the Rico special geological map the upper member has been represented by a distinct pattern, in order better to exhibit the structure, but the two lower members have not been divided. This division is made simply as a matter of convenience, and there is no intention of raising the divisions to the rank of formations.

Lower division.—The lower division is about 800 feet in thickness, excluding the porphyry sills which have been intruded between its strata. At the base there are shales and impure limestones which have been considerably baked and metamorphosed, but which still contain abundant identifiable fossils, which correspond with similar strata occurring along the western side of the Animas Valley. Above this the rocks are green or gray grits, or sandstones, alternating with gray shales and containing several beds of black shale and occasional thin, impure limestones. The ore-bearing horizon of Newman Hill, known as the "contact," is associated with one of the black shales of this lower division. A bed of rock gypsum, reaching in some places a thickness of 30 feet, occurs locally above the black shales of the "contact" series, and was probably more widely distributed originally, since wherever it has been seen there is evidence that it has been attacked by circulating waters and in part removed by solution. Above this bed are 250 feet of rocks which are nowhere exposed to view, and above them lie 200 feet of massive and flaggy sandstones that constitute the uppermost strata of the lower division.

Containing as it does the Newman Hill "contact," and at least one other ore-bearing horizon, the lower division of the Hermosa formation at Rico becomes important in the study of the geologic features of the ore deposits and numerous details as to its character and distribution may be found in the Rico report.

Medial division.—The second division of the Hermosa is made up very largely of blue bituminous limestone, carrying many fossils and occurring in massive beds from 5 to 100 feet in thickness, separated by shales and sandy shales. In the lower part there are some intercalated strata of green sandstone and green or black shales, and locally these continue through the series, separating beds of limestone which elsewhere lie close together. The medial member has a thickness somewhat in excess of 600 feet and is a prominent feature in the stratigraphy of the region. Its massive limestones appear as white ledges on the western and northern faces of Dolores Mountain and in Deadwood Gulch. The best section of this part of the Hermosa is that seen in the precipitous face of Sandstone Mountain, which is represented in fig. 2.

Upper division.—The upper division of the Hermosa, which is represented separately on the special map, contains some bands of limestone similar to those of the medial division, but they are thin and unimportant in comparison. Its strata are mainly black and gray shales alternating with green grits and sandstones. Occasional reddish sandstones are observed, and two black shales are present in the lower third of the division. The top of the upper division, and of the Hermosa formation as a whole, is well defined from the base of the next higher formation. The topmost member consists of about 30 feet of fine-grained, mica-bearing green shales, immediately above which comes the red, sandy, fossiliferous limestone of the Rico beds. At the base of these throughout the Rico Mountains, a band of blue limestone, usually from 6 inches to 1 foot in thickness, is always present, and this stratum is characterized by the minute spindle-shaped shells formerly known as *Fusulina cylindrica*, now called *Triticites secalicus*. Detailed sections of the Hermosa formation are given in the Rico report.

Fossils and correlation.—Invertebrate fossils are numerous and well preserved in the Hermosa formation. By far the larger number are brachiopods, though gasteropods occur, and also the characteristic foraminifer *Fusulina cylindrica*. Most of the species are identical with forms occurring in the Missourian stage 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 collection of organic forms is found at various places in Colorado. In the Gunnison region similar fossils are found in the Weber and Maroon formations, as described in the Anthracite-Crested Butte folio of the Geological Survey, showing that the Hermosa comprises the former and part of the latter formations. 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.	Seminula subtilita.
Productus cora.	Limipecten occidentalis.
Productus punctatus.	Acanthopecten carboniferus.
	Myalina subquadrata.

The detailed studies which have recently been made of the sedimentary rocks of the San Juan region have led to a grouping of the Carboniferous and Trias quite different from that employed by the Hayden Survey. Reference to the Hayden Atlas of Colorado will show that the strata between the Devonian and the Jurassic sandstone (corresponding to La Plata) were mapped as Middle and Upper Carboniferous. The mapping of the former division corresponds in general with the occurrence of the Hermosa formation, leaving the latter as the equivalent of the Rico, Cutler, and Dolores formations.

RICO FORMATION.

Definition.—In the report on the geology of the Rico Mountains, the name of that group of peaks was given by Mr. Spencer to a formation, assumed to be about 300 feet in thickness, occurring between the Hermosa (Carboniferous) and strata then assigned arbitrarily to the Dolores (Triassic) formation, but now distinguished as the Cutler formation. The Rico formation is made up of sandstones and conglomerates with intercalated shales and thin fossiliferous limestones which are usually sandy. In this region the formation is conformable upon the Hermosa and is followed by the Cutler with seemingly perfect parallelism in stratification.

The prevalent reddish color of the Rico beds, as well as their general lithologic character, allies them rather with the Cutler than with the Hermosa complex, and they have undoubtedly been classified hitherto as the basal part of the "Red Beds" in this vicinity. The fossils of the Rico limestones have been studied by G. H. Girty in connection with a thorough revision of the Carboniferous invertebrate fauna of Colorado, the results of which have been published as a Professional Paper (No. 16) of the Survey. From Mr. Girty's examination of the Rico fauna it appears that while many of the species are common to the Hermosa formation, others are types usually considered Permian, and on his suggestion the Rico is referred to the Permo-Pennsylvanian. The fauna as a whole has an aspect differing from that of the Hermosa, in that it is largely composed of lamellibranchs as contrasted with the brachiopod assemblage predominating in the lower formation. Later collections from the Rico, however, show its fauna to be more closely assimilated to that of the Hermosa formation than at first appeared to be the case.

The base of the Rico formation can usually be very accurately located in the field by its lowest fossil-bearing stratum. The boundary between the Rico and Cutler formations is, however, quite arbitrary, being based on the highest known occurrence of the Rico fossils. The former is made to include only that part of the section characterized by the Permo-Pennsylvanian fauna, while the Cutler comprises the apparently unfossiliferous "Red Beds" of this region, extending to the horizon at which Triassic fossils are known to occur.

Description.—The general characteristics of the Rico formation in the vicinity of Rico are, first, its calcareous nature, in which it resembles the strata above and below; second, the feldspathic constitution and the coarseness of its sandstones, in which respect it differs from the Hermosa and resembles the Cutler; and third, its chocolate or dark-maroon color, which contrasts sharply with the gray or green of the Hermosa and which is more or less distinct from the bright vermilion of the Cutler and Dolores. Locally, through metamorphism, the deep-red color has been changed to green, as seen in the cliff exposures north of Silver Creek, in the vicinity of Uncle Ned Draw, and in the cliffs exposed on the northern slopes of Dolores Peak.

The bulk of the formation is made of sandstones and sandy shales composed of such materials as are derived from the disintegration of granite. The sandstones are mostly coarse or conglomeratic, always showing grains of fresh feldspar mixed with mica flakes and quartz. When conglomeratic the pebbles are chiefly of schists and quartzite.

U. S. GEOLOGICAL SURVEY
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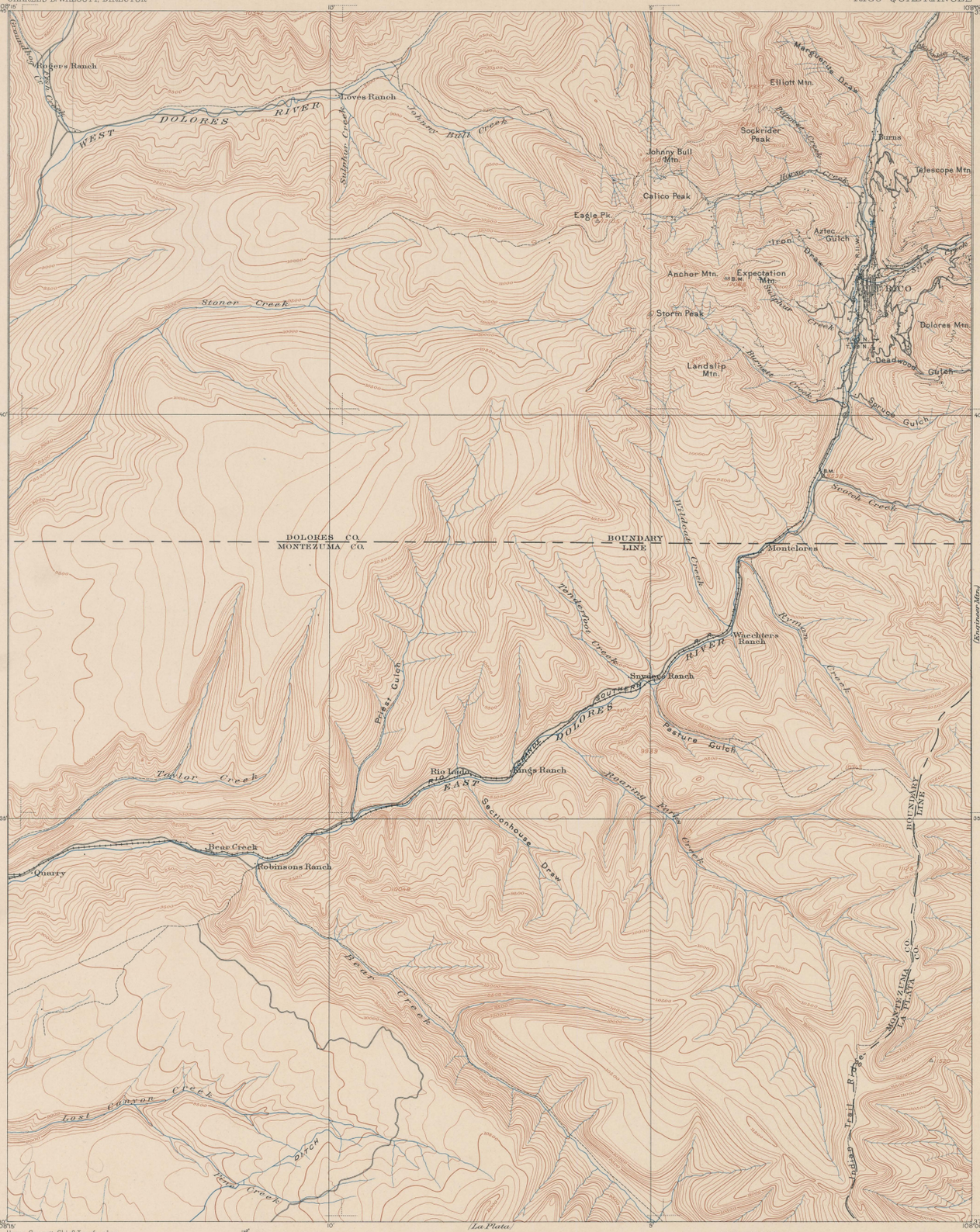
TOPOGRAPHY

COLORADO
RICO 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

Canals and ditches

Ponds

Fresh marshes

CULTURE
(printed in black)

Roads and buildings

Private and secondary roads

Trails

Railroads

Bridges

U.S. township and section lines

County lines

Triangulation stations

B.M. ×
Bench marks

Henry Gannett, Chief Topographer.
E. M. Douglas, Topographer in charge.
Triangulation by E. M. Douglas.
Topography by T. M. Bannon and W. M. Beaman.
Surveyed in 1894 and 1898.

APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{62500}$

Contour interval 100 feet.

Datum is mean sea level.

Corrected positions of meridians and parallels shown by intersections of dotted lines.

DIAGRAM OF TOWNSHIP

Edition of June 1899 reprinted Sept. 1905.

U. S. GEOLOGICAL SURVEY
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AREAL GEOLOGY

COLORADO
RICO QUADRANGLE

LEGEND
(continued)

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

Basic dikes
(includes several allied rocks, the most common being augite-vogesite)

Tcp — Dikes of Calico Peak porphyry
(monzonite porphyry, characterized by large orthoclase crystals)

Tcps — Calico Peak porphyry, alunitized
(a porphyry changed by solfataric action into a mass consisting chiefly of alunite)

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

Tpm — Pyroxenic monzonite-porphyry
(occurs in dikes)

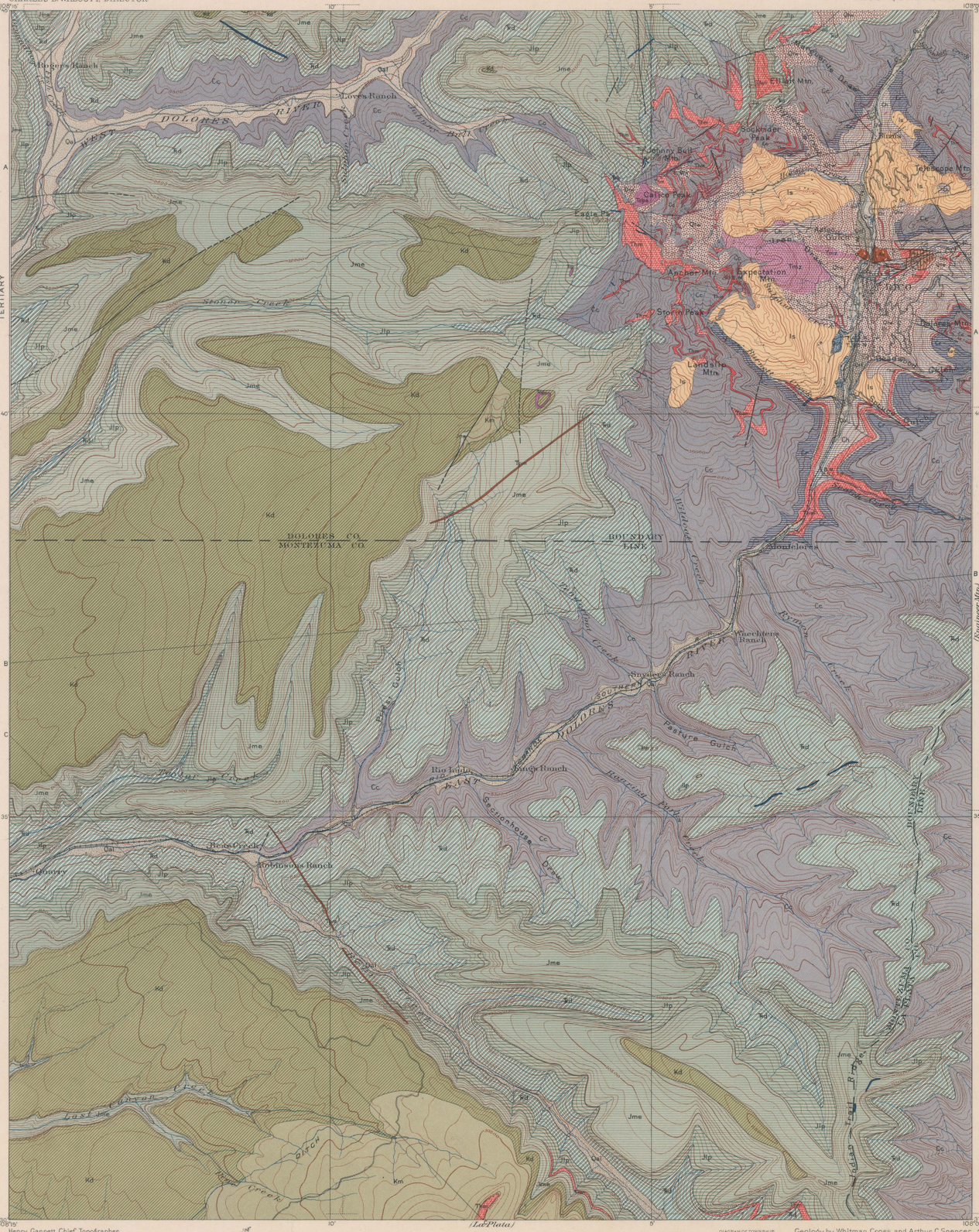
Thm — Hornblendic monzonite-porphyry
(the oldest intrusive rock of the Rico Mountains; occurs in dikes and sheets and small laccoliths)

TERTIARY

Faults
(doubtful location indicated by dashes)

Concealed faults
(covered by younger deposits)

Sections



LEGEND

Ls — Landslides
(a confused mixture of large and small blocks of various formations from the slopes above)

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

QUATERNARY

Qcr — Calcareous tufa
(in terraces and mounds)

Qtf — Torrential fans
(accumulations of loose rock fragments at mouths of ravines and gulches)

Qal — Alluvium
(sands, gravels, and soils of valleys)

Qtw — Talus and wash

CRETACEOUS

Upper Cretaceous

Km — Mancos shale
(dark shale with local calcareous and sandy layers, fossiliferous. Includes Benton and Niobrara formations and part of the Pierre)

Kd — Dakota sandstone
(alternating quartzose sandstone and carbonaceous shale, locally containing coal)

JURASSIC

Jme — Mc Elmo formation
(alternating sandstones and shales)

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

UNCONFORMITY

TRIASSIC ?

Td — Dolores formation
(calcareous shale and conglomerate, locally fossiliferous, prevailing color bright red)

UNCONFORMITY

CARBONIFEROUS

Permian ?

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

Pennsylvanian

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

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

UNCONFORMITY

DEVONIAN

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

UNCONFORMITY

CAMBRIAN ?

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

UNCONFORMITY

ALGONKIAN

Au — Uncompahgre formation
(massive white or gray quartzite, locally conglomeratic)

METAMORPHIC ROCKS OF UNKNOWN ORIGIN
(Areas of metamorphic rocks of unknown origin are shown by hachures)

ALGONKIAN ?

As — Schist
(dense, bluish-gray rocks with subordinate schistose structure)

Legend is continued on the left margin.

Henry Gannett, Chief Topographer.
E. M. Douglas, Topographer in charge.
Triangulation by E. M. Douglas.
Topography by T. M. Bannon and W. M. Beaman.
Surveyed in 1894 and 1898.

TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{62500}$

1 Mile 0 1 2 3 4 5 Miles
1 Kilometer 0 1 2 3 4 5 Kilometers

Contour interval 100 feet.
Datum is mean sea level.
Corrected positions of meridians and parallels shown by intersections of dotted lines.

Edition of Oct. 1905

DIAGRAM OF TOWNSHIP.

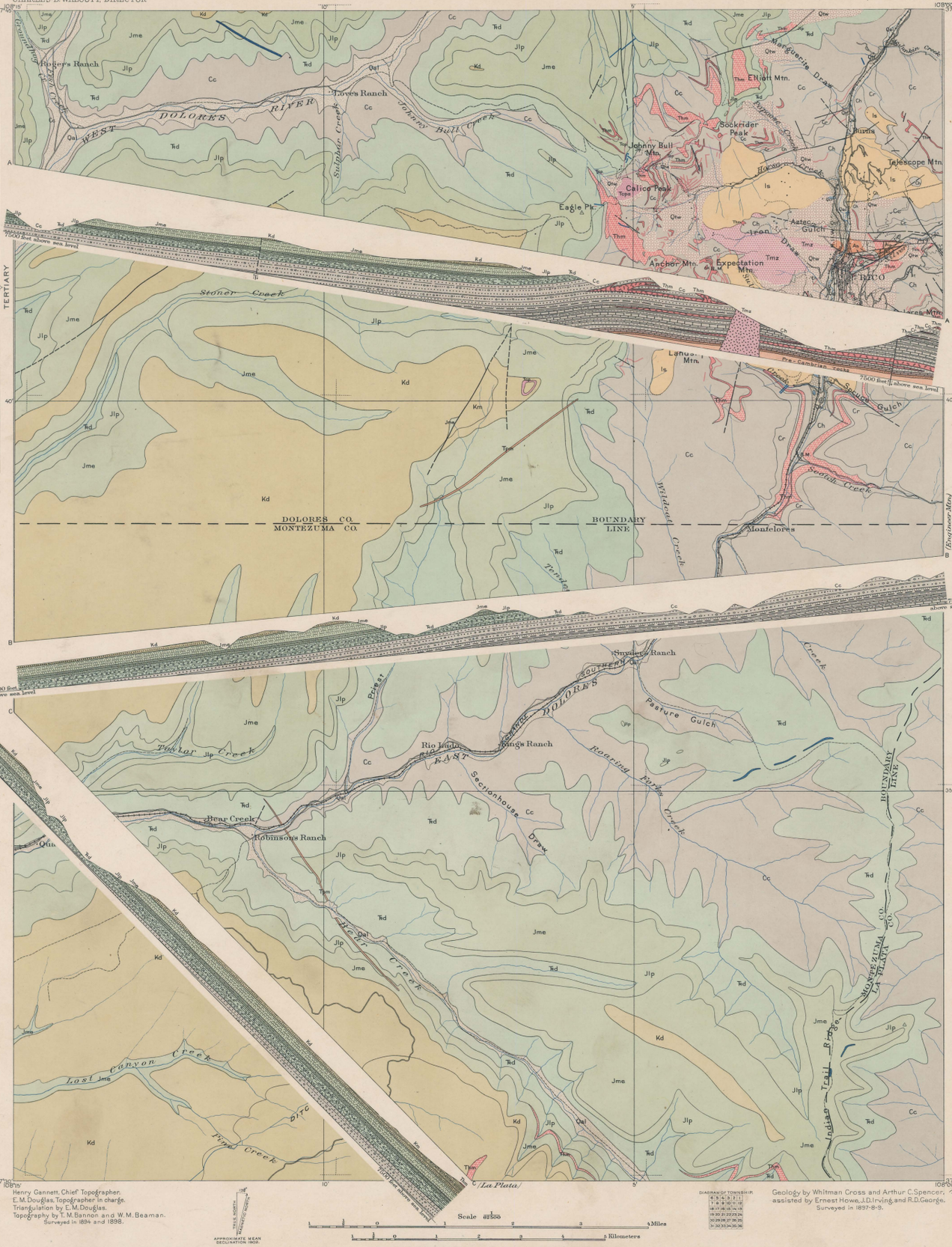
6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

Geology by Whitman Cross and Arthur C. Spencer, assisted by Ernest Howe, J. D. Irving, and R. D. George.
Surveyed in 1897-8-9.

U. S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

STRUCTURE SECTIONS

COLORADO
RICO QUADRANGLE



LEGEND (continued)

SHEET SYMBOL — SECTION SYMBOL

IGNEOUS ROCKS

- **Basic dikes** (includes several alkali rocks, the most common being augite-vogesite)
- Tcp — **Dikes of Calico Peak porphyry** (monzonite-porphyry characterized by large orthoclase crystals)
- Tcpa — **Calico Peak porphyry, alunitized** (porphyry changed by solfataric action into a mass consisting chiefly of alunite)
- Tmz, Tmz — **Monzonite** (a granular rock forming a large stock)
- Tpm — **Pyroxenic monzonite-porphyry** (occurs in dikes)
- Thm, Thm — **Hornblendic monzonite-porphyry** (the common intrusive rock of the Rico Mountains; occurs in dikes and sheets and small laccoliths)

Faults (doubtful location indicated by dashes)

Concealed faults (covered by younger deposits)

LEGEND

SHEET SYMBOL — SECTION SYMBOL

- Is — **Landslides** (a confused mixture of large and small blocks of various formations from the slopes above)

SEDIMENTARY ROCKS

QUATERNARY

- Qct — **Calcareous tufa** (in terraces and mounds)
- Qtf — **Torrential fans** (accumulations of loose rock fragments at mouths of ravines and gulches)
- Qal — **Alluvium** (sands, gravels, and soils of valleys)
- Qtw — **Talus and wash**

CRETACEOUS

Upper Cretaceous

- Km, Km — **Mancos shale** (dark shale with local calcareous and sandy layers; fossiliferous. Includes Benton and Niobrara formations and part of the Pierre)
- Kd, Kd — **Dakota sandstone** (indurated quartzose sandstone with carbonaceous shale locally containing coal)

JURASSIC

- Jme, Jme — **Mc Elmo formation** (alternating sandstones and shales)
- Jlp, Jlp — **La Plata sandstone** (massive white sandstone with thin blue limestone and calcareous shale)

UNCONFORMITY

TRIASSIC ?

- Trd, Trd — **Dolores formation** (calcareous shale and conglomerate, locally fossiliferous; prevailing color bright red)

UNCONFORMITY

Permian ?

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

CARBONIFEROUS

Pennsylvanian

- Cr, Cr — **Rico formation** (sandstone, limestone, and shale, of red or gray color; fossiliferous)
- Ch, Ch — **Hermosa formation** (sandstone, shale, and limestone, of grayish color; fossiliferous)

UNCONFORMITY

DEVONIAN

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

UNCONFORMITY

CAMBRIAN ?

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

UNCONFORMITY

ALGONKIAN

- Au — **Uncompahgre formation** (massive, white or gray quartzite, locally conglomeratic)

METAMORPHIC ROCKS OF UNKNOWN ORIGIN

ALGONKIAN ?

- As — **Schist** (dense, bluish-gray rocks with subordinate foliation structure)

Legend is continued on the left margin.

Henry Gannett, Chief Topographer.
E. M. Douglas, Topographer in charge.
Triangulation by E. M. Douglas.
Topography by T. M. Bannon and W. M. Beaman.
Surveyed in 1894 and 1898.

TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION 1902.

Scale 1/62500

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

DIAGRAM OF TOWNSHIP

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
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Geology by Whitman Cross and Arthur C. Spencer, assisted by Ernest Howe, J. D. Irving, and R. D. George.
Surveyed in 1897-8-9.

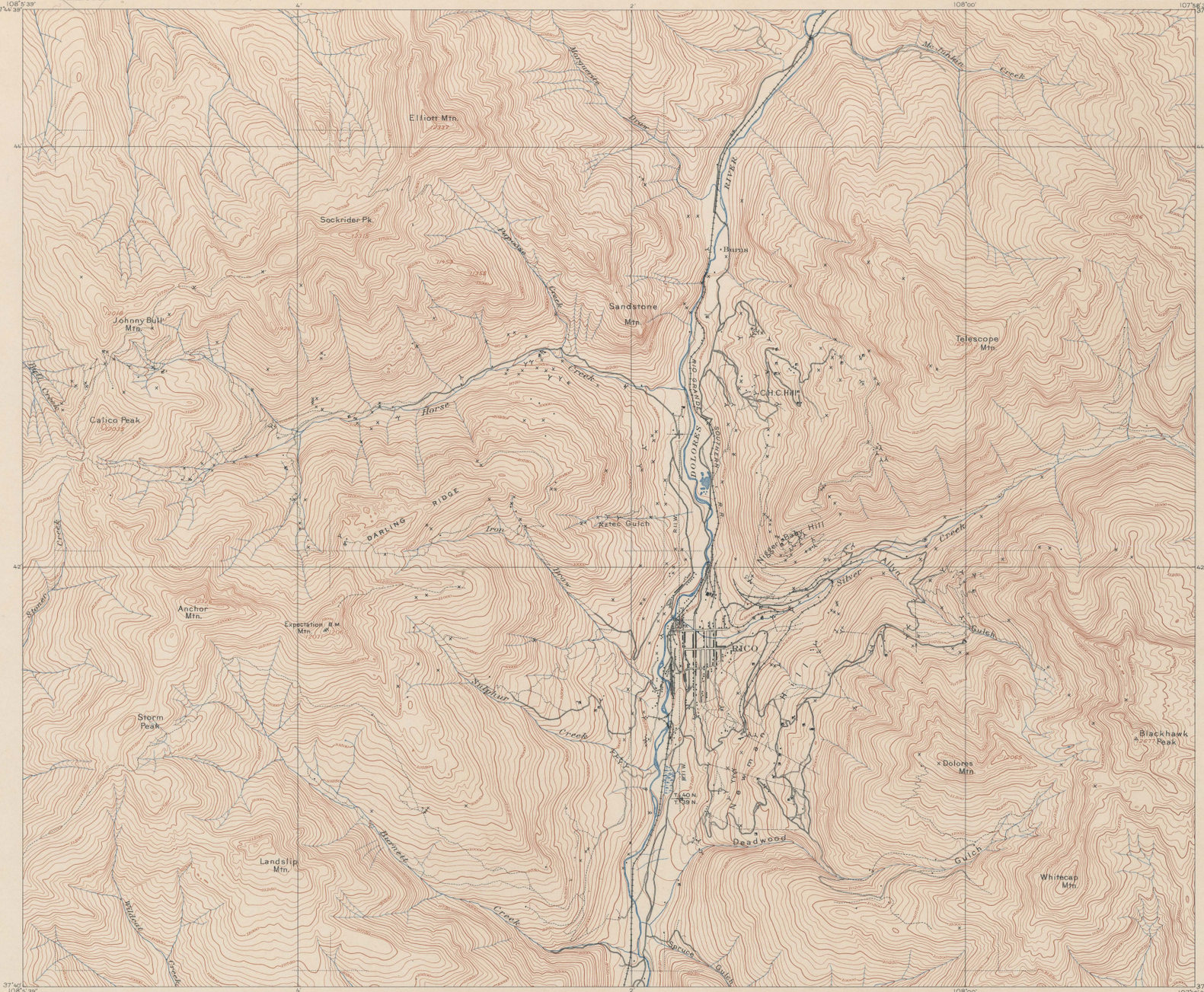
Corrected positions of meridians and parallels shown by intersections of dotted lines.

Edition of Oct. 1905.

U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT
DIRECTOR

TOPOGRAPHY

COLORADO
(DOLORES COUNTY)
RICO SPECIAL MAP



LEGEND

RELIEF
(printed in brown.)

12065 — Figures *(showing heights above mean sea level instrumentally determined.)*

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

Depression contours

DRAINAGE
(printed in blue.)

Streams

Intermittent streams

Ponds

Fresh marshes

CULTURE
(printed in black.)

Roads and buildings

Private and secondary roads

Trails

Railroads

Bridges

U.S. township and section lines

Located township and section corners

Triangulation stations

Bench marks

Shafts

Open cuts

Tunnels

Prospects

E.M. Douglas, Geographer in charge.
Triangulation by E.M. Douglas and T.M. Bannon.
Topography by W.M. Beaman.
Surveyed in 1898.

APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{23600}$

1 Mile — 0 — 1000 — 2000 — 3000 — 4000 — 5280 Feet

1 Kilometer

Contour interval 50 feet.

Datum is mean sea level.

Corrected positions of meridians and parallels shown by intersections of dotted lines.

DIAGRAM OF TOWNSHIP

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

Edition of Aug. 1899, reprinted Aug. 1905.

U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT
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ECONOMIC GEOLOGY

COLORADO
(DOLORES COUNTY)
RICO SPECIAL MAP

LEGEND
(continued)

METAMORPHIC ROCKS OF UNKNOWN ORIGIN
(Areas of metamorphic rocks of unknown origin are shown by hachures)

ALGONKIAN ?
- As — Schist *(dense, bluish-gray rocks with subordinate schistose structure)*

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

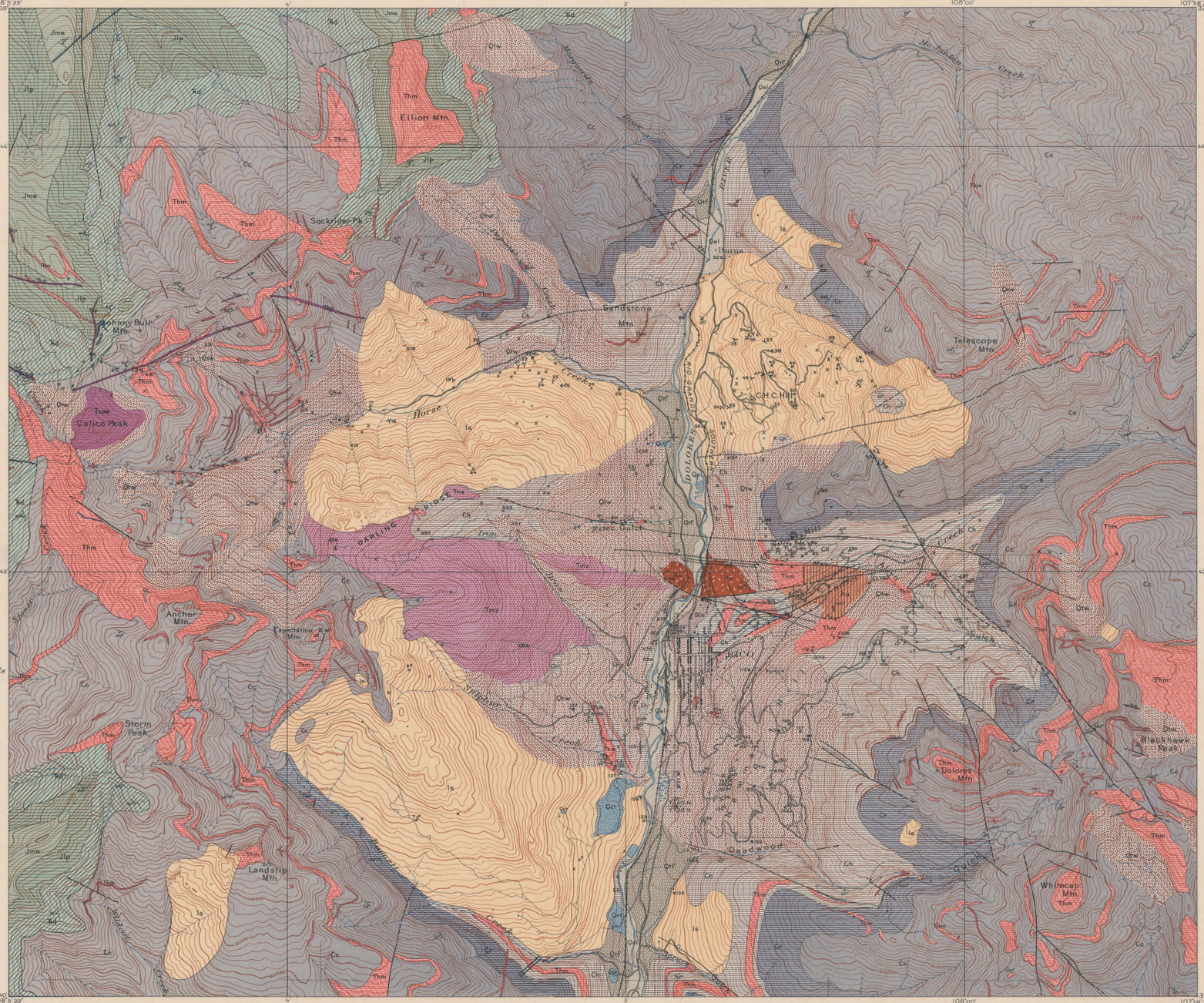
TERTIARY
- Basic dikes *(includes several allied rocks, the most common being augite-vogesite)*
- Tcp — Dikes of Calico Peak porphyry *(monzonite-porphyry characterized by large orthoclase crystals)*
- Tcpa — Calico Peak porphyry, alunitized *(a porphyry changed by solfataric action to a rock consisting chiefly of alunite)*
- Tmz — Monzonite *(a granular rock forming a large stock)*
- Thm — Hornblendic monzonite-porphyry *(the common intrusive rock of the Rico Mountains, occurs in dikes and sheets and small laccoliths)*

Faults *(doubtful location indicated by dashes)*

Concealed faults *(covered by younger deposits)*

Strike and dip of stratified rocks
- Mines
- Shafts
- Crosscut tunnels *(showing course)*
- Mine and prospect tunnels *(course not shown)*
- Prospects

Mine names, represented on the map by numbers, are printed on the back of this sheet.



LEGEND

- Is — Landslides *(a confused mixture of large and small blocks of various formations from the slopes above)*

SEDIMENTARY ROCKS
(Areas of extensive deposits are shown by patterns of parallel lines, subserial deposits by patterns of dots and circles)

QUATERNARY
- Qct — Calcareous tufa *(in terraces and mounds)*
- Qtf — Torrential fans *(accumulations of loose rock fragments at mouths of ravines and gulches)*
- Qal — Alluvium *(sands, gravels, and soils of valleys)*
- Qtw — Talus and wash

JURASSIC
- Jme — Mc Elmo formation *(alternating sandstones and shales)*
- Jlp — La Plata sandstone *(massive white sandstone with thin blue limestone and calcareous shale)*

UNCONFORMITY

TRIASSIC ?
- Kd — Dolores formation *(calcareous shale and conglomerate, locally fossiliferous, prevailing color brick-red)*

UNCONFORMITY

CARBONIFEROUS
- Permian ? — Cc — Cutler formation *(sandstone, grit, conglomerate, and some calcareous shale; prevailing color red)*
- Pennsylvanian — Cr — Rico formation *(sandstone, limestone, and shale, of red or gray color; fossiliferous)*
- Ch — Hermosa formation *(sandstone, shale, and limestone, of grayish color; fossiliferous)*

UNCONFORMITY

DEVONIAN
- DCo — Ouray limestone *(white or light-gray sandy limestone, with a few quartzite layers; fossiliferous)*

UNCONFORMITY

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

UNCONFORMITY

ALGONKIAN
- Au — Uncompahgre formation *(massive, white or gray quartzite locally conglomeratic)*

Legend is continued on the left margin.

E. M. Douglas, Geographer in charge.
Triangulation by E. M. Douglas and T. M. Bannon.
Topography by W. M. Beaman.
Surveyed in 1898.

APPROXIMATE MEAN DECLINATION 1902.

Scale 1/25000
1 Mile — 1 Kilometer
Contour interval 50 feet.
Datum is mean sea level.
Corrected positions of meridians and parallels shown by intersections of dotted lines.
Edition of Oct. 1905

DIAGRAM OF TOWNSHIP

Geology by Whitman Cross and A. C. Spencer.
Surveyed in 1898-9.

NAMES OF MINES.

Location indicated on the map by numbers.

NUMERICAL LIST.

1. Johnny Bull.
2. Gold Anchor Tunnel.
3. Albion.
4. Caledonia Shaft.
5. Utah.
6. Marriage Stake.
7. Hand-out Shaft.
8. Golden 1900.
9. Belzora.
10. San Juan.
11. Zenith.
12. Christina Shaft.
13. Lackawanna.
14. Flying Fish.
15. Flying Fish Upper Tunnel.
16. Southern Consolidated Tunnel.
17. Puzzler.
18. Petzite.
19. Great Western.
20. Mohawk.
21. Hess and Garren Tunnel.
22. Puzzle Extension (incline).
23. Puzzle (main shaft).
24. M. A. C. Upper Tunnel.
25. M. A C. Lower Tunnel.
26. Hoosier Girl Shaft.
27. Ontario.
28. Dolly Tunnel.
29. J. E. Watson Tunnel.
30. Governor.
31. A. B. G.
32. C. V. G.
33. Hureka.
34. Wabash.
35. Blaine and Logan Tunnel.
36. Pigeon.
37. Logan Tunnel.
38. Logan No. 2 Shaft.
39. Leap Year.
40. Monterey.
41. Silver Wing.
42. Undine.
43. Roger Tichborne Shaft.
44. Logan Shaft.
45. Pigeon Shaft.
46. C. H. C. Shaft.
47. C. H. C. Tunnel.
48. Limestone Tunnel.
49. Mountain Spring Tunnel.
50. Wellington Shaft.
51. Crebec Shaft.
52. Princeton.
53. M. M. P.
54. Iron Giant.
55. Lily D.
56. Logan Tunnel (site).
57. C. A. R.
58. Sambo.
59. Lake View.
60. Columbia.
61. Aztec.
62. California.
63. Zulu Chief.
64. Magnet.
65. Eureka.
66. Uncle Remus Shaft.
67. Eagle.
68. Little Leonard.
69. Yankee Boy.
70. Shamrock.
71. Smuggler.
72. Atlantic Cable.
73. Riverside.
74. Montezuma.
75. Calumet.
76. Futurity Tunnel.
77. Grand View Incline.
73. Cobbler Shaft.
79. Alma Mater.
80. Phoenix No. 1 Level.
81. Pelican.
82. Last Chance.
83. Phoenix No. 4 Level.
84. Nellie Bly Lower Tunnel.
65. Nellie Bly Upper Tunnel.
86. Eureka.
87. Old Butler Tunnel.
88. Hope and Cross.
89. Bourbon.
90. Uncle Ned.
91. Worlds Fair.
92. Argentine.
93. Iron.
94. Laxy.
95. Mediterranean.
96. Black Hawk.
97. Allegheny.
98. Lelia Davis.
99. Little Maggie Shaft.
100. Wildcat Tunnel.
101. Privateer.
102. Sunflower.
103. Forest-Payroll.
104. Union-Carbonate Shaft.
105. Union-Carbonate Tunnels.
106. Fickle Goddess Tunnel.
107. South Park.
108. Fortune and Duncan.
109. Eighty-eight.
110. Iron Dollar.
111. Hibernia.
112. Pro Patria Tunnel.
113. Revenue Return.
114. Onamo Tunnel.
115. Sceptical Shaft.
116. Golden Fleece.
117. Whim.
118. Western Tunnel.
119. Ironclad.
120. Bancroft Shaft.
121. Bancroft.
122. Derby and Evans Shaft
123. St. Louis Shaft.
124. Argonaut.
125. Little Maggie Group.
136. Tomale.
127. N. A. Cowdrey.
128. Silver Swan.
129. Trinadad.
130. Deep Shaft.
131. Stephanite Tunnel.
132. Southern Tunnel.
133. Shehocton.
134. Syndicate Tunnel.
135. Stephens (old tunnel).
136. Stephens.
137. Chestnut.
128. Chestnut (old tunnel).
139. Klingender.
140. Swansea.
141. Lexington Tunnel.
142. Enterprise Group Tunnel.
143. Silver Age.
144. Wakeman Tunnel.
145. Isabella Shaft.
146. Stanley Shaft.
147. Air shaft.
148. Laura Shaft.
149. Durango.
150. Enterprise Shaft.
151. Songbird Shaft.
152. Jumbo Shaft.
153. Montezuma Shaft.
154. Vestal Shaft.
155. Aspen Shaft.
156. Silver Glance Shaft.

ALPHABETICAL LIST.

A. B. G., 31.
Air shaft, 147.
Albion, 3.
Allegheny, 97.
Alma Mater, 79.
Argentine, 92.
Argonaut, 124.
Aspen Shaft, 155.
Atlantic Cable, 72.
Aztec, 61.
Bancroft, 121.
Bancroft Shaft, 120.
Belzora, 9.
Black Hawk, 96.
Blaine and Logan Tunnel, 35.
Bourbon, 89.
Caledonia Shaft, 4.
California, 62.
Calumet, 75.
C. A. R., 57.
C. H. C. Shaft, 46.
C. H. C. Tunnel, 47.
Chestnut, 137.
Chestnut (old tunnel), 138.
Christina Shaft, 12.
Cobbler Shaft, 78.
Columbia, 60.
Crebec Shaft, 51.
C. V. G., 32.
Deep Shaft, 130.
Derby and Evans Shaft, 122.
Dolly Tunnel, 28.
Durango, 149.
Eagle, 67.
Eighty-eight, 109.
Enterprise Group Tunnel, 142.
Enterprise Shaft, 150.
Eureka, 65.
Eureka, 86.
Fickle Goddess Tunnel, 106.
Flying Fish, 14.
Flying Fish Upper Tunnel, 15.
Forest-Payroll, 103.
Fortune and Duncan, 108.
Futurity Tunnel, 76.
Gold Anchor Tunnel, 2.
Golden Fleece, 116.
Golden 1900, 8.
Governor, 30.
Grand View Incline, 77.
Great Western, 19.
Hand-out Shaft, 7.
Hess and Garren Tunnel, 21.
Hibernia, 111.
Hoosier Girl Shaft, 26.
Hope and Cross, 88.
Hureka, 33.
Iron, 93.
Ironclad, 119.
Iron Dollar, 110.
Iron Giant, 54.
Isabella Shaft, 145.
J. E. Watson Tunnel, 29.
Johnny Bull, 1.
Jumbo Shaft, 152.
Klingender, 139.
Lackawanna, 13.
Lake View, 59.
Last Chance, 82.
Laura Shaft, 148.
Laxy, 94.
Leap Year, 39.
Lelia Davis, 98.
Lexington Tunnel, 141.
Lily D., 55.
Limestone Tunnel, 48.
Little Leonard, 68.
Little Maggie Group, 125.
Little Maggie Shaft, 99.
Logan No. 2 Shaft, 38.
Logan Shaft, 44.
Logan Tunnel (site), 37.
Logan Tunnel, 56.
M. A. C. Lower Tunnel, 25.
M. A. C. Upper Tunnel, 24.
Magnet, 64.
Marriage Stake, 6.
Mediterranean, 95.
M. M. P., 53.
Mohawk, 20.
Monterey, 40.
Montezuma, 74.
Montezuma Shaft, 153.
Mountain Spring Tunnel, 49.
N. A. Cowdrey, 127.
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Nellie Bly Upper Tunnel, 85.
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Onamo Tunnel, 114.
Ontario, 27.
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COLUMNAR SECTION

GENERALIZED SECTION FOR THE RICO QUADRANGLE.

SCALE: 1 INCH = 400 FEET.

System.	Series.	Formation Name.	Symbol.	Columnar Section.	Thickness in Feet.	Character of Formations.
CRETACEOUS	UPPER CRETACEOUS	Mancos shale.	Km		1000+	Soft, dark-gray, or almost black, carbonaceous clay shale containing thin lenses or concretions of impure limestone. Embraces the Colorado group and a portion of the Pierre division of the Montana. Fossils occur more or less abundantly at several horizons.
		Dakota sandstone.	Kd		100–250	Gray or rusty brown quartzose sandstone or quartzite with a variable conglomerate, containing small chert pebbles at or near the base. Carbonaceous shale partings occur at several horizons and coal of poor quality is locally present. Indistinct fossil leaves occur sparingly.
JURASSIC		McElmo formation.	Jme		400–1000	A complex of alternating friable, fine-grained, yellowish or grayish sandstones and shales. The sandstones are seldom more than 20 feet thick. They often include flakes of grayish clay or shale. The shales are chiefly green in color, but may be pink, dark red, or chocolate brown. Some shale layers are sandy and others highly calcareous. No fossils have been found in the McElmo strata.
		La Plata sandstone.	Jlp		250–500	Consists principally of 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, distinctly cross bedded, and form massive cliffs where exposed. The limestone or calcareous shale is locally brecciated or recemented. No determinable fossils have been found.
		UNCONFORMITY				
TRIASSIC?		Dolores formation.	Td		400	Sandy marl and fine-grained sandstone and shale of bright-red color with fine limestone conglomerate near the base, in which are found teeth of a crocodile (*Belodon*) and of a megalosauroid dinosaur, with a rare gasteropod shell similar to *viviparus*, indicating the Triassic age of the formation,
		UNCONFORMITY				
CARBONIFEROUS	PERMIAN?	Cutler formation.	Cc		1600	A complex of bright-red sandstones and lighter red or pinkish grits and conglomerates alternating with sandy shales and earthy or sandy limestones of varying shades of red.
	PENNSYLVANIAN	Rico formation.	Cr		300	Dark reddish-brown sandstone and pink grit, with intercalated greenish or reddish shale and sandy, fossiliferous limestone.
		Hermosa formation.	Ch		1800–2000	A series of grits, sandstones, shales, and limestones of varying distribution and development. Grit and sandstone in massive beds predominate in the middle and upper parts of the section, the lower portion consisting of thinner bedded sandstone, shale, and limestone layers. Numerous invertebrate fossils occur in shale and limestone.
		UNCONFORMITY				
	MISS.	Ouray limestone.	DCo		100–300	Dull yellow to buff, compact limestone, lower third shaly with thin quartzites. Abundant fossils indicate Devonian age of lower two-thirds and Mississippian age of upper part.
	DEVONIAN	UNCONFORMITY				
	CAMBRIAN?	Ignacio quartzite.	Ci		0–200	Quartzite, massive and conglomeratic in lower part, thin bedded with shale and sandy partings in medial zone, succeeded by more massive quartzite. Light gray, pink, or yellow predominates. One shell, *obolus* sp. ?, has been found near the middle of the formation.
		UNCONFORMITY				
ALGONKIAN		Uncompahgre formation.	Au			White or smoky quartzite and dark slate, mainly massive, but in a few places alternating in thinner layers. No fossils have been found.

WHITMAN CROSS,
ARTHUR C. SPENCER,
Geologists.

ILLUSTRATIONS

FIG. 1.—THE SOUTHEASTERN PEAKS OF THE RICO MOUNTAINS, FROM THE WEST SIDE OF THE DOLORES RIVER.

In the center, on the sky line, is the porphyry cap of Dolores Peak, behind which rises Blackhawk Peak. Farther to the left is the north shoulder of Blackhawk Peak, with its light-colored porphyry cliffs. On the right is Whitecap Mountain, with its porphyry sheets, and in front of it Deadwood Gulch. Across the face of Dolores Mountain may be traced the limestone ledges in the middle of the Hermosa formation.

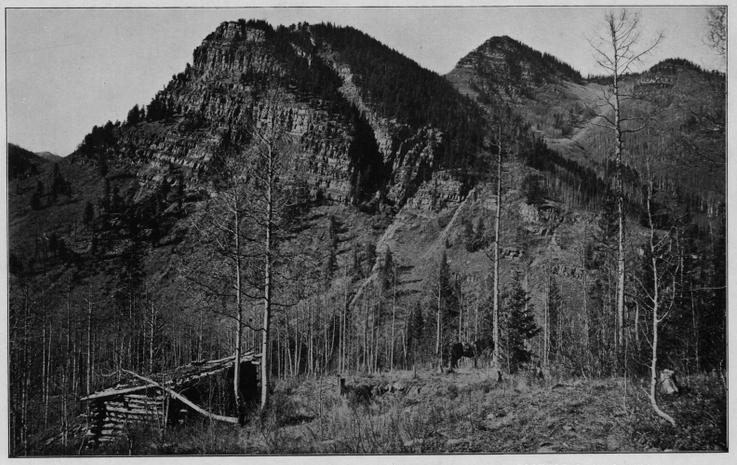

FIG. 2.—SANDSTONE MOUNTAIN, LOOKING ACROSS THE DOLORES FROM THE FOOT OF C. H. C. HILL.

The view illustrates the character of cliff exposures formed by the alternating limestone, sandstone, and shale beds of the Hermosa formation, and the similar ones of the lower portion of the Dolores red beds in the knolls to the right. The crevice crossing the summit of Sandstone Mountain marks the line of a small fault.

FIG. 3.—DARLING RIDGE AND HORSE GULCH, FROM SANDSTONE MOUNTAIN.

At the head of Horse Gulch, on the right, is Calico Peak, and on the left Anchor Mountain. The snow-covered slope of Darling Ridge on the left, from the creek to the forested crest, is wholly occupied by landslide débris. The Puzzle mine is situated at the foot of the snowy slope, in a landslide block.

FIG. 4.—TORRENTIAL FAN AT THE MOUTH OF AZTEC GULCH, FROM EAST SIDE OF THE DOLORES RIVER.

Shows the characteristic form and grade of a torrential fan. The face at the bottom of the main fan is an erosion scarp cut by the river. A secondary fan is now being formed in front of that scarp.

FIG. 5.—TELESCOPE MOUNTAIN AND THE UPPER PART OF C. H. C. HILL, FROM SANDSTONE MOUNTAIN.

The highest point is the summit of Telescope Mountain. On the left is a scarp of Hermosa and Rico strata. On the right is the ridge leading down to Nigger Baby Hill. The foreground and central part of the view show the landslide topography of C. H. C. Hill. The Pigeon vein, or "big fissure," runs beneath the snow-covered bench. The Pigeon mine buildings in foreground.

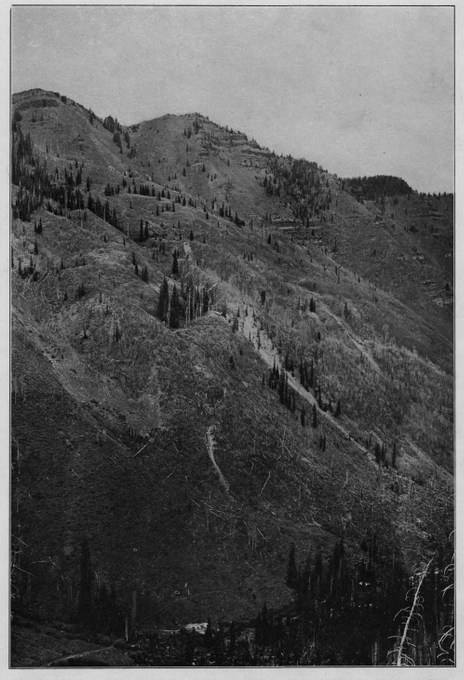

FIG. 6.—DETAILS OF LANDSLIDE TOPOGRAPHY IN THE AREA ON THE NORTH SIDE OF HORSE GULCH.

The view shows characteristic landslide trenches, ridges, and mounds, where disintegration has smoothed out the originally more angular forms of slide blocks. In the background are strongly contrasting ledge outcrops.

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