DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

GEOLOGIC ATLAS

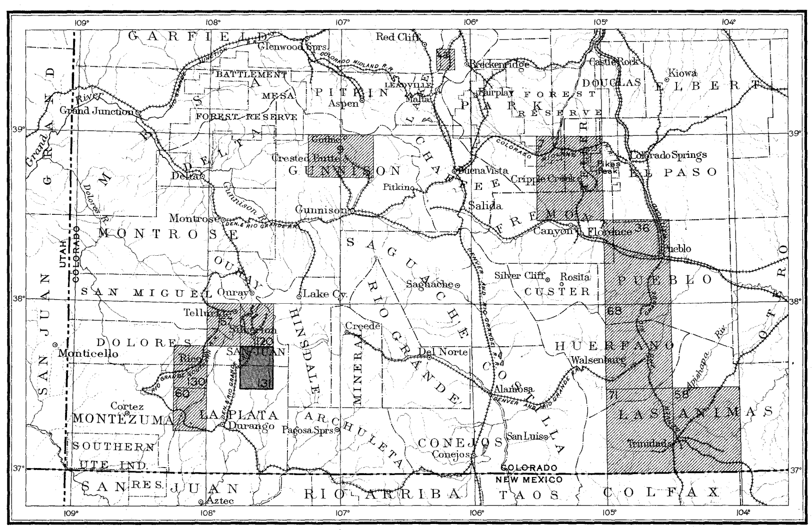
OF THE

UNITED STATES

NEEDLE MOUNTAINS FOLIO

COLORADO

INDEX MAP



SCALE: 40 MILES = 1 INCH

NEEDLE MOUNTAINS FOLIO

OTHER PUBLISHED FOLIOS

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

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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).

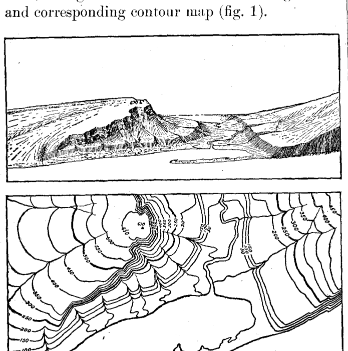


FIG. 1.—Ideal view and corresponding contour map.

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.......	....	Ŧ	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......	....	Æ	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:

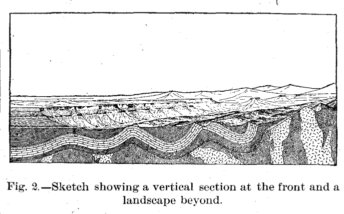


Fig. 2.—Sketch showing a vertical section at the front and a landscape beyond.

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:

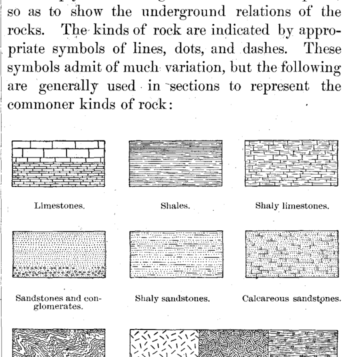


Fig. 3.—Symbols used in sections to represent different kinds of rocks.

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

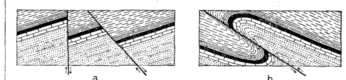


Fig. 4.—Ideal sections of strata, showing (a) *normal* faults and (b) a *thrust* fault.

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 NEEDLE MOUNTAINS QUADRANGLE.

By Whitman Cross, Ernest Howe, J. D. Irving, and W. H. Emmons.

TOPOGRAPHY AND GENERAL GEOLOGY.

By Whitman Cross and Ernest Howe.

INTRODUCTION.

Geographic position.—The Needle Mountains quadrangle is situated in parts of San Juan and La Plata counties in southwestern Colorado. It lies between 37° 30′ and 37° 45′ north latitude and 107° 30′ and 107° 45′ west longitude and contains about 236 square miles. Animas River, an important tributary of San Juan River, separates the northwestern portion from the rest of the quadrangle by its deep canyon, while Vallecito Creek, Florida River, and Bear Creek (one of the forks of the headwaters of the Rio Grande) have their sources in the Needle Mountains.

Relation to adjacent mountains and plateaus.—The Needle Mountains form the southwest buttress of the San Juan Mountain group, a region of considerable elevation, composed largely of late volcanic rocks, that extends westward from the San Luis Valley on the east nearly to Dolores River and is limited on the north by Gunnison River. On the south the mountains are bordered by foothills of sedimentary rocks that are drained by San Juan River and its eastern tributaries. The Needles occupy an intermediate position between the foothills and the volcanic areas. At the northeast corner of the quadrangle are a few outlying patches of the volcanics, and to the south appear the gently upturned sedimentary rocks of the foothills, that merge, toward San Juan River, with the nearly horizontal beds of the plateaus of New Mexico.

GEOGRAPHY AND TOPOGRAPHY OF THE QUADRANGLE.

Physical features.—Crossing the central portion of the quadrangle from east to west is a range of extremely rugged mountains of granite and schist, from which rise sharp peaks, the summits of four of which are over 14,000 feet in elevation, while nearly 6000 feet below Animas River rushes through a canyon which separates the West Needles from the main group. Adjoining these peaks on the north is the Grenadier Range, whose serrated crest of quartzite extends from Animas River eastward to Vallecito Creek. These, with the main mass of the Needles and a few high peaks of quartzite, form a mountain group that is the most important physical feature of the quadrangle.

South of the mountains, and separated from them by the deep valley of Needle Creek, is a plateau dissected by Florida River and tributaries of the Animas and having a slight inclination to the south and southwest. It is composed of the same granite that forms the main mass of the Needles, and on this rest isolated remnants of sedimentary rocks of early Paleozoic age.

The Continental Divide crosses the extreme northeast corner of the quadrangle from northwest to southeast. This is a region of moderate relief, when compared with the neighboring Grenadier Range, though its elevation is almost everywhere above 12,500 feet. On one side are the sources of the Rio Grande and on the other rise Vallecito Creek, an important tributary of Pine River, and Elk Creek, a branch of the Animas.

Central granite peaks and the Grenadier Range.—The central portion of the Needle Mountains quadrangle is occupied by massive peaks of granite or quartzite that have, on account of their wonderfully sharp pinnacles and abrupt faces, suggested the name which has long been applied to the mountain region as a whole. From Needle Creek on the south to Elk Creek on the north and from the Vallecito to the Animas they form a group of peaks almost unequaled in this country in altitude and in the boldness of their forms. Some of the more prominent ones are shown in figs. 4, 8, and 9 of the illustration sheets. They are composed of granite, schist, or ancient quartzites that form the core of a dome-like uplift, the influence of which may be noted in the outlying rocks for 15 to 20 miles in all directions. This central mass has been deeply dissected by streams tributary to the Animas or the Vallecito, and the various rocks are well exposed and their relations to one another clearly shown.

Canyons.—Almost as striking a topographic feature as the central massif is the canyon of Animas River (fig. 6), which crosses the northwest corner of the quadrangle in a somewhat irregular course, in a gorge nearly 15 miles long and from 3000 to 4000 feet deep. At a few places the river flows between rock walls and on a rock bottom, and at such points the roadbed of the railway has been blasted from the solid rock; but for the most part narrow strips of alluvium are to be found on both sides of the stream at the base of the canyon walls, and at Elk Park (fig. 6) and Needleton these widen out and form open "parks." The canyon itself is an almost impassable barrier between the east and west Needles. A few trails extend up into the mountains to the east, following the larger streams, but the western wall is almost without a break and can be surmounted only on foot after long and arduous climbing.

Needle Creek, which is the largest stream that enters the Animas within the quadrangle, has carved for itself a narrow valley that offers the only means of reaching by a trail a pass to the Vallecito or the mesas to the south. It sharply defines the southwest limits of the central mountain area. Part of this valley is shown in fig. 4, which presents a view looking across the lower part of the valley from Mountain View Crest toward Pigeon and Turret peaks.

The Vallecito, which heads at the Continental Divide, in the extreme northeast corner of the quadrangle, can hardly be said to occupy a canyon in its upper portion, but rather a deep valley hemmed in by lofty mountain walls of quartzite or granite (fig. 7). Below its junction with Johnson Creek the walls come closer together and canyon conditions prevail, culminating in a mere rift in the rocks 1000 feet deep where the stream leaves the quadrangle. Florida River also drops suddenly into a very bare, narrow canyon a short distance below Lower Park. Not the least striking of the canyons is that of Lime Creek, a part of which lies just inside the western boundary of the quadrangle. This canyon limits the West Needles in that direction.

West Needles.—This group of peaks belongs structurally with the main mass of the Needles, but topographically it is more closely related to Mountain View Crest and the mesas south of it. That is, the summits of the West Needles form the outer rim of the core of the dome-like uplift and from them the surface of the older rocks upon which the younger sedimentaries rest slopes gently away as it does south of Needle Creek. The West Needle Mountains extend from Snowdon Peak southwestward to the junction of Cascade Creek with the Animas, and to them rightfully belongs the outlying mountain called Potato Hill, in the Engineer Mountain quadrangle to the west.

Mesas.—Sloping away gently in all directions from the central mass of the Needles are the old land surfaces upon which the Paleozoic sediments were deposited. To the north and east the pre-Paleozoic land surface lies beyond the boundaries of the quadrangle, or is almost entirely covered by volcanic or other rocks. South of Needle and Johnson creeks and west of the Vallecito, however, this surface has been preserved and reexposed by the removal of the sedimentary rocks which covered it. To-day it can be recognized in the broad, southward-inclined table-land, which has been more or less deeply dissected by modern streams between which lie isolated mesas. Figs. 1 and 2 well illustrate these features. Fig. 2 shows, in addition to the north end of Stag Mesa, resting upon the Eolus granite, the escarpment of Paleozoic rocks on the west side of the upper Animas Valley and in the far distance the La Plata Mountain group. Fig. 1 shows Lime Mesa in the middle distance, seen nearly from the north. In the far distance to the right and left, respectively, are the valleys of Animas and Florida rivers.

The comparatively low relief is in strong contrast to the sharp peaks of the Needles, and for this reason the mesas form one of the pronounced physical divisions of the area.

Culture.—The difficulty of access and the relative unimportance of their mineral resources, together with the rugged, forbidding character of the Needles, have not encouraged permanent settlement. A few prospectors spend the summer months in the vicinity of Needle Creek and Chicago Basin, or at the head of Bear Creek. Elsewhere human habitations are rarely seen, the log cabins of prospectors being now deserted and falling into ruin, while the few trails are little traveled and bad. The most important signs of man's occupancy are the Denver and Rio Grande Railroad, which follows the Animas Canyon upstream to Silverton, a few miles to the north of the quadrangle, and a storage reservoir which has recently been constructed in Upper Park, near the head of Florida River, and which is connected by a good trail with the ranches to the south.

Names.—During the present survey names have been given to a considerable number of peaks and other prominent features in the quadrangle which had previously possessed no such means of identification. Endlich Mesa, between Florida River and Vallecito Creek, was named after F. M. Endlich, of the Hayden Survey, who first made there a collection of Devonian fossils from the Ouray limestone. Mountain View Crest and Overlook Point, as well as many of the names of the Grenadier Range, have been suggested by peculiar topographic features. Irving Peak, after Prof. R. D. Irving, seems an especially appropriate name for the first and most prominent peak of Algonkian rocks seen on ascending the Vallecito. Emerson, Amherst, and Greylock mountains all possess some memorial significance in their names. The peaks of quartzite extending in a bow from the Animas Canyon to the Vallecito have been named the Grenadier Range, from their characteristic profile.

DESCRIPTIVE GEOLOGY.

ROCK FORMATIONS.

ANCIENT METAMORPHIC ROCKS.

SCHISTS AND GNEISSES.

Age.—A considerable area within the quadrangle is occupied by gneisses and schists which have every appearance of being of very ancient origin. They have been profoundly metamorphosed by compression, folding, and mashing, so that the original character of the rocks which now make up the complex has been completely obliterated, but their composition indicates an igneous rather than a sedimentary origin. Their relation to the other rocks of determinable age in the region points to their own greater antiquity, for they are either overlain or intruded by the others, except the Irving greenstones, from which they are separated by the great mass of the Eolus granite. The oldest rocks in contact with them are those of the Needle Mountains group, of Algonkian age, and they contain in a few places characteristic pebbles of the schists, conclusive evidence of the relative youthfulness of the Uncompahgre. For these reasons the gneisses and schists have been considered to be of Archean age and were so described in the Silverton folio.

Distribution.—These rocks follow the canyon of the Animas from a point to the west in the Engineer Mountain quadrangle, in a band 3 or more miles wide, northward to the Algonkian quartzites near Elk Park, with an arm extending northeastward from the mouth of Ruby Creek to Balsam Lake. They are interrupted at several places by intrusive bodies of granite. North of the zone of Algonkian rocks the schists again appear at the mouth of Whitehead Creek and extend continuously along the northern border of the quadrangle from near Molas Lake to Beartown. These exposures continue for a few miles northward in the Silverton quadrangle until covered by sedimentary or volcanic rocks.

General character.—The complex varies in petrographic detail from place to place, but it possesses no clearly marked divisions which it is practical or desirable to recognize as cartographic units. Although certain zones are lighter or darker in color than others, the schists as a rule are a uniform gray, but tricks of weathering may cause them to have a distinctly banded appearance, even when seen from a distance. This banding is due to alternations of nearly black amphibolites with rocks richer in quartz and the feldspars, the various bands being only a few feet or yards in thickness.

The general character of the complex is made still more varied by the presence of granite bodies which have intruded the schists and which have sent out irregular arms and dikes, in some places coinciding with the direction of schistosity, elsewhere crosscutting. The most striking example of this is the Twilight granite, which, for 2 miles before Animas River leaves the quadrangle, ribs the canyon walls of black amphibolite with its nearly white parallel dikes. So numerous are these dikes that it has been impossible to represent them, even diagrammatically, on the map. An area has therefore been outlined in which the Twilight intrusive occurs either exclusively or in excess of the Archean schists; but within its limits considerable schist may often be found. The character of these intrusions and their relation to the schists will be discussed later. The schists on the north side of Whitehead Creek and east of Molas Lake are cut by a complicated network of dikes and veins that are doubtless offshoots from the larger granite masses in the Silverton quadrangle.

Petrography.—When examined in detail the schists show great diversity both in composition and texture. The commonest variety is a moderately fine-grained, well-laminated rock of a dark-gray color which on weathered surfaces becomes a lighter shade of reddish brown. Quartz and feldspar can be distinguished in fine grains and with them is hornblende or a dark mica. Bands of such rock may be found at almost any point in the canyon, while in a number of places it predominates. Distinct from this are rocks which are coarse textured and irregularly foliated rather than banded. They are as a rule very light in color and contain greater amounts of quartz and the feldspars in proportion to the dark minerals than do the finer-grained schists which have been described. Rocks like these occur on the east side of the Animas in the neighborhood of Needleton, and are supposed to be granites which have had their original structure destroyed by compression or mashing. Such rocks are not common in the region and are to be clearly distinguished from the other intrusive granites. Nearly black amphibolites are very common in almost all parts of the complex. As their name implies, they are composed very largely of dark amphiboles or hornblende and the majority are finely laminated and cleave well along the lines of schistosity. Some of these amphibolites appear to have been intruded as dikes into the other rocks at a very remote period. From their present composition they are assumed to have been diabases or other equally basic rocks, but the regional metamorphism has obliterated all of their original characteristics and brought about a complete recrystallization of their constituents. For the purposes of description the various rocks composing the Archean complex of the Needle Mountains may be grouped under three general heads—gneiss, biotite-schist, and hornblende-schist.

Gneiss.—Rocks of this sort are in almost all cases light colored and moderately coarse textured. Some are strongly banded or laminated, while others have but an imperfect foliation, and this variation may occur even in different parts of the same mass. All are feldspathic and many of them contain feldspar in excess of the other minerals. A dark mica is uniformly present, the parallel arrangement of whose blades helps to bring out the banded or foliated structure. A microscopical examination shows them to have about the same mineralogical composition as granites. With orthoclase are associated microcline and plagioclase, to be recognized, however, only in the more imperfectly banded or less mashed varieties. In those rocks which have undergone great compression it is almost impossible to estimate the relative amounts of quartz and feldspar, so completely have the original crystal grains been broken down and granulated, while diagnostic features of the feldspars have been completely obliterated. Next to feldspar, quartz is the most abundant mineral, and these two make up the greater part of the rock. Biotite is conspicuous on account of its dark color and in places is a very abundant constituent. It occurs in small scales or blades arranged in more or less parallel positions. Certain accessory minerals, which are characteristic of granites, are also found in many of the gneisses. These include garnet, magnetite, and apatite. Muscovite, except as an alteration product of the feldspar, is rare.

So far as one may judge from their petrographical character, the gneisses seem to be metamorphosed intrusive granites.

Biotite-schist.—As has been said, the commonest rocks of the Archean complex are biotite-schists. Many of them are but little different in composition and appearance from the gneisses, while others are with difficulty distinguished in the field from the hornblende-schists. Most of them are much finer grained and more perfectly schistose than the gneisses. This schistosity and the excellent cleavage which accompanies it are doubtless emphasized by the large quantity of biotite present, which also gives the rock a much darker color. The rocks are compact and well laminated, with alternating dark and light narrow bands which combine to give a general dark greenish-gray color to the whole. According to the amounts of the light silicates present they weather to rusty pinks or dark browns. The microscope shows that they consist of quartz and orthoclase in nearly equal proportions and each but slightly in excess of dark-brown or greenish biotite. In rare cases a little muscovite and accessory apatite and titanite occur. Magnetite is not common. There are no crystal boundaries, but all the minerals occur in elongate grains or blades arranged with the greater diameters parallel. It is not possible to determine with any certainty the original character of these rocks; they may well have been either sedimentary or igneous.

Hornblende-schist.—Next to the biotite-schists, hornblendic ones are the most numerous. They are nearly black and have a fine fibrous texture, which is lustrous on fresh surfaces. A few of them are banded like the biotite-schists, but the greater part are densely schistose. In rare instances they are less dense and compact and consist of coarser aggregates of hornblende. The lighter-colored minerals are as a rule inconspicuous. When examined microscopically, they are found to be made up very largely of a peculiar bluish-green hornblende in long needles, all nearly parallel, generally some biotite, and interstitial feldspar and quartz. The feldspar is fine grained or granulated and difficult to determine in all cases, but it appears to be generally orthoclase with variable amounts of plagioclase. Accessory titanite, ilmenite or magnetite, and apatite are uniformly present, and in some cases actinolite is found. The parallel arrangement of the mineral particles and the marked schistosity which results from this is one of the most characteristic features of the rock. As a rule those amphibole-schists which are supposed to represent mashed basic dikes are richer in hornblende than the others.

Garnet-schist.—At only one locality in the quadrangle, although found elsewhere in the region, do garnet-schists occur. They are exposed at the south end of a wider portion of the canyon about 2 miles north of Needleton. The rock is very coarsely laminated and has the earthy, greenish color characteristic of decomposed amphiboles. Certain bands are composed almost entirely of more or less crushed red garnets as large as small peas or even hickory nuts. Garnet is also present in the amphibolitic portions as an important accessory. The rock as a whole consists of nearly equal amounts of amphibole, probably actinolite, orthoclase and plagioclase feldspar, and quartz with accessory garnet, magnetite, and apatite. Secondary muscovite, chlorite, and hematite are common.

Structure.—The only structure that can now be made out in the Archean complex is a comparatively simple one, and its nature is evident from even a superficial examination. The innumerable bands or layers which succeed one another like the strata of sedimentary formations have dips of high angles, which vary from one side to the other of the vertical. The general strike of the schistosity, which is the same as that of the banding, swings, with local variations, from a few degrees east of north where Animas River leaves the quadrangle to a nearly east-west direction just below Elk Park. Although the prevailing strikes in the strip along the northern border are east and west, a difference of 90° within a mile has been observed in a few places. As in the area to the south, the dips are all nearly vertical.

Greater complexity of structure doubtless exists and there may be repetitions of various bands through faulting or close folding, but no evidence has been found which could warrant the definite assumption that such conditions do or do not prevail.

IRVING GREENSTONE.

Name and definition.—The name Irving greenstone is here proposed for a complicated series of schists, greenstones, and subordinate quartzites, a portion of which is prominently exposed in the southeastern part of the quadrangle and of which Irving Peak is composed. In many respects similar to the Archean schists of the Animas Canyon, the Irving greenstone must, nevertheless, be distinguished from them, on account of the distinctive character of certain of the more massive members of the series and the presence of sedimentary rocks. The actual base of the Irving has nowhere been seen, for on the west it has been found only in contact with the Eolus granite, while to the east it appears to be in many cases in fault or shear contact with the Vallecito conglomerate or the Uncompahgre quartzite. The portion of the formation observed belongs within the area represented as "metamorphic Paleozoic" on the Hayden map. It has been described by Howe in the Journal of Geology (vol. 12, 1904, pp. 501-509).

Thickness and structure.—The thickness of the Irving greenstones and schists is not known. The formation consists very largely of unstratified eruptive rocks, into which other igneous masses have been intruded. All have been extensively affected by dynamic metamorphism, which has so often obliterated the original structure that it is impossible to say whether or not the series, now consisting largely of rocks with a nearly vertical schistosity, exposed between the Vallecito conglomerate and the Eolus granite represents a simple section. If there has been no repetition through folding or thrust faulting, more than 10,000 feet must be allowed as the minimum thickness now exposed. What are supposed to be the lower portions are limited by a fault contact with the Eolus granite. The Vallecito formation, a conglomerate made up largely of greenstone pebbles, has been infolded in a complicated manner with the Irving schists in the area to the east, and both have acquired a schistosity younger than that common to the Irving formation as a whole. This makes it extremely difficult to distinguish between the two formations, particularly in the region northeast of the Quartz Mill. Wherever it has been possible to discover evidence of original bedding in the sedimentary rocks, the dips or strikes have been found to be more or less discordant in different areas. A secondary schistose structure, often well developed, is difficult to distinguish from a possible bedding, but it is not a constant feature of the Irving formation, certain portions, both sedimentary and igneous, being massive and unmashed. In this massive character they differ much from the Archean rocks.

Distribution.—The Irving greenstones are exposed for a little over 7 miles on one side or the other of Vallecito Creek from the southern boundary of the quadrangle northward. On the west they are sharply bounded by probable fault contact with the Eolus granite, and to the north, east, and south, where not covered by the Paleozoic formations, they are seen in contact with the Needle Mountains group, their eastern limit being not more than a mile beyond the border of the quadrangle. The contact with the Uncompahgre quartzite, north of Irving Peak, is clearly a fault, but the greenstones and the Vallecito conglomerate, which are also indicated on the map as in fault contact, may, so far as can be seen in the area examined, be in original contact with one another, modified by infolding of the two terranes and accompanied in places by minor shearing. The presence of the Irving elsewhere in the quadrangle or in the region immediately surrounding it has not been observed.

General description.—The rocks which make up the Irving complex possess a great variety of textures, but a composition that is very uniform in the different groups. The majority may be broadly described as greenstones; some resemble massive granular rocks, others are porphyritic with a dense groundmass, while still others are finely laminated schists. Hornblende, chlorite, epidote, and rarely biotite can be recognized megascopically in nearly all, and usually these dark minerals appear to be in excess of the lighter silicates. What feldspar there is has evidently been much altered. The greenstones are dark greenish brown or black and give a somber tone to the hillsides and canyon walls where they are exposed. The most significant features of the rocks in different parts of the complex are the variations in texture and structure, which are conspicuous in the field and still more so when the rocks are examined microscopically. These variations are due partly to original textural differences in the rocks themselves and partly to the dynamic metamorphism that has produced in some instances finely laminated schists, in which all traces of original structure have been obliterated, and in others breccias, in which the fragments have been welded together by pressure, with a rude schistosity, not well marked as a prevalent structure, but sufficient to modify the massive appearance.

With the greenstones are a few lighter-colored rocks, generally much mashed, which appear to have been granitic intrusions; there are also more recent granite-porphyries and pegmatites. Probably the least numerous are bands of extremely siliceous rocks which were formerly sandstones or quartzites. At only two places is their sedimentary origin beyond doubt, namely, at a point south of the quadrangle line near the granite contact and at another just west of the saddle north of Irving Peak. The rocks at these two localities are simple massive quartzites like many that belong to the Uncompahgre formation. At other localities quartz-schists have been found which may have been massive quartzites like the others, but have yielded to the influence of dynamic metamorphism and have had developed in them secondary schistose structures and new minerals. The alternation of harder and softer layers has in many cases caused a ribbed surface when the rocks have been subjected to long weathering. The relation of the quartzites to the greenstones is obscure; they do not appear to have been formed as contemporaneous deposits, but rather to have been torn away from their original positions as members in a larger series of quartzites, by the intrusion of the basic magma of the greenstones, and held as inclusions in it. The appearance of quartzite here and there in the Irving section is of interest as indicating the source from which the quartzite bowlders of the Vallecito conglomerate were derived. In this connection should be mentioned the occurrence of a 15-foot band of more or less siliceous magnetic iron on the hillside west of Irving Peak. It is interstratified with siliceous schists or mashed quartzites, and itself bears evidence of sedimentary origin. Parts are composed of nearly pure magnetite, while others are of coarse yellowish quartz, intermediate portions showing an almost schist-like banding due to the alternation of the two minerals. This single observed occurrence is an example of many such beds which must have once existed and which supplied the magnetite, hematite, and jasper pebbles so characteristic of the Vallecito conglomerate and the lower horizons of the Uncompahgre formation. The structure of the Irving greenstone and the character of the complex as a whole is more fully discussed in later sections.

Petrographic details.—A microscopical examination of the rocks is necessary to an understanding of the origin of the various members of the Irving series and of their probable age relations to one another. In the following paragraphs some of the more important details will be given. For purposes of description the rocks will be grouped under the three general heads of quartzites, greenstones, and granitic rocks.

Quartzites.—This general term includes a number of quartzites and certain other siliceous rocks whose original character is not all clear. Beginning with the massive quartzites, a suite of rocks may be chosen which shows a gradual transition to fine grained schists containing feldspars, dark mica, and even hornblende in appreciable amounts. Microscopically, rocks at this end of the series are hardly to be separated from the more siliceous mashed eruptives; the structures are the same and the considerable quantity of feldspar makes it extremely doubtful whether the rocks in question could be classed with the quartzites. It is entirely reasonable to suppose that certain of the more feldspathic of the quartzose rocks may have been originally deposited as arkose sandstones, especially when it is remembered that the rocks from which these sediments were probably derived belonged to the Archean, in which no very pure siliceous rocks are now known to occur. These matters are of more theoretical than practical importance, since the occurrence of the quartzites is not prominent and they can not be differentiated from the rest of the Irving complex for purposes of mapping.

Greenstones.—This field term is a useful one to apply to the rocks of rather varied texture but similar composition that make up the greater part of the Irving series. Some are very dense and fine grained, others are coarsely granular or porphyritic, and many are now well-laminated schists. The field relations are often obscure, and practically no information as to their origin can be obtained there, except that they were probably intruded into the older sedimentary rocks. The microscope shows that at present the rocks consist very largely of pleochroic green hornblende, considerable feldspar, and generally biotite and quartz, with accessory ilmenite or magnetite. All have undoubtedly been derived from the same magma and crystallized as gabbro or diabase; subsequently they were profoundly metamorphosed through dynamic action, and at present it is only in the more massive examples that any trace of the original structure or composition can be found. The processes by which a complete change in the mineralogical composition of gabbro or diabase may be brought about have been discussed in detail by G. H. Williams in his description of the similar greenstone rocks of the Lake Superior region. Briefly, the original pyroxene alters to a fibrous green hornblende (uralite) and the labradorite to zoisite and albite; quartz, orthoclase, chlorite, muscovite, and biotite may also be developed. In some cases the original granular or ophitic structure may still be made out, while extreme alteration brings about a complete recrystallization and develops a finely laminated schist which betrays no sign of its former character. Such has probably been the history of the Irving greenstone-schists. In no specimen has it been possible to find a pyroxene in the stage of passing over into uralitic hornblende, but there can be little doubt as to the secondary nature of the mineral. It occurs commonly in large, irregular patches, the different parts of which seldom extinguish at the same time; the borders are uneven and ragged, and high powers of the microscope show that they are fringes of fine green needles or fibrous aggregates of uralite. In the more massive rocks may still be made out lath-shaped, striated feldspars whose general appearance suggests that they were basic plagioclase, though they are never fresh enough to make satisfactory measurements of their extinction angles; they are now largely altered to zoisite, albite, and calcite. In many cases the arrangement of the feldspar is that typical of diabase. Later alteration products, such as chlorite, are common and in some cases have completely replaced the hornblende. Ilmenite, surrounded in many instances by a border of secondary titanite, is to be found in most of the greenstones.

Partly on account of the ophitic or granular structure of the unsheared specimens and partly by comparison with the rocks of other regions, in which all the stages of alteration are shown, the greenstones of the Irving series are considered to have been derived from gabbro or diabase and to have acquired their present character through dynamic metamorphism. Rocks which possess the diabase habit are by far the commonest.

Granitic rocks.—Rocks having a composition like that of granite occur as intrusives of different periods in the Irving complex. The youngest are simply aplites and pegmatites or granite-porphyries and appear to be closely related to the Eolus granite, if, indeed, they are not actual offshoots from the great mass to the west. They are, with the exception of the pegmatites, dense, finely granular pink or red rocks composed of orthoclase, microcline, and quartz, with small quantities of biotite and the usual accessories of granite. They cut the greenstones and quartzites without regard for schistosity or bedding, and rarely show signs of a mashing which was probably connected with the movements in which the Uncompahgre was involved. Evidently older than these are light-gray gneisses and schists which at some points lie as sheets between altered diabase or quartzite and elsewhere appear as if they were crosscutting bodies. Some are coarse gneisses, in which biotite occurs in disconnected lenticular patches or lamellæ; others are fine-grained, evenly banded biotite-schists whose schistosity is often more linear than in planes. The microscopic structure of all indicates mashing. In some only the edges of the quartz and feldspar grains have been granulated, in others the original structure has been completely broken down and probably recrystallization has taken place. They consist of orthoclase, microcline, a little plagioclase, abundant quartz, and variable amounts of biotite; in addition to their principal constituents accessory magnetite and apatite are prominent in many specimens. Garnet is not uncommon and a little green hornblende has also been found. Alterations of feldspar to muscovite and kaolin and of biotite to chlorite occurred frequently, and the resulting dull-green color in some cases caused the rocks to be mistaken for greenstones in the field. A number of specimens, supposed in the field to be quartzites, have been found, on microscopical examination, to be more probably of eruptive origin, on account of the prominence of feldspar, biotite, and the accessory minerals, though quartz may be the most abundant single mineral. There can be little doubt that these rocks formerly intruded the greenstones and quartzites as granite dikes or irregular crosscutting bodies, and that they were afterwards involved in the dynamic metamorphism of the region.

Age and correlation.—It is impossible to tell what the relations may have been between the Archean rocks of the Animas Canyon and the Irving greenstone, because the space between them is occupied by the great mass of Eolus granite. That they are petrographically distinct there can be no question, and the presence of sedimentary rocks in the Irving formation is a good reason for believing that it is of later age. Little can be learned from a study of the Irving-Uncompahgre and Irving-Vallecito contacts, except that where the formations are not sharply separated by faults they are intricately infolded and the original contacts of sedimentation have been obscured. The lower portions of the Vallecito conglomerate, however, are largely made up of greenstone pebbles and bowlders, with many of quartzite, and this is sufficient to prove the greater age of the Irving and indicate the former abundance of quartzite in it. For these reasons the rocks of the Irving formation are considered to be most probably of Algonkian age.

No other rocks of similar character are known to occur in the San Juan Mountains, but similar schists have been found by Cross near Salida, in the Sangre de Cristo Range, concerning the occurrence and distribution of which there is very little information. Petrographically these rocks and those of the Irving formation appear to be practically identical. In many respects the Needle Mountain rocks closely resemble the greenstones of the Marquette and Menominee regions, described by G. H. Williams. The Menominee greenstone-schists have been reexamined and described by W. S. Bayley, who has named them the Quinnesec schists. They are believed to be of Archean age, on account of their lithological and structural features, although it is stated that there is no positive proof that they are older than the Huronian.

SEDIMENTARY ROCKS.

Algonkian System.

NEEDLE MOUNTAINS GROUP.

Introductory statement.—The name Uncompahgre formation was proposed in the Silverton folio for a great succession of supposed Algonkian quartzites, slates, and subordinate conglomerates, represented in the Uncompahgre Canyon by several thousand feet of upturned strata. The exposures of these beds begin in the Silverton quadrangle and extend for a few miles northward almost to the town of Ouray, but neither top nor bottom of the larger conformable series to which the visible section belongs is here shown. The name was proposed for the entire assemblage of conformable quartzites and slates, of which it was known that extensive exposures existed in the Needle Mountains.

During the survey of the Needle Mountains quadrangle it was found that the main quartzites and slates were like those of the Uncompahgre section, but from structural complexities the portion represented was less, and, as in the Uncompahgre Canyon, the upper and lower parts were not seen. In the Vallecito Canyon, however, at the southern margin of the quadrangle, a heavy conglomerate was discovered and traced to the east, where it was found in such relations with the Uncompahgre quartzites and slates as to appear unquestionably as the lower part of the group. To this conglomerate the name Vallecito is given and to the group which includes it and the Uncompahgre, together with higher formations that may hereafter be recognized, the name Needle Mountains is applied.

The total thickness of the Needle Mountains group is unknown. Two thousand feet or more of the basal conglomeratic member occur about 2 miles east of the quadrangle, in the vicinity of Emerald Lake, on the Lake Fork of Pine River, while more than 5000 feet must be allowed for the overlying quartzites and slates of the Grenadier Range. The complicated folding and shearing within the group and the complete unconformity with overlying beds, indicating a long period of deformation and erosion preceding the deposition of the earliest fossiliferous rocks, make it impossible to estimate the original thickness of the Needle Mountains group or to recognize an upper limit of the section.

VALLECITO CONGLOMERATE.

The basal formation of the Needle Mountains group, the Vallecito conglomerate, is exposed on both sides of Vallecito Creek for about 1 mile northward from the southern boundary of the quadrangle. This, however, is a less complete section than that exposed on Pine River. In the neighborhood of the Quartz Mill the rock is a very compact conglomerate. The well-rounded, water-worn pebbles and bowlders range from one-half an inch in diameter to 12 inches in rare instances and are composed of vein quartz, purplish quartzite, and many varieties of schist, mostly dark amphibolites and rocks rich in chlorite, clearly derived from the Irving series of greenstones. A few massive granular fragments have also been observed. The cement is a fine-grained, dark-gray quartzose material, at some points in excess of the pebbles and bowlders which it incloses and at others quite subordinate. Generally the rock has the appearance of having been compressed or sheared. Many of the pebbles are fractured and the cracks are filled with vein quartz; others are bent or welded into their neighbors, while the cement looks as if it had flowed about the pebbles.

Higher up in the section the conglomeratic character becomes less pronounced. Coarse grits or finer-grained, cross-bedded sandstones and arkoses begin to appear and form an important part of the series, but in no case, so far as observed, to the exclusion of conglomerate beds. In the upper portions greenstone pebbles are much less numerous, most of the materials being quartzites with a considerable amount of jasper, gray hematite, and magnetite.

The change from conglomerate to fine-grained quartzite is not seen in the quadrangle, but above Emerald Lake (east of the quadrangle, in the Pine River drainage) the dark, massive conglomerate is succeeded, with no structural break, by nearly pure quartzite-conglomerate or quartzite similar to rocks formerly considered as basal members of the Uncompahgre in the West Needles and the Grenadier Range. These quartzites are terminated by a fault against the Irving greenstones after only a few hundred feet of exposure, but the close relationship of these upper quartzites and those of the Grenadier Range is hardly to be doubted.

At several places on the north side of Tenmile Creek, in contact with the Eolus granite, a more or less mashed quartzite-conglomerate occurs, nowhere more than 20 feet thick, which grades upward into the fine-grained massive quartzites. It is lithologically very similar to the upper part of the conglomerate east of the Vallecito and may represent a small band that escaped the faulting or shearing which separated the rest of the conglomerate from the overlying beds.

UNCOMPAHGRE FORMATION.

Name and definitions.—The rocks of Algonkian age which constitute the main part of the Grenadier Range (figs. 5, 8, and 9, on the illustration sheet) and which are characteristically exposed in the canyon of the Animas (fig. 6) and in the upper portion of the Vallecito (fig. 5, to the right) are lithologically the same as those which occur in the Uncompahgre Canyon to the north and to which the name "Uncompahgre" was given in the Silverton folio.

Description.—The lower 1500 feet are massive quartzites of light colors, gray and white, and with the exception of occasional pebbly layers they are uniformly fine grained and compact. Above these massive rocks occurs a great series of alternating quartzites and slates or shales. The quartzites are often thin bedded, and even in more massive horizons individual layers are separated by shaly partings. The quartzites show but little variation in texture. Some are less purely quartzose than others, but the admixture of argillaceous material is nowhere great and the only marked differences which they show among themselves are those of color, the range being from the purest white through pinks, reds, purples, and grays to black.

Rocks which in the field were referred to as "slates," of a composition distinctly argillaceous, occur in several well-marked horizons and also associated with thin-bedded quartzites. In all cases they seem to have been clay rocks which have undergone varying amounts of dynamic metamorphism, resulting in the development of secondary minerals and structures, and of rocks whose outward appearances are often very different. On the one hand are soft black shales, while the other extreme is represented by compact massive argillites and andalusite-schists. In the deformation that has affected the whole Uncompahgre series the clay rocks have suffered the most. Secondary minerals, such as chiastolite, garnet, chlorite, sericite, etc., are frequently seen, and original structure and bedding are in many places completely obliterated by readjustments necessitated by the folding, which caused movements in the rock analogous to flowage. Schistosity also is developed in these rocks, both parallel to the bedding and cutting it at various angles. The quartzites, consisting essentially of silica, are naturally less favorable to the production of new minerals than are the slates or clay rocks, which contain various elements necessary for their formation, and hence the quartzites as a rule show simple induration through the deposition in them of silica. The entire series of rocks is traversed by fracture planes, now filled with secondary quartz, which have their best development in the brittle quartzites. These joints run through the quartzites in different directions and cause the rocks to break off in large slabs or blocks, forming high, precipitous cliffs.

The lithologic character of the rocks and the deformation to which they have been subjected have had a material influence on the topography. The Grenadier Range (figs. 8, 9, and the extreme left of 5) owes the ruggedness of its jagged peaks and their 2000-foot precipices to a massive quartzite, dipping steeply to the north, which extends in a great bow from the Animas Canyon across the Vallecito to the region about Mount Oso, at the head of Pine River. The slates, on the other hand, generally occupy gentle slopes and saddles, or have influenced streams in the carving of their valleys.

Distribution.—The Uncompahgre formation crosses the quadrangle in its northern portion. Its exposure is less than a mile wide in the neighborhood of Lime Creek, but from this point eastward the rocks exposed cover a wider and wider zone, and at the eastern margin of the quadrangle there are continuous outcrops for more than 8 miles. The rocks occurring in this area consist of the massive quartzites and slates only; in the southeast corner of the quadrangle the Vallecito conglomerate is found on both sides of the canyon of the Vallecito. The only other occurrence of the Uncompahgre is just south of Mountain View Crest, where there is a small patch of quartzite resting on the Eolus granite and intruded by small dikes of the same.

PALEOZOIC SECTION.

The section of Paleozoic rocks which occurs in the Needle Mountains quadrangle and adjoining regions is developed in two unequal parts. Prominent in the upper portion are the massive limestones, sandstones, and shales of the Hermosa formation, which has an average thickness of over 2000 feet. This formation is known, from the evidence of fossils, to be of Pennsylvanian (Upper Carboniferous) age. Above the Hermosa are about 200 feet of shales and sandstones, of peculiar greens and browns, which have been described as the Rico formation, of late Pennsylvanian age. Following the Rico conformably are about 1500 feet of red sandstones and shales of the Cutler formation that are of probable Permian age. At the base of the Hermosa is a thin horizon of reddish shales and chert nodules which has been named the Molas formation and whose age is also Pennsylvanian. Below these Pennsylvanian rocks are from 300 to 500 feet of sediments of rather varied character which have been separated, on lithologic grounds and by means of the fossils preserved in them, into three distinct formations, ranging in age from Cambrian to Mississippian (Lower Carboniferous). These have elsewhere been named, beginning with the lowest, the Ignacio, Elbert, and Ouray formations.

The accompanying somewhat generalized section of the Paleozoic rocks will serve as a basis for the discussion of various divisions, especially of the lower ones.

CAMBRIAN SYSTEM.

IGNACIO QUARTZITE.

Name and definition.—The lowest lithologic division of the Paleozoic section in the Animas Valley is made up of quartzites, and varies in thickness, in the area thus far examined, from a few feet to 200 feet. From layers near the middle of these quartzites a single generically determinable shell has been found, identified by Charles D. Walcott as *Obolus* sp.?, related to forms found in the middle or upper Cambrian at various localities in the western United States. Minute fragments of other undeterminable shells were found in association with the fossil named. From this evidence it is assumed that in this region, as elsewhere in Colorado, the Cambrian system is represented only by a thin series of quartzites belonging probably to its upper division, and for those the name Ignacio formation or quartzite was proposed in the Silverton folio, from the lakes in the Animas Valley above Rockwood, near which the formation is very well exposed. It is at present believed that all the Paleozoic quartzites beneath the "Salt shales," or Elbert formation, belong to the Ignacio, except a thin band locally developed at the base of the Elbert, which contains Elbert fossils; and, although the top of the Ignacio may be followed by a stratigraphic break, as shown by its complete absence in the country directly east of Vallecito Creek, there is ordinarily no angular unconformity and no recognized evidence of the exact plane representing this break in the local sequence of rocks.

Generalized section of Paleozoic rocks.

			Feet.	Feet.
Carboniferous.	Cutler.	19. Bright-red sandstone, lighter-red or pinkish grits and conglomerates, alternating with sandy shales and earthy or sandy limestones; nonfossiliferous	1500	
	Rico.	18. Dark reddish-brown sandstones and pink grits, with intercalated greenish or reddish shales and sandy fossiliferous limestones	300	
	Hermosa.	17. Limestones, grits, sandstones, and shales of variable distribution and development. Limestone, in thick, massive beds, predominates in the middle and upper parts of the section, the lower portion being mainly sandstones and shales, with a few limestone layers. Numerous invertebrate fossils occur in the shales and limestones	2000	
	Molas.	16. Shale, red and calcareous, containing numerous nodules of chert and saccharoidal limestone which are fossiliferous; becomes more sandy and shaly upward; different strata can not be distinguished. Rests on a weathered and broken surface of the uppermost Ouray limestone	75	
	Ouray.	15. Limestone, dull rusty brown, earthy, laminated, and wavy; fossiliferous. Yellowish, with large rounded cherts near top	25	3900
Devonian.		14. Limestone, massive, blue, not always continuous	5	
		13. Limestones, similar to 15, without cherts	20	
		12. Limestone, thin bedded, dense, bluish gray; certain layers extremely fossiliferous	25	
		11. Quartzite and sandy limestones; no fossils	4	
		10. Sandy limestone containing numerous crinoid stems and a few cup corals	25	
	Elbert.	9. Shale, fine red clay, not forming distinct outcrops	10	
		8. Limestone, dense, gray, conchoidal fracture in several beds, very variable in development and not always present; not fossiliferous	0–35	
		7. Sandstone or quartzite, variable in character; extremely fossiliferous in places	1	
		6. Thin limestones or calcareous shales containing pseudomorphs or salt crystals	30	
		5. Dense gray limestones with thin shale parting; in lower part fish scales have been found locally; forms ledges	30	
		4. Limestones, sandy and impure, with thin fossiliferous quartzites and shale layers; reds and yellows	25	210
Cambrian.	Ignacio.	3. Quartzite, massive, fine grained, beds 2–5 feet thick	25	
		2. Quartzite, thin bedded, fine grained, often with reddish shaly parting or sandy layers	20	
		1. Quartzite conglomerate, fine grained, in places giving way to red crumbling shales and sandstones, resting unconformably on pre-Paleozoic rocks	5–50	95
		Total		4205

Lithologic character.—The Ignacio consists of nearly pure siliceous strata, with some feldspar locally in the lowest beds. The greater part is fine grained, white, gray, or pinkish, and highly indurated. The lower portion is commonly a massive quartzite of prevalent pink or reddish color, while the succeeding strata are nearly white. Distinct bedding is common, as is an irregular jointing. Above this the strata are often wavy in bedding, with shale partings, in which mud cracks, trails, and other markings are common. These layers are friable sandstones in places. More massive quartzite layers generally succeed this series, but not in a thickness equal to those below.

At the bottom of the formation a true basal conglomerate is often found in hollows of the granite, schist, or Algonkian quartzite floor. The hard quartzites of the last named are most abundant among the pebbles, which range in size up to a rare diameter of 1 foot.

DEVONIAN SYSTEM.

The existence of Devonian sediments in the San Juan region was established in 1874 through a collection of fossils made by F. M. Endlich, of the Hayden Survey. The formation containing the invertebrate fauna discovered by Endlich has been named the Ouray limestone, and the beds immediately below it, containing an upper Devonian fish fauna, have been distinguished as the Elbert formation.

ELBERT FORMATION.

Name and definition.—The name Elbert formation is applied to a succession of calcareous shales, thin limestones, and occasional quartzite beds, aggregating less than 100 feet in thickness as a rule, and characterized by scanty remains of ganoid fishes. These strata occur below and conformable with the Ouray limestone, the main portion of which is of Devonian age, and are usually found resting upon the Ignacio quartzite, although a great stratigraphic break comes between these. The name is derived from Elbert Creek, a western tributary of the Animas, which drains the Ignacio Lakes and flows for some miles upon a broad bench where all the lower Paleozoic formations are well exposed. The formation was first described and named by Cross in 1904 (Am. Jour. Sci., 4th ser., vol. 18, pp. 245–252).

Lithologic character.—The formation is mainly composed of calcareous shales and thin, sandy limestones, varying in details of development from place to place. The beds are drab, buff, or yellowish in color. The shaly layers break up readily on exposure, so that outcrops are obscured by the resulting scales and thin plates. Quartzites are present, but are always very thin and subordinate to the calcareous and shaly portion.

The shaly beds are in many places characterized by pseudomorphous casts after salt crystals. They occur, as noted by Endlich, on the under side of slabs, as is natural, considering their origin. The crystals of salt must be supposed to have formed on or near the surface of the mud of a desiccating body of salt water, and to have been dissolved by the influx of fresh water and the crystal space filled by the sand or mud of a new deposit. The crystals are usually more or less clearly skeleton cubes with sunken faces. They range in size up to an inch or more in diameter. So abundant are these casts that they may be found at nearly every outcrop, but they are much more perfect and of larger size in some localities than in others.

An important variation in the lithologic character of the Elbert formation is in the appearance of dense, earthy, nonfossiliferous limestone, of conchoidal fracture, in several beds in its upper portion; each bed may be several feet in thickness. Thin shales usually separate the massive beds. This development was specially noted at Bluebird Park, south of Molas Lake.

The reddish clay or shale stratum at the top of the formation in the section already given seems to be a persistent feature.

Fossils.—The presence of fish plates, scales, and bone fragments in beds closely associated with the salt-cast shales was observed by Endlich, although he did not collect specimens for study. The locality at which the remains were found is on Endlich Mesa, about 1 mile south of the Needle Mountains quadrangle line. During the present resurvey strata carrying fish remains were found at several points, the most productive locality being on the east edge of Endlich Mesa, below and just north of a triangulation station of the Hayden Survey, situated on the Ouray limestone at its present northern limit on this border of the mesa. This station, which deserves a name and may be known as Devon Point, is where Endlich obtained the first Devonian invertebrates from the Ouray limestone and now becomes of further interest as furnishing fossils determining the age of the Elbert formation.

As noted in the section given above, a thin calcareous sandstone at the base of the Elbert at Devon Point carries a great many fragments of fish scales, plates, and bones, and similar remains are abundant in a thin, discontinuous quartzite stratum below the red shale at the top of the formation.

Fish remains have also been found in the course of the present work on a slab of quartzite in a talus pile near the limestone quarries south of Rockwood. The talus occurs below a bench where the Elbert formation is in place, but the stratum from which the fossil-bearing slab came could not be identified. A further locality carrying similar fossils is less than a mile south of Columbine Lake, in the Engineer Mountain quadrangle.

All the vertebrate remains obtained have been studied by Dr. C. R. Eastman, who has described them in the American Journal of Science, 4th ser., vol. 18, 1904, pp. 253–260. The slab from near Rockwood exhibits three specimens of a placoderm ganoid, *Bothriolepis*, a well-known genus of the upper Devonian, the species being apparently new. The same form is abundantly represented in the collection from Devon Point, where it is associated with other ganoid fishes of Devonian types, *Holoptychius* being the most prominent. From near Columbine Lake a scale apparently belonging to the genus *Coccosteus* was obtained.

These fish remains are characterized by Dr. Eastman as belonging to a distinct upper Devonian fauna, allied particularly, so far as known, to that of the Catskill and Chemung groups of New York and Pennsylvania and also to that of certain European formations.

Correlation.—No beds having the lithologic character of the Elbert formation have been found in other parts of Colorado, but according to Eastman the scanty fish remains obtained by Spurr from the "Parting Quartzite" of the Aspen district, Elk Mountains, indicate a close correlation between the two formations. This is rendered all the more plausible by the presence of the Ouray invertebrate fauna in the Leadville limestone, which overlies the "Parting Quartzite" throughout central Colorado. It is thus rendered probable that strata corresponding to the Elbert formation in age, however differing in composition, are present below the Ouray or Leadville limestone in many districts.

It is also possible that an equivalent of the Elbert exists in the lower Kanab Canyon, adjacent to the Grand Canyon of the Colorado, in Arizona, where Walcott found "placoganoid fishes of a Devonian type" in a formation consisting of "but 100 feet of purple and cream-colored limestone and sandstone, passing into gray calciferous sandstone above."

Distribution.—The Elbert formation is particularly well shown on the south slopes of the Needle Mountains in connection with the other lower Paleozoic formations. It caps several of the summits of Mountain View Crest and in such places the ground is covered by plates of thin limestone coated with well-defined casts of salt crystals.

About Lime and Stag mesas and at other similar localities the Elbert shales cause a bench or gentle slope between the ledge- or cliff-making Ouray and Ignacio formations.

The Elbert occurs beneath the Ouray east of the Vallecito Valley, but its beds are very much diminished in thickness, if present at all, under the Ouray patches of the Continental Divide and on the west slope of the West Needle Mountains. They are believed to be absent at these localities, as indicated on the map.

OURAY LIMESTONE.

Name and definition.—In 1900 A. C. Spencer, after studies in connection with the United States Geological Survey work, proposed the name Ouray limestone, from the town of Ouray, on the southern border of which is a prominent outcrop, 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 then 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 at a number of localities a distinctive Mississippian (Lower Carboniferous) fauna has been observed in the upper part of the most prominent limestone ledge of the formation. Since it is impossible to draw a line between the two portions, the Ouray becomes preeminently a lithologic unit transgressing the faunal boundary between the Devonian and Carboniferous systems.

Lithologic character.—The Ouray formation as at present known has a thickness varying from 100 to 250 feet. The upper and major part of the formation is massive limestone, either in one bed or with very thin intercalated shales, so that mesas, benches, and prominent cliffs of the limestone are characteristic topographic forms. Below the more massive portion a third or less of the section is made up of beds of limestone, with distinctly 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 by 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 color and character occurring only near the base of the Ouray. No change in character of the limestone occurs toward the top, unless a prevalence of coarse-grained, rotten beds, observed locally, and belonging to the Carboniferous portion, in some places at least, be found to be characteristic. The conditions of sedimentation seem to have remained the same and deposition seems to have been continuous from Devonian into Carboniferous time.

The Carboniferous portion of the Ouray is at present indistinguishable lithologically from the Devonian. Its existence was detected through the presence of Mississippian invertebrate fossils in the chert pebbles of the succeeding formation. During the investigation as to the origin of these pebbles Dr. George H. Girty found that some of the fossils contained in them occurred also in the uppermost strata of the massive limestone hitherto supposed to belong wholly to the Devonian. The localities at which the Carboniferous forms have been found in the limestone are few—mainly near Cascade Creek, in the Engineer Mountain quadrangle. Chert pebbles have been but rarely found in place in these upper horizons, and this fact, together with their abundance in the succeeding Molas conglomerate, shows that an interval of erosion followed the formation of the limestone. In the area thus far studied this erosion effected the removal of nearly the whole of the chert-bearing portion of the Mississippian and an unknown amount of the subjacent massive rock, but nowhere cut away enough of the Ouray to make angular unconformity noticeable except in small detail. At no known point has the erosion penetrated to the horizon of Devonian fossils in the massive limestone. Inasmuch as neither that horizon nor that of the Carboniferous forms is recognizable in many sections the question as to how much, if any, of the Ouray should, in such cases, be referred to the Carboniferous is a matter of doubt.

Fauna.—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. Fossils have been obtained at Ouray and at several localities in the Needle Mountains, Engineer Mountain, and Durango quadrangles, as well as at the point where Endlich first found a few characteristic species, not far south of the Needle Mountains quadrangle.

The invertebrate fauna of the Devonian portion of the Ouray has been fully described by George H. Girty and compared with similar faunas hitherto collected in Colorado, but not separated from Carboniferous.

Twenty-eight species or varieties are discriminated in his report, and others have since been obtained. Nearly all classes of organic life are represented in the fauna, but brachiopods and mollusks are most abundant. Some of the more important species are—

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

In addition to the invertebrate fauna a single shark's tooth was found, which has been made by O. P. Hay the type of a new species, *Cladodus formosus*. It is said to be most closely related among known species to certain Pennsylvanian forms, such as *C. springeri* of Russia. The tooth was found on Lime Mesa under conditions making it probable that it came from the Devonian portion of the Ouray, although the limestone fragment containing it was not in place.

Correlation.—The Devonian fauna of the Ouray limestone has been shown by Dr. Girty to be represented more or less fully in older collections from various parts of Colorado, notably in 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 in the San Juan region will not be possible, however, until further examinations have been made. Dr. Girty says:

> In general the Devonian fauna of the Ouray belongs to upper Devonian time. It is but distantly related to the Devonian faunas of New York, and its relation to those of the Mississippi Valley, or even to 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.

CARBONIFEROUS SYSTEM.

MISSISSIPPIAN SERIES.

UPPER PART OF OURAY LIMESTONE.

As has been shown in describing the Ouray limestone, it is known that a Mississippian fauna occurs in the upper part of that formation, in certain localities, separated from the uppermost Devonian fossiliferous horizon by about 50 or 75 feet of massive limestone in which no fossils have thus far been discovered. The erosion in the interval following Mississippian sedimentation removed those strata completely over large areas. As neither the upper Devonian nor the basal Carboniferous horizon is everywhere fossiliferous, it is impossible to decide in many places whether the upper portion of the Ouray limestone ledge is Carboniferous or not.

From the great quantity of Carboniferous chert nodules in the succeeding formation it must be assumed that above the known horizons of the Ouray there once existed in this region a considerable thickness of chert-bearing limestone of Mississippian age. It seems not unlikely that somewhere on the slopes of the San Juan Mountains notable remnants of these beds may be found.

From a comprehensive study by G. H. Girty of all Carboniferous invertebrate fossils thus far collected in Colorado, and available to him, the following brief summary concerning the Mississippian of the San Juan region may be made. Thirty-two determinable species have thus far been obtained from the chert pebbles of the Molas formation, which were derived from the eroded beds, and from two localities in the upper zone of the Ouray limestone. This fauna is closely similar to that of the Wasatch limestone of Utah and the Madison limestone of the Yellowstone National Park. It is also similar to the small faunas obtained in Colorado from the Leadville limestone in the Mosquito Range, at Aspen, Crested Butte, and near Salida, and that from the Millsap limestone of the Front Range near Canyon and in Garden and Perry parks. Dr. Girty concludes that the Leadville limestone, which was originally assigned to the Mississippian because of fossils found it its upper part, and the Ouray limestone, which has been considered Devonian on account of the fauna in its lower and middle portions, are equivalent. He thinks that careful search would in many cases show both faunas where only one is now known.

The most diagnostic forms are—

Zaphrentis tantilla.	Spiriferina solidorostris?
Menophyllum ulrichanum.	Eumetria marcyi?
Schuchertella inæqualis.	Camarotœchia metallica.
Chonetes illinoisensis.	Myalina arkansasensis?
Productella concentrica.	Myalina keokuk.
Productus parviformis.	Straparollus utahensis.
Productus lævicosta.	Phillipsia peroccidens.
Spirifer centronatus.	

PENNSYLVANIAN SERIES.

MOLAS FORMATION.

Name and definition.—The name Molas formation was proposed in the Silverton folio for the lowest of the three formations of the Pennsylvanian series distinguished in the Animas Valley and adjacent regions. The name is derived from Molas Lake, which lies on the bench at 10,500 feet, west of the Animas Canyon, in the extreme northern part of the Needle Mountains quadrangle. The lake basin is partly excavated in the Molas beds and they are well exposed for some distance to the south.

The Molas formation is distinguished as a cartographic unit on lithologic grounds, being a well-characterized element in the Carboniferous section, and because it records, in certain peculiarities of its sediments, important events of the preceding interval of erosion, including the almost total destruction of a Mississippian formation. There may be a further reason for separating the Molas and Hermosa formations in certain observed faunal differences, which are, however, as yet not sufficiently established to warrant laying much stress upon them.

The Molas beds were not included in the original definition of the Hermosa formation by A. C. Spencer, though the Hermosa was said to rest on the Ouray limestone. In the localities examined before that definition was formulated there was, in fact, a hiatus in the observations, the thin Molas beds being nowhere well exposed.

The Molas formation was defined in the Silverton folio as a thin series of reddish calcareous shales and sandstones, with many chert pebbles and some of limestone, quartzite, and other rocks, and with thin fossiliferous limestone lenses, the fossils showing intimate relations to those of the lower Hermosa limestones. It occurs immediately below the Hermosa formation and rests upon a surface of erosion. It represents the earliest sediments of the Pennsylvanian in this region.

Lithologic character.—The Molas formation is specially characterized by its deep-red, friable, sandy strata, which are variably calcareous and often shaly. They are seldom very distinctly bedded and disintegrate so rapidly on weathering that good exposures are rare. In the lower part of the formation dark chert nodules abound, in many cases making a large part of flat lentils or discontinuous layers. Many of these cherts carry a Mississippian invertebrate fauna, the origin of which has already been discussed. In the uppermost part of the formation, on Stag Mesa, some thin limestones contain the fauna described in a succeeding paragraph, which is believed to characterize the Molas beds.

The best section of the formation thus far observed is situated on the southwest slope of the Needle Mountains, on the south side of Tank Creek. At that locality there is a continuous section, about 75 feet in thickness, representing the whole formation, as there developed, between the Ouray limestone and the Hermosa complex. There is no distinct stratification in the section. At the base is a zone of gradation into the Ouray limestone, for the upper zone of the latter is much broken up, with the red calcareous mud of the Molas filling the interstices. This relation of the formation is very common. For some feet above this transition zone there is a chaotic mixture of chert and limestone fragments, with not a few of bluish or white quartzite, but none of granite or schist. In all the lower part of the section much of the material is an impure limestone, reddish in color, but with the saccharoidal texture of the Ouray. It is probably a calcareous sandstone. The matrix in which the fragments of chert, quartzite, and limestone are held is a red marl-like material. There are in places indications that a calcareous mud was broken up before consolidation and was worked over with the fragments of foreign rocks. From the base upward the section becomes more and more sandy, but chert fragments were found almost up to the fossiliferous limestone of the Hermosa.

While the Molas beds exhibit much variability in texture, the section described is in most respects characteristic.

The chert pebbles which are one of the most notable features of the formation are so abundant locally as to form dark conglomerate layers. These are in many places not continuous. The chert is distributed through the whole formation, and on the inclined mesas south of the Needle Mountains, most of which have scarps of the Ouray limestone, the chert pebbles form, over large areas, almost continuous coatings of residual material, mingled with some of the reddish sandy shale. Many small isolated remnants of the Molas also occur on these mesas.

The cherts are, as a rule, well-rounded pebbles up to 6 inches in diameter. They are dark gray, green, red, white, or nearly black. Some are banded, some homogeneous. In only a portion of them can fossils be found.

Fauna.—On Stag Mesa some thin, discontinuous limestone beds rich in fossils were found intercalated in red and highly ferruginous sands of the Molas and only a few feet below the characteristic limestone at the base of the Hermosa. At no other point have the fossils of the Molas yet been discovered.

The fossils mentioned have been studied by George H. Girty, who has made the following summary statement concerning them:

The fauna of the Molas formation, though at present imperfectly known, comprises representatives of the echinoids in *Archæocidaris triplex?*, of the bryozoa in *Rhombopora lepidodendroides*, of the brachiopods in *Rhipidomella pecosi*, *Spirifer boonensis?*, and *Seminula subtilita*, and of the pelecypods in *Myalina perniformis?*. The *Rhombopora*, *Spirifer*, and *Seminula* occur also in the Hermosa formation, and in the case of the latter with the same varietal modifications and with equal abundance. Thus the Molas fauna is seen to be related to that of the Hermosa formation, but contains no species in common with the Ouray limestone. Some points of individuality distinguish the Molas fauna from that of the Hermosa, but it can not be conjectured how far this distinction would be borne out by full collections.

Stratigraphic relations and distribution.—In the Silverton, Needle Mountains, Engineer Mountain, and Durango quadrangles the Molas formation rests upon a surface due to the erosion by which the Mississippian rocks were almost completely removed. Although it has not been observed overlying any other formation than the Ouray limestone, the nature of the case permits the supposition that somewhere in the region adjacent to the San Juan Mountains it must transgress the lower Paleozoic formations and rest upon Algonkian quartzites, granite, or schist.

From the nature of the Molas beds they waste away rapidly on exposure. At the base of the high Hermosa escarpment on the west side of the Animas is a bench underlain by the Ouray limestone. The surface of this bench represents the Molas horizon. Red sandy outcrops occur here and there and chert nodules are scattered about in many places, but talus and other débris conceal the contact with the Hermosa.

On the southern slopes of the Needle Mountains are several dipping mesas caused by the Ouray limestone, and in patches scattered over the surface are remnants of the Molas, represented mainly by rounded chert pebbles.

The Molas and Hermosa seem to be thoroughly conformable, and probably the former is the product of the first epoch within the long period of Pennsylvanian sedimentation. The red color of its sediments and the other peculiarities mentioned characterize it.

HERMOSA FORMATION.

Name and definition.—The Hermosa formation was named and defined by A. C. Spencer in 1900. It includes the series of alternating limestones, shales, and sandstones, having a maximum thickness of 2000 feet, which occurs on the northern and southern flanks of the San Juan Mountains. It lies between the Molas and Rico formations. An extensive invertebrate fauna, especially characterized by brachiopods, is found in the formation from bottom to top. This fauna is distinctly Pennsylvanian in character. The name is derived from Hermosa Creek, a tributary of Animas River which traverses a large area of these rocks in the Engineer Mountain quadrangle.

Description.—The Hermosa presents a variable development of limestone, sandstone, and shale in different districts. Thus at Rico there is a fairly well-defined division into three sections, the lower consisting chiefly of sandstones and shales with but little limestone, the middle portion being rich in massive limestone beds, the upper containing mainly black and gray shales alternating with green grits and sandstones and with a few limestone layers.

In the Animas Valley, near the mouth of Hermosa Creek, the lower third of the complex is made up of green sandstones and shales with some gypsiferous shales, while the rest of the formation shows limestone layers distributed throughout. Along the great scarp facing the Animas for 10 miles in the Engineer Mountain quadrangle the limestones become more and more prominent and certain bands are very thick.

In the southern part of the Needle Mountains quadrangle the formation has essentially the same characteristics as on the western side of the Animas Valley above Rockwood. In the northwest corner of the quadrangle the limestone members are thinner, but distributed with great regularity in the section.

The limestones are usually massive, bluish gray in color, and commonly contain bituminous matter, causing a distinct odor when struck by the hammer. Many layers are rich in fossils, while others appear to be destitute of them.

The sandstones are generally fine grained, gray or greenish, consisting largely of quartz but in many cases rich in feldspar. They are massive or thin bedded with shale partings. The cement is calcareous as a rule and the green color is due to an amorphous substance, the character of which has not been determined.

The shales vary from those which are greenish and sandy in character to dark, calcareous, bituminous varieties.

With all this variety in constitution the basal stratum of the Hermosa over the entire area examined is constant. It is a highly fossiliferous limestone somewhat less than 15 feet in thickness. The uppermost strata are not so well known, but in the Rico Mountains they consist of fine-grained micaceous, greenish, sandy shales beneath which is a thin but persistent dark limestone filled with the minute shells of *Triticites secalicus*, formerly called *Fusulina cylindrica*.

Few members of the Hermosa complex reach a thickness of 100 feet. Some limestones and shales attain that figure, but thicknesses ranging from 10 to 50 feet are much more common. Individual strata change laterally, both in character and in thickness. Under these conditions it has been found impracticable to subdivide the complex into smaller lithologic units for purposes of mapping. As will appear from the statements concerning the fauna, no division lines on that basis can be suggested.

Fauna and correlation.—Dr. Girty has summarized his views as to the fauna and correlation of the formation as follows:

The fauna of the Hermosa formation is distinctly Upper Carboniferous, or Pennsylvanian, in age. It contains such characteristic species as—

Triticites secalicus.	Spirifer boonensis?
Lophophyllum profundum.	Spirifer rockymontanus.
Campophyllum torquium.	Spirifer cameratus.
Chætetes milleporaceus.	Squamularia perplexa.
Archæocidaris ornata.	Spiriferina campestris.
Fistulipora carbonaria,	Spiriferina kentuckyensis.
Rhombopora lepidodendroides.	Ambocœlia planiconvexa.
	Seminula subtilita.
Prismopora serrata.	Limipecten occidentalis.
Chainodictyon laxum.	Acanthopecten carboniferus.
Stenopora carbonaria.	Edmondia subtruncata.
Orthotetes crassus.	Allerisma terminale.
Meekella striaticostata.	Chænomya leavenworthensis.
Chonetes mesolobus.	Naticopsis altonensis.
Productus gallatinensis.	Euomphalus catilloides.
Productus cora.	Bellerophon crassus.
Productus nebraskensis.	Patellostium bellum.
Productus punctatus.	Phillipsia major.
Marginifera wabashensis var.	

If the formation be divided into three portions, especially as the division was carried out in the Rico region, the fauna of each is to a certain extent characteristic. That of the lower division consists almost altogether of brachiopods. In the middle division a number of gasteropods are introduced, while in the upper, in addition to brachiopods and gasteropods surviving from the middle division, a considerable force of pelecypods appears. The brachiopods remain nearly constant in number, but form a diminishing proportion of the entire fauna. The brachiopodous representation remains fairly uniform, though some changes occur in species and abundance. The lower bed especially is often characterized by *Productus gallatinensis*, *Productus inflatus*, and a large variety of *Spirifer* of the *rockymontanus* type.

The fauna of the Hermosa formation occurs in also the Weber limestone and lower Maroon formation of the Crested Butte district, and in the Weber formation of the Tenmile and Leadville districts. From this fact and the similarity in stratigraphic occurrence a correlation of these formations appears to be justified. The Hermosan fauna represents early Pennsylvanian sedimentation, and it is probably older than the upper Coal Measure faunas of the Kansas and Nebraska sections.

RICO FORMATION.

The formation succeeding the Hermosa in the normal section of the San Juan region was first identified in the Rico Mountains and was named and described in 1900 by A. C. Spencer in the report on that area. It is a thin formation, not easily identified in regions of poor exposures, and though its presence in the northwest corner of the Needle Mountains quadrangle and in the adjacent parts of the neighboring quadrangles has been demonstrated by Mr. Spencer through the finding of a few fossils, it was not possible to trace it or to define its thickness. It is assumed from the existence of fossils that the formation is present in a narrow band between the Hermosa and Dolores formations, as shown by the map.

The Rico formation, in the mountains from which it derives its name, is a series of sandstones and conglomerates with intercalated shales and sandy fossiliferous limestones, about 300 feet in total thickness. Lithologically it resembles the red-bed complex above it more than the Hermosa below, but its fossils are clearly of Carboniferous type, and related to those of the Hermosa. The general characteristics of the formation near Rico are, first, its calcareous nature, in which it resembles the strata above and below; second, the arkose character and the coarseness of its sandstones, in which respect it differs from the Hermosa and resembles the Dolores; and, third, its chocolate or dark-maroon color, which contrasts sharply with the gray or green of the Hermosa and is more or less distinct from the bright vermilion of the Dolores. The color distinction was found to be insufficient for mapping purposes, even in the restricted area of the Rico Mountains.

PERMIAN (?) SERIES.

CUTLER FORMATION.

Name and definition.—The sandstones, grits, conglomerates, shales, and calcareous beds, mainly of reddish color, occurring between the Rico beds and the Triassic Dolores strata, form the greater part of the well-known "Red Beds" section of the region and have been hitherto provisionally included in the Dolores formation. In the Telluride and La Plata folios and in other publications the Dolores has been consistently defined as including the Triassic strata of southwestern Colorado, with the statement that fossils demanding a reference to the Triassic have been found only in the upper part of the "Red Beds" section. On the western and southern slopes of the San Juan Mountains no stratigraphic break in the "Red Beds" has been found, but the field work of 1904 in the Ouray quadrangle, on the northern side of the mountains, revealed a notable angular unconformity occurring immediately below the most commonly fossiliferous bed of the Dolores formation. Through this unconformity the Dolores strata may be seen to transgress more than 1000 feet of older "Red Beds" and several hundred feet of the Hermosa formation, the full extent of the unconformity being obscured by erosion.

In view of these facts, the strata between the Rico beds and the base of the Triassic are distinguished as a formation and named from Cutler Creek, which enters Uncompahgre River from the east about 4 miles north of Ouray and along which a considerable part of the section is well exposed. As the Cutler beds are conformable with the underlying Hermosa and Rico strata they are provisionally referred to the Permian series. It is recognized, however, that the Cutler formation may belong, wholly or in part, to the Pennsylvanian series, the stratigraphic break above them being in that case much greater than the observed field relations indicate. No fossils have been found in the Cutler beds.

The name Dolores will continue to be applied to the Triassic strata as originally defined, embracing the fossiliferous conglomerates and overlying beds.

Description.—The Cutler formation is a complex of sandstones, grits, and conglomerates, alternating with sandy shales and earthy or sandy limestones. The greater part of the formation has a bright vermilion-red color, but there are some pale-red or pinkish grits and conglomerates. A calcareous cement characterizes nearly all the strata. Individual beds of uniform character are in few cases more than 25 feet thick, and the formation shows great lateral variation in composition and thickness.

Distribution.—The Cutler formation occupies the extreme northwest corner of the quadrangle. Its southwesterly dip brings it against the Telluride conglomerate with angular unconformity a few miles to the north, in the Silverton quadrangle, and the formation is but partially represented in the Needle Mountains quadrangle. To the southwest, in the Engineer Mountain quadrangle, the "Red Beds" of the Cutler are very prominent and they also occupy large areas in the Rico, La Plata, Durango, and other quadrangles on the southern slope of the San Juan Mountains, while in the valley of Uncompahgre River, in the Ouray quadrangle to the north, their unconformable relation to the Dolores is best shown.

DISTRIBUTION OF THE PALEOZOIC ROCKS.

The most conspicuous occurrences of the Paleozoic sedimentary rocks are at the northwest and southwest corners of the quadrangle. The more extensive section is that to the northwest, though it probably does not represent the maximum thickness of the formations nor their most characteristic development; that on the south is a part of the complete section traversed by the Animas Valley, in which all formations to the Wasatch (Eocene) are exhibited. On the map the section to the northwest is made to include the Rico formation, for, although it has not been positively identified here, it has been recognized in the immediately adjacent parts of the Silverton and Engineer Mountain quadrangles, and from these known occurrences its position in the present quadrangle was determined. The small patch of the Cutler formation represented in the extreme corner above the Rico is also very poorly exposed, and it has been described from better occurrences outside the quadrangle. Between the Rico and the older Paleozoic rocks the Hermosa is exposed on both sides of the east fork of Lime Creek in a fire-swept region almost bare of green timber. The alternation of hard limestones and sandstones with soft shales has helped to develop a bench- or step-like topography, and individual horizons may be followed by the eye for several miles in and out among the hills. With the exception of the Molas the older Paleozoics are poorly exposed and do not have here their usual development. The Ignacio is altogether absent except at two places, south and east of Molas Lake, where it is in the form of a coarse conglomerate 50 feet thick, indicating that coastal conditions probably prevailed there at the time of the Ignacio sea. Southwest of Snowdon Peak a considerable patch of Ouray limestone rests directly upon the Archean rocks and upon it lies a small remnant of the Molas.

The most characteristic sections of the older formations, from the Ignacio to the Molas, are found in the southern third of the quadrangle. These occurrences, of which Lime and Stag mesas may be taken as examples (figs. 1 and 2 on illustration sheet), present strata resting on the granite floor with a gentle southerly or southwesterly dip and are directly connected with the section of Paleozoic and later sedimentary rocks exposed on both sides of the Animas Valley. Each of the formations is exhibited in very typical exposures. The Ignacio commonly forms broad benches covered by loose blocks of quartzite split from the solid rock by frost. This is particularly true of the isolated patches capping the higher points of Mountain View Crest, West Silver Mesa, and the two occurrences east of Sheridan and Emerson mountains. Buff-colored, rounded hilltops or slopes characterize the few occurrences of the Elbert shale where it is unprotected by the Ouray, as at Overlook Point and at the head of Virginia Gulch. Elsewhere the Elbert is at many points obscured by its own débris or that from the Ouray above it and may not be easily detected.

The Ouray limestone forms the prominent escarpment of Lime Mesa (shown in fig. 1), as well as those of West Silver Mesa and Stag Mesa (fig. 2). The first two mesas are almost entirely covered by the Ouray, in which there are a considerable number of sink holes and other erosional features, such as the ribbed surfaces, or "karrenfelder," common in limestone regions.

On the surface of many of these mesas lies considerable material derived from the Molas, and at a few points Molas in place. The loose material consists of residual chert nodules and red clays. The most extensive exposures of the Molas are on Stag Mesa, where the development is less shaly than conglomeratic, the bowlders and pebbles consisting of chert and limestone. This phase of the Molas also occurs on the south side of Canyon Creek, near the western boundary of the quadrangle, and fossils were obtained at this locality.

In this area good exposures of the Hermosa are almost entirely lacking, and the most noteworthy feature of the region occupied by the formation is the number of landslides in which its rocks have been involved, both southeast and northwest of Canyon Creek. Landslide or glacial débris covers much of the region occupied by these rocks and the characteristic cliff exposures presented on the west side of the Animas Valley are here almost entirely absent; the gentle lower slopes are soil covered and the steeper hillsides south of Pole and Canyon creeks support a dense forest growth.

Although of small size, the occurrence at Devon Point, on Endlich Mesa, of the three oldest Paleozoic formations is one of the most important. It was here that Endlich discovered the Devonian invertebrates of the Ouray limestone and noted the existence of fish remains in the underlying shales now assigned to the Elbert formation.

Besides these occurrences Paleozoic rocks are preserved in the southeast corner of the quadrangle, east of the Vallecito, and are also represented on the Continental Divide, in the northwest corner, by two small patches of Ouray limestone, one of which, near the trail to Bear Creek, is nearly covered by San Juan tuff. In both of these localities the Ignacio formation is significantly absent, and on the Continental Divide the Elbert as well has not been found. East of the Vallecito the presence of the Hermosa is known only from a few outcrops, as it is covered by a thick mantle of soil and vegetation.

TERTIARY SYSTEM.

EOCENE (?) SERIES.

TELLURIDE CONGLOMERATE.

Name and definition.—The Telluride conglomerate is a well-marked formation which underlies the San Juan tuff and was laid down in the period immediately preceding the beginning of the long succession of volcanic eruptions in this region. It includes the sediments first deposited after the tremendous erosion that prepared the peneplain on which it rests. It was first identified in the Telluride quadrangle, where it is finely developed and exposed, and in the Silverton folio the formation was renamed after that area, since the term San Miguel, under which it was originally described, was preoccupied for a Cretaceous formation in Texas.

Description.—The Telluride formation varies greatly in texture and thickness, ranging from a thin, coarse conglomerate in the Silverton and Needle Mountains quadrangles to a complex of fine-grained conglomerates, sandstones, and shales about 1000 feet in thickness as developed in Mount Wilson, on the western border of the Telluride area. Nearly all stages of this change can be studied in the distance of 17 miles between the eastern ledges of Grand Turk, north of Molas Lake, and the exposures on Mount Wilson. The formation is described in detail in the Telluride folio. It is made up of detritus of schists, granite, Algonkian quartzite, and slate, and lesser amounts of the harder sediments of the Paleozoic formations, in particular of limestone. The bowlders of the conglomerate often exceed 1 foot in diameter, but are generally only a few inches. Many are well rounded, but subangular fragments are common, especially of the local material, which has not been transported far. The isolated exposures of the conglomerate found east of Animas River, about the head of Whitehead Gulch, are naturally made up of local materials.

Stratigraphic relations and distribution.—As stated above, the Telluride formation conformably underlies the San Juan tuffs. While no volcanic matter appears in the Telluride proper, there is a zone of transition in some places, the pebbles of quartzite or schist being scattered through a few feet of the tuff and sporadically for a hundred feet or more. In general the line is sharply defined through a sudden change in materials. The impression is that the mechanical process of deposition was practically continuous, but that there was a sudden change in the nature of the débris after the outburst which began the great volcanic period.

The only occurrences of the Telluride conglomerate in the Needle Mountains quadrangle are a few exposures near the heads of Whitehead and Elk creeks and at the divide between the two. The relation of the conglomerate to the older rocks indicates that in general it occupies the beds of watercourses that existed when the conglomerate was being formed. The materials consist of coarse gravels or bowlders, as a rule unstratified and in many cases only partly rounded or waterworn, indicating a near-by source. The bowlders and the coarse matrix in which they rest are almost entirely composed of quartzites from the Algonkian area to the south.

Age and correlation.—The Telluride conglomerate has yielded as yet no fossils by which its age may be determined. The reference to the Eocene here is in accord with the assignment in the Telluride and Silverton folios, no additional data bearing upon the question having been discovered. The conglomerate is later than the great orogenic movement which affected the entire older sedimentary section in this region, and also later than the enormous erosion which produced the peneplain on which the conglomerate rests. The observed angular unconformity at its base transgresses the section from the Algonkian to the Mancos shales (Cretaceous).

The relations mentioned suggest a correlation of the Telluride conglomerate with the Arapahoe formation of the Denver region, and such a comparison carries with it the further correlation of the San Juan tuffs with the Denver beds, which are composed largely of andesitic débris. Both the Arapahoe and Denver formations are fossiliferous, and according to current paleontological opinion they should be considered Cretaceous, though separated from the Laramie proper by an interval of great orogenic disturbance and subsequent erosion. The Denver beds have, in fact, an equivalent, indicated by plant remains, in the Animas beds of the section well shown a short distance below Durango, but there is no conglomerate comparable with the Telluride in that section and the correspondence of the San Juan tuffs and the Animas beds is purely lithological, so far as known. Under these circumstances it is thought best to await further investigation in the San Juan region before making any positive correlations of the Telluride and San Juan formations with similar formations in other districts. For a discussion of this question the reader is referred to the Telluride folio and to the monograph on the "Geology of the Denver Basin" (Mon. U. S. Geol. Survey, vol. 27, 1896).

QUATERNARY SYSTEM.

Deposits of subaerial origin of Pleistocene and Recent age in the Needle Mountains quadrangle fall under three heads: Glacial débris, valley alluvium, and rock streams. The landslides will also be described here, though of exceptional character and not properly to be regarded as sedimentary.

GLACIAL DÉBRIS.

Glacial deposits occur throughout the region, but in only a comparatively few places have they been indicated on the map. Elsewhere they may often be recognized, but they are not of sufficient importance to represent, since by so doing the relations of the massive rocks which underlie them would be obscured. In many cases in the larger valleys glacial gravels have been recognized which do not appear to have been deposited directly by the ice, but seem to have been worked over and redistributed by later stream action; some undoubtedly represent contemporaneous "outwash" gravels. They have been left on many narrow, steep ridges with outcrops of rock in place in the ravines on either side or as knobs projecting through them, as in the stream entering the Animas at the lower end of Elk Park and heading to the north of Snowdon Peak. Evidently the gravels were once thick near the mouths of the high basins where the descent is rapid to the main valley. These deposits probably represent the morainal material from the basin glaciers and belong to the later periods of glaciation.

The most extensive moraines in the region are those which are found at various points on the plateau south of Needle Creek. Near the head of the Virginia Gulch drainage there are two that possess distinct boundaries and are of considerable size and very typical form. Probably more extensive accumulations occur on the hillside between Tank and Canyon creeks, but later landslides have covered or otherwise obscured them, so that a long lateral moraine on the northwest side of Canyon Creek and a corresponding one on the southeast side are the only ones that can now be recognized. Less than a mile west of the boundary of the quadrangle, both north and south of Canyon Creek, accumulations of glacial gravels occur whose position and materials indicate that they are lateral moraines deposited by the glacier which occupied the Animas valley and canyon. It is possible that much of the morainal material which is found generally over the gentle slopes below Stag Mesa and north of Canyon Creek may also have been derived from this source.

Small terminal moraines occur near the mouths of many of the larger streams that enter the Animas. Some of them, as in Needle Creek, have been almost completely destroyed by subsequent stream action. In the northwest section, east of Lime Creek, near the laccolith of granite-porphyry, is a moraine of some size; three small ones east of the canyon of Lime Creek were probably laid down by a small glacier heading in the region south of Snowdon Peak.

Extent and character of glaciation.—Only partial evidence is to be found in the Needle Mountains quadrangle as to the extent of the glaciation to which the region was subjected. Judging from the morainal material alone one would be led to suppose that the ice was restricted to the smaller valleys and that no great glaciers filled the large valleys of the Animas, Florida, and Vallecito. In other words, the conditions prevailing in the Needle Mountains during that part of the Glacial period of which the best records are left appear to have been nearly the same as those which exist at the present time in the Alps and similar mountain regions. It is known, however, from the existence of well-defined terminal and lateral moraines in the Animas Valley, that during the last recognized period of maximum glaciation an ice stream descended the valley as far as what is now the site of the town of Durango, some 25 miles southwest of the Needle Mountains, and that glaciers of corresponding magnitude occupied the Vallecito and the valley of the Florida. The rock débris found in the terminal moraines consists very largely of material derived from the Needle Mountains. The grooved and polished surfaces of bare rock that are to be seen everywhere throughout the Needles, except on the sharper peaks and ridges, together with the foregoing facts, indicate that while glaciation was at its height the greater part of the Needle Mountains area was buried beneath a thick mantle of ice and snow, from which only the higher summits projected. So far as known, no strictly limiting moraines belonging to this maximum period are to be found within the area of the present quadrangle, but the greater part of the drift which lies on the slopes south of the Needles and west of Snowdon Peak is to be regarded as the material deposited during the recession of the ice.

The relatively small accumulations of glacial materials which possess the distinct forms of terminal or lateral moraines are believed to have been deposited, as has been said, by the small hillside or valley glaciers that lingered for a considerable time after the region as a whole became free from ice.

VALLEY ALLUVIUM AND DETRITAL CONES.

Notwithstanding the youthfulness of the Needle Mountains nearly all the larger valleys contain alluvial deposits. Undoubtedly much of the material is of glacial origin, but it has been very generally worked over by the streams in the main valleys or cut through by the lateral streams and mixed with their débris. This redistribution has been more complete in some places than in others and makes it difficult to draw sharp lines between moraines and stream gravels. Well-stratified and, locally, terraced gravels occur nearly continuously in that portion of the Animas Canyon which is included in the Needle Mountains quadrangle. The materials are of local origin and have been supplied principally by the branch streams that have built large fan-like deposits of detritus at their mouths.

More complex accumulations are found in Vallecito Creek from the base of The Guardian to a mile or more below the mouth of Johnson Creek. The large area in this valley represented on the Hayden map as moraine is a mixture of probably true moraine, river gravels, and torrential fans, the last being the most extensive at the surface and the glacial deposits beneath. In the more southerly portion the deposits are fluviatile, covering a broad, flat area nearly at the present stream level and traversed by old stream channels. From near bench mark 9577 northward the conditions are quite different. The stream flows for a large part of this distance in a narrow channel 50 feet or more deep and often with rock walls and a rock bottom. Above the stream, on both sides, is a broad bench covered with detritus and often swampy. North of the mouth of the creek which enters the Vallecito from the east opposite The Guardian this detritus is in the form of hummocks and mounds which suggest glacial origin. These facts seem to indicate that at one time extensive moraines existed here, but that since their formation the main stream has fed upon them and the two or three large tributaries entering in this vicinity have nearly obliterated them, either by the removal of old material or the addition of new in the form of broad alluvial fans. The result has been that little, if any, of the accumulations can now be distinguished as of true morainal form, and it has been necessary to class the whole with the fluviatile deposits. The alluvium of Needle Creek is undoubtedly of this character, while that of the smaller streams represents the overloading by detritus from the fans of the lateral ravines and gulches.

LANDSLIDES.

Evidence is found in the southwest corner of the quadrangle that landslides have materially changed the character of the post-Glacial topography. They have been confined entirely to the areas occupied by the Hermosa formation, where the alternation of shale with massive limestone or sandstone leads to favorable conditions for landslips. The principal region in which such accumulations are found is that immediately adjoining Canyon Creek and its tributaries, Camp Creek and Pole Creek. They may be recognized by the uneven surface, due to great blocks of rock tilted at various angles, with finer materials partly filling the spaces between them. No regular drainage system exists in such areas, but stagnant pools, morasses, or deep trenches are common. The slides are of considerable antiquity, and the disordered heaps of rock and soil have yielded somewhat to the influence of the weather and have long been covered by forest or grass. Even the scars on the hillsides at the points from which the slides took place have as a rule been healed and in many cases the places where solid rock occurs may be recognized only by steeper slopes and more even surfaces.

In nearly all cases the slides seem to have come from the sides of the steep ridges separating the smaller valleys and ravines or at the heads of the streams. This seems to be clearly the case on both sides of Canyon Creek, while to the northwest, on the lower slopes southwest of Stag Mesa, the present moderate relief and the low angle of the slopes can apparently be adequately explained in no other way. High, narrow ridges must have existed in this area, and the slipping of their materials into the drains not only lowered the ridges, but filled the drains and resulted in the present irregular topography, of low relief. The upper limits of these slides are pretty clearly shown and may be traced about the ends of the ridges from one drain to another.

The only other locality where landslide conditions prevail is in the Florida drainage, east of the divide at the head of Camp and Pole creeks, the characteristics being the same as those of the region to the west. While the upper limits of the landslides are almost everywhere well defined, the lower or outer edges are much harder to map, partly because the accumulations are less thick and partly because in a great many cases the loose rock and soil have slipped down over glacial gravels or moraines, causing a mingling of the two sorts of material. This is particularly the case in the Florida or Spruce Gulch area.

On the broad floor of Elk Creek, about 3 miles from its mouth, a great heap of rock débris three-fourths of a mile in length extends nearly from one side of the valley to the other. Its surface is hummocked and crevassed and a steep slope nearly 75 feet high bounds it on all sides. It possesses many of the characteristics of a rock stream, though its position in the middle of a long valley is unusual. It seems probable, however, that the material has been supplied by landslides from the quartzite cliffs to the south. The rocks here are much jointed and the well-developed planes of cleavage lying at high angles have caused enormous masses of rock to slip from the cliff face to the valley below.

ROCK STREAMS.

Closely connected with landslides in their origin are large accumulations of angular rock fragments and sand or soil that occur in some of the high mountain basins or cirques. They were first described in the Silverton folio, where they were given the name "rock streams." There are numerous occurrences of such deposits in the Silverton quadrangle, and the reader is referred to that folio for a full discussion of their nature and origin. It is sufficient to state here that they appear to have originated as landslides falling upon the surface of the glaciers which at the time covered the floors of the cirques, and with the gradual melting of the ice the material settled to the position it now occupies. The nature of the material itself closely resembles that of ordinary talus accumulation at the base of cliffs, but the low angle at which it rests and the distance of the outer extremities from the cliffs which have supplied the débris at once distinguish it from simple talus.

Rock streams occur in the basin south of Snowdon Peak, in a cirque southwest of Balsam Lake, and under Aztec Mountain, in the southern part of Chicago Basin. Another occurrence is west of Storm King Peak, at the head of Tenmile Creek. This does not possess the stream-like character of the others, but is to be classed with the smaller occurrences in the Silverton quadrangle. These were supposed to have been formed by snow banks which permitted rocks from the exposed cliffs above to roll down and out beyond the zone of ordinary talus accumulation. The resulting forms are in many instances like broad terraces with steep sides 50 feet or more high and not infrequently separated from the cliff base by a depression or trench.

IGNEOUS ROCKS.

PRE-TERTIARY INTRUSIVE ROCKS.

The most prominent rocks of igneous origin in the Needle Mountains are granites which intrude the Archean schists and in some cases the Algonkian quartzites and greenstones. They display not a little textural and mineralogical variation and in certain individual masses various periods of intrusion may be recognized. The different occurrences or bodies have been given local names for purposes of description and mapping. They include (1) the Twilight gneissose granite, which makes up a greater part of the West Needles, including their culminating point Twilight Peak, and is particularly well exposed where Cascade Creek joins Animas River, in the Engineer Mountain quadrangle, 5 miles below Needleton; (2) the Whitehead granite, in the northern part of the quadrangle; (3) the Tenmile granite, named from a stream that enters the Animas southeast of Snowdon Peak; (4) the Eolus granite, a great body that occurs in Mount Eolus and other high peaks and about the headwaters of Florida River; and (5) the Trimble granite, which intrudes the Eolus in the neighborhood of Trimble Pass. In addition to these, dikes of aplite and pegmatite cut both schist and granite, and a single occurrence of granodiorite has been observed.

TWILIGHT GRANITE.

Relation to the schists.—One of the most noteworthy of the older igneous rocks of the Needle Mountains region is the Twilight granite. It occurs as an intrusive in the Archean schists in both the Needle Mountains and Engineer Mountain quadrangles, the best and most typical exposures being about the mouth of Cascade Creek, from 2 to 3 miles west of the boundary between the quadrangles. As shown on the map, a large area is occupied by this granite along this boundary, extending from a little south of the point where the Animas leaves the Needle Mountains quadrangle to the Uncompahgre quartzites on Lime Creek; the body extends far enough eastward to include the peaks of the West Needles. As will be explained later, the lines representing the boundaries of the Twilight granite are in most cases quite arbitrary and do not indicate any contacts that can be actually found or followed in the field.

Character of the intrusions.—The Twilight granite is essentially gneissose in texture, but varies from a purely granular rock to a distinctly foliated gneiss, which in the canyon is very light colored, in places almost white, while the schists which it intrudes are very dark amphibolites. In the canyon area the granite intrudes the schists in the form of dikes from a few inches to 10 or 20 feet in width, the plane of intrusion corresponding to the schistosity of the older rocks. The dikes recur with wonderful regularity and the intervening bands of schist are about as wide as the dikes themselves. The zone of most regular banding is in the Engineer Mountain quadrangle and lies between Cascade and Little Cascade creeks, extending about three-fourths of a mile across the strike of the schists. To the south the granite shows a greater tendency toward irregular intrusion and at many points cuts across at right angles or diagonal to the schistosity; in some instances the schist has been brecciated by the force of the intrusion and fragments of all sizes are included in the granite. Transitions from one form of intrusion to the other are found in the field; the different stages are shown in figs. 10 and 11. Offshoots from the dikes, cutting across the schistosity, occur very generally and range from the merest threads to bodies 12 to 18 inches in width (fig. 10). As the region of irregular intrusives is approached the dikes become smaller and less prominent, while the offshoots are more and more numerous and variable in their habit, until finally dikes near together are connected by innumerable bands and what schist there is appears as included masses in the granite (fig. 11).

The granite of the West Needles and south of Potato Hill, in the Engineer Mountain quadrangle, appears to be the central mass of which the dikes just described are apophyses. In only a few places have schists been found in that area, and their field relations indicate that they are inclusions in the granite. The gradual decrease in volume of the granite away from the central mass is well shown in the Animas Canyon from the western boundary of the Needle Mountains quadrangle eastward for about a mile and a half. Here there are a number of bands of granite 200 to 300 yards in thickness, separated from each other by narrower areas in which schists predominate, but which also contain the Twilight granite. Finally, the outermost zone is essentially like that described near Cascade Creek, where the granite and schist alternate in narrow bands until the granite disappears altogether.

From this description it will be seen how difficult a matter it is to draw boundaries for the Twilight granite, since the relatively small scale of the map makes it quite impossible to represent on it any of the numerous small irregularities that have been described. The line as drawn includes that area within which the Twilight intrusive predominates; schist may be found in considerable quantity within the generalized boundary, while many small dikes of the granite may occur outside of the line, but do not extend far beyond it.

Texture.—The texture of the Twilight rock varies with its mode of occurrence. In the main dikes the rock is a distinct gneissose granite, with the banding parallel to the walls of the dike and hence generally to the schistosity of the amphibolites. Larger irregular masses have the gneissic texture where the intrusive is in excess of fragments of included schist; the laminations are not parallel, however, but fold or flow about the inclusions in whatever position they may happen to lie (fig. 11). In places where the brecciated schist predominates and the intrusive is more in the nature of a cement, and also in the small offshoots from the dikes, the body of the intrusive rock has a distinctly massive texture and is often pegmatitic. The change from gneissose to granular rock is abrupt, but there is not the slightest evidence that the granular or pegmatitic offshoots occur as later intrusions. In all cases their origin seems to have been contemporaneous with that of the larger gneissoid dikes. In some of the larger offshoots from the main dikes there is a good banding at right angles to that of the dikes themselves; in offshoots of intermediate size there is apt to be a suggestion of gneissic structure near the contacts, while the mass of the interior is granular. The textural relations show clearly that the gneissoid banding of the intrusive is a primary flow texture and not one induced by pressure or mashing in the solid rock.

Petrographic description.—The rock is light gray or almost white in color except in the region between the West Needle Mountains and Potato Hill, where it is more dense and pink or red. It is of a medium grain and is usually foliated or gneissic in texture. The dark silicates are nowhere in excess, but are always found in sufficient quantities and so arranged as to emphasize the characteristic foliation to the rocks. The principal constituents are feldspar, quartz, biotite, and hornblende. Their relative proportions are extremely variable. In most instances feldspar is in excess of quartz and both more than the ferromagnesian silicates, but it is not uncommon to find quartz in excess of the feldspars. Biotite may be entirely lacking and hornblende the only dark silicate present, or the reverse may be true. The plagioclase feldspars are almost uniformly present and as a rule are quite prominent, in some cases exceeding orthoclase in amount. The rock, therefore, has a monzonitic character in such portions. The plagioclase ranges from albite to andesine in composition, oligoclase being the most abundant. Biotite is found in irregular patches arranged so as to give the rock a foliated appearance. Near the western boundary of the quadrangle, in the Animas Canyon, it occurs in thick masses from which cleavage flakes may be easily removed by the point of a knife; elsewhere it is in thin, disconnected blades. The accessories most often found are magnetite and garnet; apatite, titanite, and zircon occur sparingly, and rarely muscovite is present as an original mineral. At first sight the texture in the dikes seems to be due to the same cause as in the amphibolites—that is, some secondary structure introduced by great pressure after the consolidation of the intrusives—but if the different conditions of occurrence and the variations in structure are taken into account, as well as the fact that under the microscope none of the gneissose granites show any evidence of having been crushed or subjected to unusual strains since their consolidation, it becomes evident that the banding of the granite must be an original texture which was assumed during consolidation.

All the principal constituents show a tendency to form elongate or rudely lenticular grains parallel to the general foliation of the rock, but none are more striking in this respect than the plagioclase feldspars.

In ordinary eruptive granites not having a foliated or banded structure anhedra of plagioclase are very rare and nearly idiomorphic individuals are the rule. In the Twilight granite, however, parallel elongation of the plagioclase grains has been brought about apparently regardless of any crystallographic directions in the minerals themselves. Sometimes, it is true, stubby laths are found in which the longer diameters are parallel to the general foliation, but alongside or at a short distance behind or ahead of them other grains of plagioclase occur in which the elongation has taken place at right angles to the twin lamellæ, or in many cases at an oblique angle. The occurrence of elongate automorphic and anhedral grains side by side, as well as the absence of any evidence of crushing or strain subsequent to their crystallization, would seem to indicate that this structure is a primary one, the result of original crystallization from a magma, and evidence found in the field fully corroborates this view.

TENMILE GRANITE.

Occurrence.—The Tenmile granite is exposed on both sides of the Animas Canyon from a short distance below Elk Park to the mouth of Ruby Creek, its highest outcrops being 2500 feet or more above the river. Its greatest width is nearly 3 miles in an east-west direction. West of the river the contact of the granite with the Archean schists is poorly exposed at the north and south ends of the body. To the east conditions are more favorable for observation. An attempt has been made to show on the map in a generalized manner the great irregularity of the contact between the granite and the schist, but it is impossible to represent the actual details. Unlike the Whitehead body there is no network of intersecting dikes surrounding the central mass, but rather a series of elongate bodies, nearly parallel to one another and to the general boundary of the granite, which decrease in size outward from the main body. At the north and south ends many arms extend into the schists, in places for nearly half a mile, the outlying members being hardly recognized as belonging to the Tenmile granite, because of their fineness of grain and the subordinate character of the dark silicates. In almost all cases the apophyses, of which there are a countless number, are parallel to the schistosity of the Archean complex. While the irregularities of contact are great, the actual contacts of the apophyses and the schists are sharply defined.

Petrographic description.—The Tenmile rock as a whole is a rather coarse light-pink or gray granite, but there is an intricate mingling of granite of other textures, shades, and colors, ranging from coarse pink pegmatites to fine dark-gray gneissoid rocks rich in biotite, that resemble some mica-diorites. The association of these rocks is most intimate, but notwithstanding the diversity of their megascopic characters, their mineralogical compositions show no marked differences.

The lighter-colored rock closely resembles the Whitehead granite, both megascopically and microscopically. The feldspars are orthoclase, microcline, and a very little plagioclase; quartz is abundant, while biotite is nowhere prominent, and there is generally a little muscovite. Accessory magnetite, apatite, and titanite are found in nearly all the specimens. The darker rock, which appears to be quite distinct in the field, is more variable in texture, ranging from coarsely granular to finely banded gneissic, and contains a greater percentage of the dark silicate biotite. In many places unmistakable transitions of one rock into the other have been found and a comparison of thin sections has proved that they are essentially the same. The principal differences seem to be the greater amount of biotite in the dark rock, together with a slight increase in the quantity and basicity of the plagioclase. Hornblende also is occasionally found in the darker rock.

Relations of the dark and light varieties.—That there has been more than one period of eruption is evident, and the differences between the lighter and darker rocks are to be attributed to the lack of uniformity in composition of a single magma. A more acid portion, possibly contemporaneous with the Whitehead intrusion and derived from the same source, was erupted first and before its complete consolidation the slightly more basic portion was forced into the first intrusion. In places fissures formed in the older granite and these were filled by the younger rock as dikes; in other places the lighter-colored rock was fractured and coarsely brecciated, the fragments being included in the darker granite, while at some points the older rock was still so nearly liquid that no sharp boundaries are seen and the two rocks seem to blend into one another. The banded or gneissic texture characteristic of the darker rock and occasionally found in the lighter granite shows no evidence of having been induced secondarily through pressure after the consolidation of the rock, but rather is primary, produced while the magma was still in a viscous condition, and probably corresponds to flow texture like that of the Twilight gneissose granite. Inclusions of schist are not uncommon in the Tenmile granite. As a rule the included masses are large, 20 to 50 feet in diameter, with sharp contacts with the granite, and at many points cut by pegmatite veins or dikes which enter from the granite. There is no evidence of fusion and assimilation of schist material by the granite magma.

WHITEHEAD GRANITE.

Occurrence.—As shown on the map, the occurrence of the Whitehead granite is restricted to the region about the mouth of Whitehead Gulch, to the southeast of Molas Lake, and near the Continental Divide, at the head of the north fork of Elk Creek. It probably has a much wider distribution than this, being associated with the Archean schists along the whole northern side of Whitehead Gulch in the form of innumerable dikes and irregular bodies, but on account of the small size and the confused relations of individual occurrences it has been impossible to represent the granite in this area. West of Animas River the granite amounts to little more than a network of dikes except at two points near the Archean-Uncompahgre contact, where it has a more massive development. A small patch directly east of Molas Lake, which is part of a larger body extending northward in the Silverton quadrangle and which was described in that folio as the Molas granite, may, for convenience, be mentioned here with the Whitehead granite. East of the river and directly north of the mouth of Whitehead Gulch there is a rather large body for which no very sharp boundary can be drawn, as it sends out into the schists a multitude of dikes and arms which branch and rebranch until they gradually disappear. The occurrence near the Continental Divide is essentially the same as that at the mouth of Whitehead Gulch. The contacts of the individual dikes with the schists are in all cases sharp and well defined. Although lying so close to the Uncompahgre formation, the Whitehead granite is nowhere seen to intrude the quartzites and it is assumed to be older than the Algonkian.

Petrographic description.—The Whitehead granite is a rather coarse-textured rock, pink or light red in color, in which the dark silicate biotite is not prominent. Near contacts with schist the granite is much finer grained, locally somewhat gneissic in structure, and darker colored on account of the greater abundance of biotite; in the Molas body the rock is often coarsely porphyritic. Microscopically the rock is found to be a very typical biotite-granite with the usual granular texture. The essential minerals are the feldspars (orthoclase, microcline, and a little oligoclase), quartz, and biotite; the last-named mineral, though uniformly present, becomes in some cases of almost secondary importance and occurs as minute flakes sparingly disseminated through the rock. In addition to these principal constituents muscovite is occasionally found as an original mineral. The usual accessories are rather lacking, magnetite and apatite being the commonest, with a little titanite and zircon.

EOLUS GRANITE.

Occurrence.—The most conspicuous granitic intrusive of the Needle Mountains is the Eolus granite. It occupies about a third of the whole quadrangle and extends southward for several miles until it is covered by the sedimentary formations; it is also found in the Durango and Engineer Mountain quadrangles. Many of the highest peaks of the region—four of them over 14,000 feet in elevation—are composed of this granite. Its distribution is so clearly shown on the map that it needs no further discussion here except in regard to the occurrence in Tenmile Creek and that at the head of the gulch north of Leviathan Peak. The rock of these two localities, although isolated from the main body, is of precisely the same petrographical character, and because of the nearly horizontal contacts with the overlying rocks the exposures in question are thought to belong to thick sheet-like extensions of the main mass. With the exception of the great fault which bounds the body on its eastern side, most of the contacts of the Eolus granite with the older rocks are primary. This is uniformly true in the case of the Archean schists. In the Leviathan Peak and Tenmile Creek areas and on Mountain View Crest the Eolus is seen to intrude the Uncompahgre quartzites, although elsewhere faults generally separate them. The Tenmile granite is also cut by apophyses from the Eolus where they are in contact southwest of Mount Garfield. The Eolus granite is older than the Paleozoic sedimentary rocks, for the Ignacio quartzite, of late Cambrian age, is found to rest unconformably on the granite. For these reasons the Eolus is considered to be of early Cambrian age.

It is not unnatural that a body of granite as large as this should show some variation in texture and mineral composition in different parts of the mass, but marked differences are, as a rule, local, and the general character of the rock throughout is extremely uniform.

Petrographic description.—In its typical occurrence the Eolus granite is coarsely granular and is composed of pink feldspar, bluish quartz, and black biotite and hornblende, the last two minerals being grouped together and occupying a very prominent position in the rock. Near contacts a primary gneissic texture is commonly developed, though locally the rock may be merely of much finer grain and contain a larger portion of the dark silicates. About the head of Needle Creek the granite becomes coarsely porphyritic, with large Carlsbad twins of pink feldspar held in a groundmass of but little finer grain than that of the average rock. Still another variation is found at the divide south of Emerald Lake, where biotite and hornblende are of such abundance that the rock is extremely dark and is hardly recognized as belonging to the Eolus. The granite weathers readily to a coarse sand composed of broken feldspar crystals, hornblende, and quartz.

Under the microscope orthoclase is found to be the predominating feldspar; microcline is almost uniformly present and in some cases in amounts equal to the orthoclase. In the porphyritic Needle Creek rock the phenocrysts are microcline, which also occurs in excess of the other feldspars in the coarse groundmass. The lime-soda feldspars are much more prominent than in the Whitehead or Tenmile granite, especially near contacts, where andesine has sometimes been found in excess of orthoclase. In the Needle Creek occurrence they are much more subordinate. Biotite occurs abundantly in large patches without crystal boundaries; it is jet black in hand specimens and in thin sections either brown or green. It contains numerous inclusions of magnetite and apatite. Quartz is less abundant in rocks of this type than in the biotite-granite to the north, but megascopically it is very characteristic, for it is everywhere of a bright-blue color. Hornblende is uniformly present, though in varying amounts, at some points equaling the biotite; its color is green to yellowish and it is strongly pleochroic. Pale-green augite has been found in specimens collected near contacts, and at one locality it was only slightly less in amount than biotite and more than hornblende. It was at this same locality that plagioclase exceeded orthoclase, but both occurrences are evidently quite local and of comparatively little importance.

TRIMBLE GRANITE.

Occurrence.—In the region northeast of Missouri Gulch and including Vallecito Basin a fine-grained gray granite is found intruded in the Eolus. The contacts between the two rocks are very sharp and, except in the southwestern part, there are almost no apophyses. Offshoots from this (the Trimble) granite which intrude the Eolus have in many cases the form of nearly horizontal sheets whose actual relations are difficult to represent on the map. For this reason the contacts in the southwestern portion have been somewhat generalized, and the irregularities are greater than the map shows. The rock is uniform in texture, except near contacts with the Eolus, where a faint banding may be made out. At these places, also, a porphyritic appearance is not uncommon, due to a slightly finer texture of the rock as a whole and the development of large phenocrysts of feldspar which are in many instances arranged with their greater diameters parallel to the contacts.

Petrographic description.—With the exception of the contact facies, the Trimble granite has an even texture and is of a moderately fine grain; the color is light gray with a pinkish tinge. There is a very uniform sprinkling of fine specks of a dark mica and lath-shaped crystals of feldspar 2 to 3 mm. long. The rock consists of microcline with relatively subordinate amounts of orthoclase and plagioclase, quartz, biotite, and locally a little muscovite, with magnetite or apatite as accessories. The structure is very characteristically hypidiomorphic-granular. The contact phases differ from the ordinary rock only in the presence of phenocrysts of feldspar, many of them 1 inch long, and in the color, which is slightly pinker.

GRANODIORITE.

Just west of the junction of Virginia Gulch with Florida River a body of dark rock cuts the Eolus granite. It is about three-fourths of a mile long and half a mile wide, and apparently has no offshoots or apophyses, nor has any similar rock been found elsewhere in the quadrangle. The rock is moderately coarse grained, even textured, and of a clear-gray color; a noteworthy feature is the large quantity of the darker silicates present. The microscope shows that plagioclase, ranging from oligoclase to andesine, is more abundant than orthoclase or microcline, and that hornblende, biotite, and rarely a little augite nearly equal the feldspars; a very little quartz may also be present. The accessories are magnetite, apatite, and titanite. The rock is to be regarded as a granodiorite containing a rather unusual amount of the dark silicates.

APLITE AND PEGMATITE.

Occurrence.—Throughout the whole region of the Needle Mountains dikes and veins of aplite and pegmatite are very common. As a rule the pegmatites are more intimately associated with the larger masses of granite, while the aplites are seen everywhere in the granites and far away in the schists. The dikes of pegmatite are nowhere very large or of great prominence; they are in few cases more than 3 or 4 feet in width and may be but a few inches. They are particularly well developed in association with the Whitehead and Tenmile granites.

Petrographic description.—Though nowhere very coarse, the pegmatites are extremely variable in texture; many pegmatite dikes change their habit and become, within a few feet, fine-grained aplite. The principal constituents, feldspar and quartz, are most irregularly intergrown, few of the individual minerals measuring more than an inch in diameter and none exhibiting perfect crystal forms. The feldspars are orthoclase and microcline, no plagioclase being present in the sections examined. Besides the quartz occasional large blades and plates of biotite and, more rarely, muscovite occur. The color is usually pink to bright red, but white dikes or veins are not uncommon.

The aplitic dikes may attain greater width than the largest pegmatites, but as a rule they are not wider than from 8 to 15 inches. They have sharp contacts with the rocks they are cutting, whether it be granite or schist, and pass from one to the other with no apparent change in structure or in the character of their mineral constituents. They are fine grained and even textured, in many cases saccharoidal. The color varies from white to bright pink or purplish. They are very nearly of the same age as the associated pegmatites. In about an equal proportion of the occurrences they cut the pegmatites or are themselves cut by the coarser rock. The constituents are usually only feldspar and quartz, though sometimes a little biotite or muscovite is found. The accessories are nowhere prominent. Garnet is fairly abundant locally. Magnetite occurs regularly, but sparingly, and hematite is often found as a pigment. Of the feldspars, orthoclase is uniformly in excess of microcline and plagioclase. Micropegmatite is strikingly developed in places, and quartz is everywhere very prominent, in many instances equaling or surpassing the feldspars.

LAMPROPHYRIC DIKES.

Occurrence.—Dikes of mica-syenite or minette are found in considerable abundance in the northern third of the quadrangle, cutting the schists, granites, and quartzites, the greater number being found in the Uncompahgre formation. A few occur as far south as Emerson Mountain and the Quartz Mill. They are commonly found intruding the softer shales and slates of the Uncompahgre, and in their field occurrence are mainly remarkable for their variability in thickness, which in few cases exceeds 10 feet, and for their lack of continuity. The occurrences in the region of the Continental Divide and in the neighborhood of Elk Park are the most noteworthy. Only a few of the more important dikes have been shown on the map.

Petrographic description.—These rocks are of a rusty-brown color on weathered surfaces, but much darker on fresh fractures and in the finer-grained varieties suggest diabase or other equally basic rocks, the coarser ones being lighter and with a pinkish tinge. The texture is variable, ranging from aphanitic to coarsely granular. Many are porphyritic, the phenocrysts being few and of small size and in nearly every case composed of the dark silicates. In the more coarsely granular varieties a lath-like development of the feldspars may be noted and flakes of lustrous black biotite are prominent. The microscopic structure is holocrystalline and in general granular, with a rather common tendency toward a trachytic development of the feldspar. In many specimens the feldspar is quite without crystallographic form and appears as a groundmass in which small flakes of biotite rest as phenocrysts. Occasionally it is found as a poikilitic intergrowth with large phenocrysts of hornblende or biotite.

The phenocrysts, when present, are of biotite and hornblende or actinolite, the mica largely predominating and generally unaltered. Hornblende, on the other hand, is not fresh as a rule, the alteration being to chlorite. The groundmass, which is of the same composition as the mass of the unporphyritic rocks, is composed largely of feldspar with abundant flakes and patches of biotite and usually a little quartz. The accessory minerals apatite, magnetite, and rutile occur in all the specimens, while in some they assume unusually prominent rôles, especially apatite. Rutile occurs very typically as fine needle-like inclusions in biotite.

The alkali feldspars predominate in the majority of the rocks, but with them a little acid plagioclase is almost always to be found. In only one instance, that of a small dike outcropping along the trail east of the Quartz Mill, has plagioclase been found to the almost complete exclusion of orthoclase. In this case the rock, a porphyry, contained well-formed, fresh phenocrysts of labradorite (Ab_2An_3), with a groundmass composed of labradorite laths and blades of biotite and accessory magnetite—a mineralogical composition corresponding to that of kersantite. All the other rocks would fall under the head of quartz-bearing mica-syenite, or minette. None are strictly fresh, the abundant alteration products being calcite, epidote, muscovite, chlorite, and hydrous oxides of iron.

DIABASE DIKES.

Dikes of diabase are not at all numerous in the Needle Mountains quadrangle, although common just to the north in the Silverton region. Those that do occur in this area are connected directly with the Silverton dikes and are found intruding the schists along the northern border of the quadrangle. Some are remarkably fresh and possess the usual texture and mineral composition of diabase; others show signs of alteration and dynamic metamorphism and, in extreme cases, are now totally different from the original rock. These differences have been observed in the same dike, one portion of which may be a normal diabase, while another is an amphibolite with schistosity often well developed. The fresh and unaltered diabase is a medium-grained rock, brown-black in color, and possessing the usual ophitic texture. Laths of plagioclase and a pyroxene may be made out megascopically and an ophitic structure is pronounced microscopically. The metamorphism which has affected these rocks is precisely the same as that noted in the greenstones of the Irving series, and needs no further description here, as it reaches its maximum only within the Silverton area. There is no means of closely fixing the age of these intrusives, but it seems probable that they belong to the time that the Irving intrusions took place.

GRANITE-PORPHYRY.

Certain rocks, found both as dikes and in larger intrusive masses in various parts of the quadrangle and probably of different ages, may be grouped conveniently as granite-porphyries. Their mineralogical composition is about the same in all cases, and chemically they would probably differ but little from one another. The dikes are usually found in the immediate vicinity of the larger granite bodies and are particularly numerous in the region of the Irving greenstones and less frequently observed intruding the Uncompahgre formation. The majority differ only in texture from the coarser granite-porphyries which were described in connection with the Eolus and Trimble granites, and undoubtedly belong to the same series of eruptions. They have not been represented on the map, because of their relative unimportance and insignificant dimensions. Two occurrences of granite-porphyry in large masses are shown on the map—one in Chicago Basin, near the head of Needle Creek, with a large dike of similar rock near the head of Virginia Gulch, and the other in the extreme northwest corner of the quadrangle, at the forks of Lime Creek.

The body in Chicago Basin intrudes the Eolus granite, from which it is distinguished with difficulty on account of the extensive metamorphism which has affected both rocks. At several localities the porphyry contains inclusions of a quartzite conglomerate or of quartzite pebbles held in a cement of porphyry. The nearest point at which quartzites or conglomerates are exposed is more than 3 miles away and they are separated from the granite-porphyry by an unbroken mass of Eolus granite. From the nearly horizontal, sheet-like character of the granite intrusion to the north, described elsewhere, it seems not unlikely that the basal conglomerates of the Uncompahgre formation may be buried beneath the granite at this point and that the granite-porphyry, in forcing its way upward into the Eolus granite, also penetrated these conglomerates and carried up fragments of them as inclusions in its mass.

The granite-porphyry at the forks of Lime Creek intrudes the Hermosa formation and is therefore Carboniferous or younger. The form of this body is that of an irregular laccolith, whose boundaries in many places cut across the bedding planes of the sediments. Near its borders the limestones have been hardened or converted into crystalline marble impregnated with pyrite or traversed by a network of fine quartz veins and druses filled with crystals of fluorite.

Granite-porphyry dikes.—The granite-porphyry dikes are from 5 to 20 feet in thickness, but show almost no variation in texture in different parts of the body, though different dikes may be more or less strikingly porphyritic. The prevailing color is pink, a few being nearly white, while others are a clear brick-red. As a rule the texture is fine grained and not strongly porphyritic to the unaided eye. The phenocrysts are not numerous and are small, few of them appearing larger than 3 mm. in diameter. The groundmass is megascopically felsitic and very dense or almost aphanitic, with here and there a sprinkling of specks of biotite. The microscope shows that the phenocrysts are orthoclase or microcline and quartz and that the groundmass is very finely granular, in some cases micropegmatitic, and is composed of feldspar and quartz, a few flakes of brown biotite, and a little magnetite, the feldspars being clouded with a fine dust, probably hematite, to which the color of the rock is due. Most of the rocks are remarkably fresh, the only secondary minerals developed being a very little muscovite and iron oxides derived from the biotite and magnetite.

Granite-porphyry in larger masses.—The porphyry of the Chicago Basin and Lime Creek bodies differs from that of the dikes more in hand specimens than in thin sections. This is due to a slightly different texture of the groundmass and very largely to the greater alteration to which the larger masses have been subjected. The rock of the Lime Creek laccolith is of a light-yellow or cream color with a faint pinkish tinge. Its groundmass is of an extremely fine texture and largely feldspathic; it contains hardly distinguishable phenocrysts of quartz and somewhat larger ones of an altered feldspar. Biotite is not at all abundant and is invariably decomposed. The groundmass far exceeds the phenocrysts in amount. The Chicago Basin porphyry and that of the dike to the southwest have larger and more numerous phenocrysts, but less in amount, than the groundmass. Most of the specimens indicate that the rock has been subjected to stresses which have not been of sufficient force to cause schistosity, but which have produced an almost microscopic system of joints that give the rock a texture on weathered surfaces much like that of the Eolus granite. Near contacts the porphyry becomes very dense, almost without phenocrysts, and well banded. The whole mass seems to have suffered alteration and to have been sparingly but quite generally impregnated with pyrite.

A microscopical examination of rocks from the two localities shows that they are essentially of the same mineralogical composition and hardly to be distinguished from the rock of the granite-porphyry dikes. The main difference seems to be in the groundmass, which in the case of the dike rock is finely but distinctly granular, the individual grains being sharply bounded as in a granite. The rocks of the larger bodies, on the other hand, have groundmasses which are essentially felsitic, with interlocking grains and micrographic or micropoikilitic intergrowths of quartz with the feldspar. None of the phenocrysts of feldspar, which are more numerous than those of quartz, are fresh, but their appearance indicates that a number should be considered as microperthite, a few are of an acid plagioclase, and the rest orthoclase. Magnetite and zircon are the usual accessory minerals, while secondary muscovite, kaolin, and oxides of iron now make up a large part of the rock. Although grouped with the granite-porphyries, these rocks are to be considered more strictly as granite-felsophyres, approaching rhyolite-porphyry in structure and composition.

TERTIARY VOLCANIC ROCKS.

The Needle Mountains are situated directly on the southern border of the large area of volcanic rocks which are the most prominent element in the San Juan Mountains. Apparently the high peaks of granite or quartzite rose above the levels of volcanic accumulation to the north during a large part, at least, of the volcanic cycle. It is not known whether the summits of the Needle Mountains area were ever entirely covered with volcanic rocks, but lavas and tuffs of several epochs certainly extended far up the northern slopes and two members of the complex are still represented by remnants which have been mapped. These rocks are much more important in the Silverton quadrangle and have received such full treatment in that folio that the present description will be brief.

SAN JUAN TUFF.

The earliest member of the San Juan volcanic succession at present known is a tuff or agglomerate composed almost exclusively of andesitic materials, which was called the San Juan tuff in the Telluride folio. It is a widespread formation all through the western San Juan region, reaching its maximum observed thickness of nearly 2500 feet adjacent to Canyon Creek, near Ouray.

The San Juan tuff is a well-stratified formation in nearly all localities. Its beds vary in texture, but are predominantly rather fine grained, with few fragments exceeding 6 inches in diameter, though coarse breccia or agglomerate is locally present. Fragments are rounded or subangular and the matrix is a fine gravel or sand. The stratification is mainly due to water and in some places there may have been lakes, but much of the arrangement is more plausibly assigned to fluviatile agencies.

The prevailing color of the tuff is dark gray or purplish, with greenish tints strongly developed in places, as on Deep Creek in the Silverton quadrangle. It is in few cases highly indurated and in consequence the formation causes gently rounded slopes as a rule.

The fragments making up the greater part of the tuffs are chiefly andesite, hornblendic and augitic types prevailing. Granite, schist, and other rocks may be very prominent in the lowest horizons at some localities, but only volcanic rocks appear in the greater part of the formation.

Erosion removed most of the San Juan tuff adjacent to the Needle Mountains before or after the eruptions of the Silverton volcanic epoch, and recent erosion has so nearly completed the destruction that only a few patches now appear. The map shows the tuff to be present on the ridge north of Elk Creek and on or near the Continental Divide. At several points it has protected the Telluride conglomerate from complete removal. The uneven character of the surface at the beginning of the San Juan epoch is well shown by the basal line of the tuff as it runs in irregular course over or around hills and ridges.

POTOSI VOLCANIC SERIES.

Relations and distribution.—In the northeast corner of the quadrangle, above the San Juan tuff, occur remnants of certain other tuffs and lava flows belonging to the Potosi volcanic series. The dominant rocks of the succession are pinkish quartz-latite and pink or gray banded rhyolite. The rocks of this series have been fully described in the Telluride and Silverton folios. They constitute one of the principal divisions thus far recognized in the volcanic section of the San Juan region, coming in time after a succession of flows and tuffs of andesite and of dark latite, together known as the Silverton volcanic series. The latter rocks possess a thickness of several thousand feet, all told, in the central part of the Silverton quadrangle. Erosion preceding the eruption of the Potosi lavas entirely removed the Silverton rocks and much of the San Juan tuff from the northern slopes of the Needle Mountains, so that the lowest Potosi lavas rest on the schists in some places, as in the head of Haynes Fork, in the Needle Mountains quadrangle. The Silverton volcanic series is represented by a few hundred feet of lavas and tuffs in Sheep Mountain, only 4 miles north of Beartown.

The remnants of Potosi lavas occurring in the Needle Mountains quadrangle belong, of course, to the lower part of the complex, the principal area being that on the ridge northwest of Bear Creek. The rocks of this locality dip northeasterly down this ridge to its end opposite the junction of Bear Creek with the Rio Grande. Below this point the Potosi lavas become one of the most important formations of the Rio Grande Valley. They also approach the Needle Mountains from the east and the extreme western tongues now remaining are shown by the map, north of Mount Nebo.

Quartz-latite and rhyolite.—The Potosi series consists principally of grayish or pinkish lavas characterized by glassy sanidine or plagioclase crystals and glistening biotite leaves in a predominant felsitic groundmass. At many points the rocks have a wavy banding or flow texture. It has been found that the most common lavas are quartz-latite, while true rhyolite is also present. In Sheep Mountain the summit is made up of rhyolite flows, succeeding several hundred feet of quartz-latite.

The latter rocks are the principal element in the ridge adjacent to Bear Creek, the lowest portion being of tuffaceous character. North of Mount Nebo there is some black, glassy, porphyritic quartz-latite belonging to a thin flow in the tuff. This material has some extension to the northeast, appearing as a black band in the pink tuff of several cliff exposures.

Andesite flows.—As represented by the map, the ridge opposite the head of Bear Creek exhibits an andesite flow in the Potosi series. While this is unusual, a similar thin flow was observed between quartz-latite masses in the Telluride quadrangle. As far as known, the andesite flows of the Potosi epoch of eruption are uniformly local and of relatively small importance. The one under discussion is clearly of quite local development. The andesite is a very dark aphanitic rock, with but few minute crystals discernible to the naked eye. Under the microscope the rock is found to be an augite-andesite of predominant microlitic groundmass, with much magnetite in very minute grains, causing the dark color.

INTRUSIVE RHYOLITE.

An intrusive rock which clearly belongs to the Tertiary volcanics of the San Juan is represented in the extreme northeast corner of the quadrangle by a stock-like body of rhyolite-porphyry, cutting the Potosi lavas and underlying schists. The mass has irregular boundaries which can not be traced accurately in the forest on the lower slopes, but it surely does not extend as far as the bed of Bear Creek and probably the larger part of the body is within the quadrangle.

The prevalent habit assumed by the rock is that of a strongly marked gray porphyry, with many distinct crystals of sanidine, quartz, and biotite in a very fine-grained cryptocrystalline groundmass. The crystals vary in size, some of the sanidines being an inch in diameter, but the average is much smaller.

Near the contacts, especially in apophyses at the southwest extremity, the rock is a very nearly white felsitic porphyry with small phenocrysts and predominant groundmass. The border zone, a few inches wide in places, is vitrophyre, the glass base being dark gray, reddish, or yellowish, and at many points exhibiting perlitic sundering. A fluidal texture is developed here and there in the glassy or felsitic groundmass of the border zone.

This rock is clearly a rhyolite, of unknown relations to the Potosi lavas of this character. Other crosscutting bodies of the same rock occur on the ridge southwest of Bear Creek, and there is a dike of similar porphyry in the Silverton quadrangle between Cunningham Gulch and Deer Park. These dikes are all characterized by a large number of sharply formed quartz phenocrysts, while the rhyolitic lavas of the Silverton and Potosi volcanic series in few cases exhibit quartz crystals.

STRUCTURE.

GENERAL STATEMENT.

The structural features of the Needle Mountains are due to several periods of deformation. The greatest complexity is to be found in the pre-Cambrian rocks, which were folded, dislocated, and compressed more than once before the beginning of Paleozoic history. Later movements also affected the pre-Cambrian terranes, but their best expression is to be found in the structure of the Paleozoic rocks.

It will be seen from the distribution of the Paleozoic sediments on the map and from the structure sections (A–A and C–C) that they dip away from the central portion of the Needle Mountains in all directions. There can be little doubt that the different formations of which these are the remnants were once connected and, together with thousands of feet of younger terranes, covered the pre-Cambrian rocks that now form the highest summits of the Needles. At some period, probably at the close of the Cretaceous, this region was locally affected by earth movements, which resulted in a quaquaversal folding or doming of the strata about a center not far from the present Pigeon Peak. The attitude of the earlier Paleozoic sediments, as well as that of younger formations, preserved beyond the boundaries of this quadrangle, is to be attributed to this domal uplift, and is independent of the broader uplift of the whole San Juan region.

ALGONKIAN ROCKS.

The structures presented by the rocks of the Algonkian system, including the relations between the Irving formation and the Needle Mountains group and the deformation of the Uncompahgre strata, are among the most interesting and striking features of the Needle Mountains region. The present distribution and structure of the Needle Mountains group were largely determined by two or more periods of great deformation which occurred before the deposition of the earliest Paleozoic sedimentary rocks and by a later faulting which followed, in the main, old lines of weakness. The broader problems touching the character and extent of the forces which have combined to bring about the present structure can not be fully discussed until the less complicated eastern extension of the Needle Mountains forms beyond the Vallecito has been examined.

IRVING GREENSTONE.

Within the Irving greenstone practically nothing can be made out beyond the fact that the rocks have suffered much from orogenic disturbances. The great preponderance of igneous rocks of essentially the same composition and appearance does not favor the solution of the grander structures that may have resulted from these movements, and the effects of dynamic metamorphism are the only recognizable records of the forces which first acted upon these rocks. The presence of pebbles of greenstone-schist in the Vallecito conglomerate is conclusive evidence that deformation occurred prior to the beginning of the Needle Mountains deposition, but it is practically impossible now to distinguish between the results of these movements and of those due to later deformation, by which the Vallecito conglomerate was also affected.

Irving-Vallecito contact.—The structural relations between the Irving greenstone and the Vallecito conglomerate are best shown on the broad ridge or mesa which lies just east of the quadrangle and separates Vallecito Creek from Lake Fork of Pine River. In a general way, the Vallecito conglomerate rests as a thin remnant on the Irving greenstone, with a gentle dip to the southeast, but from place to place sharp and abrupt changes in dip occur, and the contact surface, which follows these changes, shows that the two formations have been intricately infolded. This folding was undoubtedly accompanied by differential movements of one formation upon the other, for many of the conglomerates have a certain schistosity, shown by elongated pebbles and laminated matrix, while the greenstones, even for some distance away from the contact, have been fractured, brecciated, and sheared in a manner that in places strongly suggests flow breccia or tuffs.

NEEDLE MOUNTAINS GROUP.

Unlike the Irving formation, the Needle Mountains group consists of well-stratified sedimentary rocks, mainly quartzites with some argillaceous layers; this clearly defined stratification permits the complicated folds to be worked out in a fairly satisfactory manner. The total lack of fossils and the absence of horizons possessing peculiar lithologic features have been serious disadvantages at a number of critical points and have prevented an altogether satisfactory solution of the structural problems. The presence of argillaceous beds has been of great assistance in unraveling obscure structural relations, but it has not been possible actually to correlate the different horizons in distant localities, largely because of the variability of their lithologic character from place to place, due to differences in dynamic metamorphism and the influence that the granite intrusions have had upon them. In order to represent the structural relations more fully, the quartzite and argillaceous members of the Uncompahgre formation have been differentiated on the map, a study of which, in connection with the cross sections, will give a fair idea of the general attitude of the beds, which is that of a broad synclinal flexure of the earth's crust involving lesser plications—in other words, a synclinorium, with an axis describing a semicircle about a center not far from Overlook Point. The synclinorium is much compressed and in part hidden by overlying Paleozoic strata to the west and its minor folds are obscured by faults. To the east it becomes more open and a series of southeasterly pitching anticlines and synclines are to be made out. Section B–B, which passes through White Dome in a direction normal to the axis of the synclinorium, represents the general attitude of the beds in the Vallecito region. This same section is shown in fig. 5 on the illustration sheet. Just south of the zone of faulting that characterizes the northern boundary of the Uncompahgre is the open anticline of White Dome, slightly overturned to the south; a syncline, the trough of which is occupied by slates, flanks it on the north, and to the south for a distance of more than a mile the strata are crumpled and broken by a number of faults, one of which is shown in the section. From this zone of crumpling, which ends at the west fork of the Vallecito with a closely compressed overturned anticline, southward to the Eolus granite, the structure is simple and the folds are open. In the broad syncline of which Grenadier Range forms the southern limb the shale members are conspicuously traceable, and in the center of the flat anticline to the south the quartzites are cut through to the underlying schists and intrusive granite.

East of Vallecito Creek, from Bear Creek to a point just south of Mount Nebo, lies a region of considerable structural complexity. The folds are more closely compressed, some are overturned, and local divergence of the axes of the minor folds from the general direction of the axis of the synclinorium is not uncommon. Directly north of Mount Nebo is an unusually large area of slates in which practically no structure can be made out, on account of the crumpling and fracturing that these soft rocks have undergone incident to their deformation. South of Mount Nebo simple structures prevail, which correspond to those south of the west fork of Vallecito Creek along section B–B.

To the west the folds of the Vallecito and Bear Creek sections become more compressed and axial faults are developed by which many of the nearly vertical beds are cut out. There is also an east-west system of faults oblique to the axial faults, by means of which many more beds disappear to the west and further complexity is added to the compressed flexures. Most of these faults converge to a narrow zone which crosses Animas River at the lower end of Elk Park. To the north the strata still preserve some of the simpler structures that are common to the east.

In the Animas section the strata at the northern boundary of the Uncompahgre are in fault contact with the Archean schists, massive quartzites, overturned and dipping steeply to the north, resting against the fault. The dips soon become vertical and then southerly until the beds are terminated by a fault, on the other side of which are slates. These slates, at first sharply upturned, quickly assume dips of lower angles, and then for a distance of half a mile or more are closely folded and plicated with associated thin-bedded quartzites, and are eventually carried beneath the valley floor by the prevailing southerly dips. Beyond this point a simple southerly dip continues, becoming somewhat steeper, to the mouth of Elk Creek. The continuity of the beds is broken at several places by minor faults, but being entirely within the quartzites the faults can not be traced far nor represented on the map. Opposite the mouth of Elk Creek is the trough of a close syncline, the thin-bedded quartzites being much crumpled for a distance of several hundred feet until they gradually assume a high dip to the north. From this point to the southern limit of the Uncompahgre the quartzites and slates appear to have been very closely folded, but as this is within the zone of pronounced faulting practically nothing remains to indicate the initial character of the plications. Three principal faults are represented on the map, but it is probable that more actually occur and that all the rocks are traversed by numerous slipping planes and are very generally crushed. The beds are nearly all in a vertical position, as are those which rest against the fault that separates them from the Archean on the south.

The extremes of compression and shearing are found in the section exposed on Lime Creek, where the beds are nearly vertical and are traversed by many faults against which one horizon after another is sheared out. Section A–A of the structure-section sheet passes through a point intermediate between the Lime Creek and Animas localities and combines some of the features of both. The peculiar relations at Snowdon Peak are discussed below.

As shown by the map the Uncompahgre strata are bounded by granite or the Archean schists, where not overlain by Paleozoic strata, the Vallecito conglomerate being nowhere observed in contact with the younger Algonkian formation. A zone of shearing extends along the whole northern border of the Uncompahgre, two or more prominent faults being recognized wherever exposed. Between these faults the quartzites are crushed and brecciated and traversed by many minor fractures, and the bedding, when it can be distinguished, is found in general to be nearly vertical; in the Animas Canyon opposite Whitehead Gulch it is slightly overturned and dips to the north. The region of greatest crushing extends westward from Bear Creek for about 4 miles. West of the Animas the contact with the Archean is covered by Paleozoic rocks.

The southern contact is of a different character and for the most part is in the nature of a thrust fault. This is best shown south of Snowdon Peak, illustrated in section A–A, where the mountain crest is capped by a thin remnant of quartzite, part of a mass which was overthrust upon the schist. To the east the same relations may be recognized, especially south of Balsam Lake, where a small overthrust mass of quartzite is entirely isolated from the main area, but for a considerable distance along the southern limit the Uncompahgre is intruded by the Eolus granite. It is probable that the intrusion followed closely the thrust plane between the Algonkian and the Archean, which everywhere is marked by a zone of brecciation and evident weakness. These relations are represented in section B–B. The small patch of Uncompahgre quartzite which rests upon the Archean and is intruded by arms of the Eolus granite on the southern slope of Mountain View Crest, 5 miles from the main mass of the quartzite, is possibly an indication of the extent to which the quartzites were thrust over the Archean.

The absence of the Vallecito conglomerate at the base of the Uncompahgre, where it would naturally be expected, is difficult to explain. It is probable that it shared with the Uncompahgre in the deformation which initiated the synclinal structure of the region, and that later movements accompanied by faulting sheared out the conglomerate near the present margins and at the same time thrust the quartzites over the Archean. It is also believed that the great fault which separates the Eolus granite from the Irving greenstone may have developed as a fracture at this time and directed the intrusion of the granite. Later movements followed along this general line of weakness and for some distance determined the contact between the granite and the Uncompahgre.

PALEOZOIC ROCKS.

All the structures so far considered were developed before the beginning of Paleozoic sedimentation, with the exception of the later movements along the great fault between the Eolus granite and the Irving greenstone. Here a small patch of Ignacio quartzite resting on the Irving north of Sheep Draw is faulted against the granite. In the northwestern portion of the quadrangle the Paleozoic rocks have been dislocated at a number of places by faults which appear to be along predetermined lines of weakness or fracture in the Uncompahgre. The probable progressive character of this faulting is well shown in the region just east of the quadrangle, above Lake Fork of Pine River and not far from Irving Peak. Here the Paleozoic sediments rest in one place on both the Vallecito conglomerate and the Irving greenstone, which are sharply separated from each other by a fault, of unknown but probably great displacement. Within a distance of 50 feet another fault, parallel to the first, dislocates the Paleozoic strata a small but definite amount. There can be little doubt that this second fault is due entirely to later movements along the earlier and well-defined line of weakness.

The quaquaversal structure of the Paleozoic rocks has already been mentioned. The preservation of the tilted floor upon which they rest, even where the sediments themselves have been removed, helps to make this structure easily recognized both in the field and when represented on the map. Although to comprehend properly the relation of the encircling sediments to the exposed pre-Cambrian core of the dome, areas to the east and west of the quadrangle should be considered, still the change from southwesterly to southeasterly dips along the southern border of the quadrangle and the complementary northerly and northwesterly inclination of the strata to the north, illustrated in sections A–A and C–C, are sufficient to bring out the quaquaversal relations.

Both in the Canyon Creek drainage and in the vicinity of Lime Creek the sedimentary rocks have been dislocated by faults or locally folded. In the Lime Creek area the more complicated structure, involving the Hermosa, lies mainly in the Engineer Mountain quadrangle, but considerable deformation, independent of the broader structures of the Needle Mountains dome, occurs between the Algonkian and the Lime Creek laccolith to the north. The deformation has resulted in open folds with east-west axes, further complicated by a number of minor faults.

The principal fault of the region is that lying between the Algonkian and Paleozoic rocks and extending from the edge of the Animas Canyon westward for more than 5 miles. The Hermosa is more or less sharply upturned against the north side of this fault throughout its entire length, while at two points, one of which is near Lime Creek and the other midway between Lime Creek and the Animas Canyon, remnants of the Elbert and Ouray sediments occur on the south side of the fault, resting on the rocks of the Uncompahgre formation.

In addition to a few small faults which affect the continuity of their boundaries, the sediments of the southwest section are traversed in a southeast-northwest direction by a fault nearly 6 miles long which has dropped the strata to the southwest 500 or 600 feet. On both sides of Stag Mesa and southwest of Lime Mesa the location of this fault is clearly shown in the field by bold escarpments of the sediments and in Canyon Creek by an abrupt cliff of granite. The position of the fault is further emphasized by several streams which have taken advantage of this line of weakness to carve deep ravines.

HISTORICAL GEOLOGY.

GENERAL STATEMENT.

A connected history of the events which have combined to bring about the present geologic and physiographic features of the Needle Mountains may be traced from the evidence which has been set forth in the descriptions of the various rocks. It involves the geologic history of the whole San Juan region, and, though a record of nearly all its stages is to be found within the present quadrangle, some reference to observations in neighboring districts is necessary for a complete understanding of the sequence of events.

Since crystalline and early sedimentary rocks are the most conspicuous ones in the Needle Mountains, greater prominence is given to them here than to the younger terranes. For a more detailed account of the later sedimentary and volcanic history of the San Juan the reader is referred to the Telluride and Silverton folios.

PRE-CAMBRIAN HISTORY.

The earliest rocks of which there is any record are the crystalline schists and gneisses that are conspicuously exposed in the canyon of the Animas and at the northern border of the quadrangle. So completely have they been metamorphosed that with but few exceptions it is practically impossible to state with any certainty what their origin has been. Some are clearly igneous, such as the schists occurring near Rockwood in the Durango and Engineer Mountain quadrangles, in which a porphyritic texture is apparent. Others, from the abundance of their ferromagnesian silicates, would seem to be of igneous origin also. Many more, however, give no clew, either from their texture or composition, as to whether they were derived from igneous or sedimentary rocks. In the absence of more definite information they are grouped with similar rocks in other parts of Colorado which have been regarded as of Archean age. They have from time to time been involved in movements of the earth's crust, and the accompanying stresses have nearly obliterated primary structural relations and have produced a schistose texture in all the rocks. After schistosity had been induced to some extent, intrusions of basic magmas in dike form took place; these in turn yielded to dynamic metamorphism and became finely laminated amphibolites. Before the close of this period the Twilight gneissose granite may have been intruded also, as portions of it, at least, appear to have suffered strains which led to a development of schistose or gneissic textures.

After these movements, which probably resulted in mountain building, came a long period of erosion accompanied by deposition. Of the resulting rocks almost none now remain, and it is only from indirect evidence that it is possible to arrive at any conclusions regarding the former extent and thickness of the deposits. From the abundance of quartzite bowlders in the conglomerates of the next succeeding formation, the Vallecito, it is reasonable to assume that strata of a considerable thickness of such rocks must once have existed and that from their destruction the materials of the Vallecito conglomerate were in part supplied. Before this second great period of erosion began, these rocks, which may be referred to as the sedimentary members of the Irving formation, were intruded by basic igneous rocks, in the form both of dikes and of larger and more irregular bodies. As a result of these intrusions and of the movements which probably accompanied them, the sedimentary rocks were compressed and indurated and were changed from sandstones to quartzites. Masses of them were caught up and held as inclusions in the larger bodies of igneous rock, and the few occurrences of massive quartzite in the Irving greenstone that may be seen to-day are probably of this character.

After the period of intrusions had ended, earth movements took place, accompanied by compression and possibly folding that led to a metamorphism of the igneous rocks into greenstones and in extreme cases into schists. These movements may have affected the contact between the Irving greenstone and the Archean, but of this nothing is known. They did, however, elevate the region sufficiently to bring about its widespread degradation. The detritus resulting from this erosion, both quartzite and greenstone, as well as waste from the Archean areas, supplied the materials out of which the Vallecito and Uncompahgre formations of the Needle Mountains group were built up. At first the Vallecito conglomerate was laid down, but as erosion became less intense finer materials were deposited, and for a very long period sedimentation continued with only slight oscillations of the land surface and sea bottom, that brought about an alternation of sands and clays. After a considerably greater thickness than now remains had been laid down, orogenic movements took place which resulted in a complicated folding and faulting of these beds over a wide area, those which are now preserved in the Needle Mountains probably representing but a very small part of the whole formation. The present structure of the Needle Mountains group in the Needle Mountains region is that of a synclinorium, which was probably connected by a corresponding anticlinal structure with the same rocks in the canyon of Uncompahgre River, subsequent erosion having removed the intervening beds. The structural connections between the members of the Needle Mountains group found at Rico and those of the Needles are not known; there is nothing at either point to indicate any similarity to the relations between the rocks of the Needles and those of the Uncompahgre Canyon. The beds are probably continuous and deeply buried by Paleozoic or later sedimentary rocks. During the time that the forces which produced these structures were acting, much faulting and shearing took place, not only within the Needle Mountains group itself, but also along the contacts between the Algonkian and the Archean rocks; in addition, a complicated infolding occurred between the Irving greenstone and the Vallecito conglomerate.

At the close of the movements that deformed the Algonkian, intrusions of granular rocks, largely in the Archean, took place. The greatest of these bodies, the Eolus granite, cuts not only the Archean but the Needle Mountains rocks, and dikes of it are numerous in the Irving greenstones. Other granite bodies, which appear only as intrusive in the Archean, are also believed to belong to this general period of eruption, mainly because they show no evidence of having been subjected to severe dynamic metamorphism, which they must have endured had they existed at the time of the deformation of the Uncompahgre. Although granites are the most numerous of the granular intrusives, more basic rocks have been found in the region. Of these the granodiorite near the junction of Virginia Creek with Florida River is the only one occurring in the Needle Mountains quadrangle; but a large mass of gabbro lies just beyond the western boundary, in the southeast corner of the Engineer Mountain quadrangle.

PENEPLANATION AND PALEOZOIC SEDIMENTATION.

After the intrusions of igneous rock, which may be regarded as occurring either at the close of pre-Cambrian time or at the beginning of the Paleozoic, great orogenic movements took place which resulted in the uplift, erosion, and gradual peneplanation of an area of continental proportions. In the beveling process all the rocks of the Needle Mountains region were exposed, in one place or another, at the surface of a nearly level plain and in positions suggestive of the vicissitudes through which they had passed.

At the close of the long period of base-leveling the land areas subsided and were covered by ocean waters. The subsidence, however, was not general, for certain parts of the land were uplifted, and it was from their erosion that the materials were supplied for the deposition, in the neighboring shallow seas, of the first of the Paleozoic formations, the Ignacio. One of these uplands doubtless existed to the north of the present Needle Mountains area, as shown by the shore-line character of the basal conglomerates in the vicinity of Molas Lake; there must have been another to the east, for bowlder beds are found underlying the finer-grained Ignacio in hollows in the granite floor near Rockwood, in the Durango quadrangle, to the southwest. The land area to the north may well have represented the partially dissected anticlinal connection between the younger Algonkian rocks of the Needle Mountains and those of the Uncompahgre Canyon. The lithologic character of the Ignacio formation indicates that tranquil, shallow-water conditions prevailed which favored the deposition of sands and rarely clays.

No records have been found in this region to indicate that rocks of periods intermediate between the Ignacio (middle or upper Cambrian) and the Elbert (late Devonian) were deposited, yet where the two formations are in contact no evidence of unconformity has been observed, and it is difficult to conceive that land conditions existed during the time that intervened between the deposition of the Ignacio and that of the Elbert; nor does it seem likely that great subsidence of the sea bottom took place. The presence of Silurian beds elsewhere in Colorado, as in the Elk Mountains, may mean that the gap between the Ignacio and the Elbert is one of deposition and subsequent erosion which locally left a plain so level that the Elbert seems conformable with the Ignacio.

The seas in which the Elbert and Ouray formations were deposited covered wider areas than those of Ignacio time and at the beginning were shallow and undisturbed by strong currents. Land areas were of low relief and small islands may have been scattered about the seas, with many flats on which pools were left by the retreating tides. The evaporation of the saline waters caused the formation of salt crystals, which on the return of the tides were covered by fine silts and subsequently dissolved, leaving their casts in the sand. At the close of the Elbert the seas gradually deepened and cleared. Corals appeared for a time and then gave way to an abundant molluscan fauna when deep-sea conditions prevailed and the limestones so characteristic of the Ouray were deposited.

After the Ouray epoch, which had continued without a break from Devonian to Carboniferous time, an uplift took place which raised the sediments to the surface of the sea. This resulted, in the Needle Mountains region, in the destruction of the upper parts of the Ouray, laid down in early Carboniferous time. The erosion, probably in a large degree submarine and due to strong currents, both tidal and from revived streams from the raised lands, resulted in a churning of the sea bottom and a redeposition of these materials with others derived from the land. The deposits resulting from this stormy period, the Molas formation, were of no great thickness and consisted of muds and rolled and rounded fragments of the older beds. The Ouray is entirely absent from its appropriate place in the sedimentary section exposed in Silver Creek, near Rico, and it is possible that the greatest erosion took place west of the San Juan, in what is now the plateau country.

After the Molas the quieter conditions of deep water returned and continued, with minor oscillations, for a very long time, during which the sands, clays, and limestones of the Hermosa were deposited to a depth of 2000 feet or more.

Slight changes in the conditions of sedimentation began as the Rico formation was laid down and became more and more important as time went on. The Rico marks the beginning of a long period during which limestones were not prominent at first and later gave way almost entirely to the red sandstones and shales of the Cutler formation.

The Rico is the last formation of which the complete history is shown in the Needle Mountains quadrangle, but sedimentation continued until the close of the Cutler.

POST-PALEOZOIC MOVEMENTS.

Just what happened in the interval between Paleozoic and Mesozoic time is not apparent in the sedimentary records preserved in the southern and western parts of the San Juan Mountains, but to the north evidence has been found that deformation and elevation occurred and that the Cutler and part, at least, of the Hermosa were eroded before subsidence permitted the beginning of Mesozoic sedimentation. Breaks are recognized in the sedimentary column at various stages in the Mesozoic, but none of these concerns the present history. It is sufficient to state here that in all probability the whole sedimentary section of the San Juan covered what is to-day the site of the Needle Mountains to a depth of 12,000 feet or more.

POST-CRETACEOUS UPLIFT AND EROSION.

At the close of this long period of sedimentation widespread orogenic movements began which affected the whole Rocky Mountain region. The effects have been recognized in many localities far distant from each other, and the resulting general elevation of the land is commonly referred to as the post-Laramie or post-Cretaceous uplift. In the San Juan these movements manifested themselves in a broad doming or quaquaversal folding of all the sedimentary rocks, accompanied in places by faulting and closer folding. The erosion incident to this uplift in time reduced wide areas to low relief, but probably during all this period that region which now centers about the Needle Mountains continued to rise slowly as a local dome, and, on account of the more active erosion, older and older formations were uncovered until the pre-Cambrian rocks appeared.

TELLURIDE CONGLOMERATE.

After peneplanation a more rapid uplifting of the land of which the Needle Mountains are now a part seems to have taken place. Many torrential rivers flowed from this region over nearly level country to the northwest and possibly emptied into a shallow lake or sea. The waste that these streams carried down was deposited as the Telluride conglomerate. In the border land of the mountains it occupied gullies or the bottoms of small valleys; farther away the materials were spread out over the plains by numerous streams and became more continuous, thicker, and of finer texture. The formation, consisting of fine conglomerate, sandstone, and shale, is a thousand feet thick in the Mount Wilson group in the Telluride and Rico quadrangles, but the occurrences in the Needle Mountains quadrangle are in the form of coarsely conglomeratic valley fillings of torrential streams. There are good reasons for believing, as shown in the Silverton folio, that an interval of great erosion followed the deposition of the Telluride conglomerate. In the country lying east of the Animas and Uncompahgre rivers there is evidence that the headwaters of a drainage system, corresponding in magnitude and position to that of the Rio Grande of to-day, attacked not only the newly deposited Telluride conglomerate but also the older rocks, and developed a rugged topography. In the Telluride quadrangle, to the west, no break was recognized between the conglomerate and the San Juan tuff, and continuous accumulation appears to have taken place. These conditions may well have existed at the same time and the erosion may be accounted for by the capture of certain streams belonging to the Telluride system by the headwaters of the eastern drainage, causing sudden and active erosion, while quiet deposition continued to the west.

VOLCANIC ERUPTIONS.

Toward the close of this period of sedimentation, but after the rugged topography to the east had been developed, volcanic eruptions began and continued with explosive violence for some time. Gradually the more active eruptions gave away to quieter outpourings of lava, accompanied by occasional explosive outbursts similar to the first, but of less magnitude. In this way the vast deposits of the San Juan tuff and breccia were formed, and were covered by the lavas and tuffs of the Silverton and Potosi volcanic series. The record of these events is far from complete within the boundaries of the Needle Mountains quadrangle, and for a more detailed history of this period reference should be made to the Silverton folio.

While the greater part of the material involved in these volcanic activities reached the surface either as ash or lava, some was intruded in the form of dikes or laccoliths into the sedimentary formations and even into the older volcanic rocks. It is probable that the Lime Creek laccolith belongs to this period, while the intrusive rhyolite of Bear Creek forced its way into the tuffs and flows at a late stage in the volcanic history.

Throughout this period of vulcanism active erosion continued, wearing away the recently erupted tuffs in places, only to have the valleys refilled by fresh ejecta. At the close of the eruptions an enormous amount of material had been thrown out and deposited over a very large area, and a much greater thickness existed then than remains to-day. It is impossible to say how thick the deposits were, or to what extent they buried the mountainous region of the Needles. That they covered the mountain slopes on the north to some depth is shown by the remnants of San Juan tuff and later lavas occurring north of Elk Creek and in the vicinity of the Continental Divide.

DEVELOPMENT OF THE PRESENT PHYSIOGRAPHIC FEATURES.

After the last great eruptions had died away, active erosion began its task of removing the accumulations of volcanic débris and, in its early stages, initiated in general the existing drainage systems. In the Needle Mountains province two conditions appear to have prevailed in different parts. On the southern slopes of the domal uplift erosion had been progressing without serious interruption since early Telluride time, and it is improbable that in this region volcanic materials accumulated sufficiently to influence the drainage; it is even possible that they may never have appeared here, the southern slopes being protected by the higher central summits from the ejecta of the northern volcanoes. On the flanks of the dome a simple consequent drainage developed which, after reaching maturity, was revived, possibly more than once, by uplifts of the whole region, and eventually became superposed on the pre-Cambrian rocks. The northern slopes, on the other hand, had had their initial drainage obliterated in its early stages by volcanic outpourings, and under this protection, frequently renewed, suffered comparatively little from the attack of streams until the close of the volcanic period. In the meantime streams from the south had presumably carved deeply into the dome. One of them, the Animas, passed completely through and obtained control of the drainage beginning to develop on the volcanic rocks to the north, probably capturing a number of the heads of the youthful Rio Grande. Thus the northern flanks of the Needles came to be drained by a stream originally consequent on the southern slopes, the area left to the control of the Rio Grande being comparatively small. The upper tributaries of the Animas, at first resting on the volcanics, soon cut through them and became superposed on the older rocks which composed the former northern slopes of the Needle Mountains dome. Other laterals attacked the elevated central region and, in connection with the Vallecito and Lime Creek systems, developed an extremely rugged topography. The less active Florida drainage succeeded in removing only a part of the sedimentary cover within its province and entrenched itself on the old peneplain surface upon which the Paleozoic rested. Such tributaries of the Animas as Tank and Canyon creeks have accomplished still less, since they have left Lime and Stag mesas capped by sedimentary rocks and have only slightly dissected the Paleozoic floor where it is exposed (figs. 1 and 2).

GLACIATION.

In all its broader features the present drainage system of the region had been developed before climatic conditions changed and glaciers took up the work of rivers. Geologists who are familiar with the Pleistocene history of North America are of opinion that the glaciation which may now be recognized in the mountains of Colorado belongs to the last main stage of the Glacial epoch—the Wisconsin. In other Rocky Mountain regions, especially in the Wasatch and Uinta mountains of Utah, traces have been found of earlier stages, and it is thought that an interval of great erosion preceded the Wisconsin. If this is so, it is possible that the extensive denudation which preceded the known glaciation of the San Juan Mountains may have been contemporaneous with or followed earlier stages of glaciation, but of this no distinct evidence has been observed in the region.

So far as the Needle Mountains are concerned the glaciation which can be observed to-day may be regarded as having effected merely a modification of a youthful or at most a submature topography. It has recorded itself mainly in a slight rounding of the cross sections of the valleys, in the development of cirques at the heads of many of the streams, and in the laying down of morainal gravels upon the hillsides and valley floors. Probably the most interesting features are due to the glaciers near the heads of the smaller streams, which continued to exist for some time after the disappearance of the ice from the main valleys. Slopes and streams with northern exposure collected and retained more snow and ice than the south-facing hillsides opposite them, and glaciers in such localities remained, probably, long after the main ice stream had vanished. The familiar process of headward flattening of valley floors, initiated during the period of maximum glaciation, continued for a long time in these protected basins, so that, when the ice finally disappeared, it left not simple lateral valleys with grades that increased gradually upward, but short, broad valleys which had low grades disproportionate to their length and from which the streams descended with a marked increase in grade to the master streams. The valleys of Needle and Tenmile creeks have no flood plains; in fact, with minor exceptions, the streams flow on bed rock nearly all the way to the torrential fans at their mouths, and their discordant southern laterals can not be explained by the theory of the greater erosive power of the main ice stream, nor do they represent laterals "protected" by residual glaciers and left "hung up" by the rapid erosion of the main streams whose glaciers had disappeared, for the main streams have accomplished but very little erosion since Glacial time. The local basins must be attributed solely to the continuance of headward ice quarrying long after glacial action had ceased to be of regional importance, and they represent the only marked topographic changes that the ice accomplished.

The lateral cirques of Needle and Tenmile creeks are merely examples, possibly more perfect, of many others that occur throughout the Needles, in addition to the amphitheaters at the heads of nearly all of the larger streams (figs. 3 and 4). The lakelets which are found in many of these cirques fill rock basins that owe their origin directly to the ice. It is to the glaciers that occupied these cirques that the greater part of the morainal material found in the region is to be attributed, especially that which still covers many of the higher hillsides.

On the final disappearance of the ice the streams resumed their activity, but up to the present time have accomplished little more than the removal or redistribution of some of the morainal materials and minor erosion near the heads of the smaller laterals. Both of these processes have resulted in the laying down of gravels as flood-plain deposits on the floors of the larger valleys and the formation of detrital cones at the mouths of the smaller streams.

Contemporaneous with these latest events were the landslides which took place in the region of Paleozoic rocks in the southwestern section of the quadrangle; these, together with the closely related rock streams, have been discussed in detail at their appropriate place under the heading "Descriptive geology," on page 7.

Of the agents now at work in the degradation of the Needle Mountains, frost is undoubtedly the most active, on account of the high altitude of the region, which causes the temperature to fall below the freezing point nearly every night in the year. Owing to the compact nature of the older rocks which compose the higher summits and steeper cliffs of the Needles, remarkably little weathering has occurred and talus, so characteristic of the regions of volcanic rocks to the north, is comparatively insignificant. The Needle Mountains exhibit a striking instance of a youthful topography retained long after surrounding regions had reached early maturity, largely on account of the greater hardness of the rocks.

June, 1904.

ECONOMIC GEOLOGY.

By J. D. Irving and W. H. Emmons.

The economic interest of the area included within the Needle Mountains quadrangle centers in the gold and silver veins, which are found in considerable numbers at several localities. The ore deposits have not so far proved of great commercial importance, nor does the present development hold large promise for the future, but the mines have produced some ore and the fact that the entire area has not yet been fully developed leaves a reasonable hope that further mining may lead to important discoveries.

Mining development has been confined to two areas within the quadrangle. One of these is located in the northeast corner, in the country immediately surrounding and to the southeast of Beartown. To this may be given the name "northeastern area." The other and more important of the two includes those deposits which occur along Needle Creek from Needleton to Chicago Basin, a large number of ore bodies in the Chicago district, and others in Columbine Pass, Aztec Mountain, Bullion Mountain, East Silver Mesa, and Vallecito Basin. These may be termed collectively the "central area."

Prospecting has been carried on with considerable activity throughout the entire extent of the quadrangle, and numerous isolated occurrences of mineralization have been noted, but none of them have thus far proved to be of sufficient importance to justify a detailed study.

CENTRAL AREA.

The gold and silver veins which characterize the central area are of a very simple character, being in all cases fissure veins, usually without complications of structure. A few are extensively modified by later distortion and mineralization, but these are of secondary importance. The veins are in most cases very similar, both in detailed structure and in the manner of occurrence, but for convenience of description they may be divided into two classes—(1) unmodified fissure veins and (2) modified fissure veins.

Unmodified fissure veins are those which have been formed by the filling of open fissures in the country rock with gangue and ore minerals, the gangue minerals being in far greater amount in the vein. In this type of vein the ore formation has been due entirely to the deposition of minerals in empty cavities, and the inclosing rock is rarely if ever found to yield appreciable values. A certain amount of mineral material, notably silica and pyrite, has, however, penetrated the country rock in the immediate vicinity of the fissures, producing a high degree of alteration, which fades away gradually until unaltered rock is reached.

The modified fissures are of less frequent occurrence and of less importance than the type just described. They are sheeted zones in the country rock where the filling of open spaces has been slight as compared with the alteration and replacement of the rock intervening between the fractures. To this type of fissure Ransome, in his study of the Silverton mining region, has given the name "lode fissure," a term which may well be used to describe these deposits. Such lode fissures are formed by the occurrence of a large number of minute and generally parallel fractures, in many cases very close together and nowhere exhibiting a large amount of open space into which mineral matter might be introduced. The rock between these fractures has been altered very extensively and much of it replaced by minerals having a character wholly different from that of the original constituents of the rock. Such alteration and mineralization does not terminate abruptly at any one fissure, but fades out gradually beyond the limits of the sheeted zone, to the barren and unaltered country rock.

UNMODIFIED FISSURE VEINS.

Unmodified fissure veins are the more important of the two classes, as it is to them that the region owes whatever production it has so far attained. These fissure veins are in many instances characterized by a remarkably prominent banding and show the feature termed "crustification," usually observed in typical fissure veins, to a greater degree of perfection than the writers have before observed at any locality. These veins may best be described by considering, first, the fracture into which the ore material has been introduced, and second, the filling material.

The fissures.—The fissures are usually short, few of them exceeding 300 yards in length, and terminate at their extremities by a gradual pinching out into the country rock. In some cases, as in the Aztec mine, a fissure has been followed for a distance of 1500 feet and may be traced on the surface for as much as a mile. This is not, however, a very common occurrence, as the majority of fractures seem to have been more in the nature of lenticular spaces in the granite, without great lateral or vertical extent. Little work has been done at any great depth, so that it is difficult to determine the downward limit of the fractures, but it seems very probable that they do not extend far below the surface, because of their limited outcrop. The fissures in this region are probably merely the roots of larger fractures, the upper portions of which have been worn away by the extensive erosion to which the region has been subjected.

In detail the fissures are extremely irregular, and while they continue in general in one prevailing direction they bend from side to side at very short intervals along their course, so that a direction determined at any one point will rarely give an accurate idea of the trend of the vein. The width of some of the fissures is upward of 10 feet, the open spaces which originally existed in the vein being almost completely filled with ore and gangue mineral. The fissures vary in width from this as an outside estimate to mere knife-edge fractures, hardly discernible in the comparatively little-altered surrounding country rock. It is very probable that many of the pinches and swells which have caused these variations are due to movement on a curving fracture which has brought convex or concave surfaces on either side opposite to one another. Such movement has occurred both laterally and vertically. The fissures are rarely single, but send out many curving arms which return within a short distance to the vein from which they branched. Auxiliary fractures cross the included masses of country rock between the various arms, so that the result of the fissuring has been to produce a long zone of reticulated character. In some cases this branching has been so extensive that the vein can be described as little more than a heavily brecciated zone.

In dip the fissures usually diverge quite widely from the vertical, the average inclination being in the neighborhood of 60° to 70°. Parallel fissures generally dip in the same direction. In some cases, as in the Aztec mine, the dip varies from nearly vertical in Chicago Basin to about 65° on the south side of Aztec Mountain, where the vein has been opened in the Republic tunnel.

MODIFIED FISSURE VEINS.

Modified fissure veins occur chiefly in the gneisses and schists along Needle Creek. As briefly described above, they are zones of mineralization formed along a closely spaced series of fractures. Open spaces are of small extent and mineralization has proceeded more by means of replacement than by the filling of cavities. Such sheeted zones usually intersect others at various angles and in some places, as in the Bluff and Waterfall mine, in the southern side of Needle Creek, the zones intersect at such close intervals as to form almost a stockwork vein, no single fissure extending for any appreciable distance without being lost in its intersection with another vein trending at a widely different angle. These sheeted zones in rare cases exceed 5 feet in width and vary from that down to an extremely narrow veinlet which would not be apparent but for the silicification which has proceeded outward from the initial fracture. The zones also have many branches, this feature being more common in the hanging wall than in the foot wall. Where branches are numerous the original vein terminates within a very short distance beyond a branch and a new fissure takes its place, only to be itself lost in a new branch not far away.

These sheeted zones or lode fissures occur most commonly in the metamorphic gneisses and schists. In their strike they invariably cross the lamination of these rocks, in no instance showing a trend parallel to the prevailing schistosity. They are much less numerous than the modified type first described.

Relationship of fissures.—As in most regions where fissure veins are developed, the fissures where they intersect the surface trend somewhat regularly in certain prevailing directions. To fissures which follow with but slight divergence a single direction the term "fissure system" is usually applied. If more than one fissure system is present in a given locality intersections of the several systems occur and form a network which is in many cases rather complicated.

In the central area above described two striking instances of such fissure systems occur and the directions followed by them show so little variation that it is often impossible to detect even the slightest divergence. The stronger system, i. e., that which includes the greater number and the longer veins, trends N. 10° W. To this system belong the Aztec, St. Paul, and Apache veins, besides many others of less importance. The veins of this system usually dip about 60°, but in some instances are nearly perpendicular. The other system trends N. 80° E., exactly at right angles to the first.

These two systems intersect in Chicago and Vallecito basins and the neighboring country and form a rectangular network which is the more striking owing to the bare and uncovered nature of the rock surface. At some intersections the veins cross one another without displacement on either fissure; at others N. 10° W. fissures terminate abruptly against N. 80° E. fissures, while the reverse conditions prevail at no great distance.

Relative age of fissures.—From these observations it seems probable that all the fissures belong to a single period of formation. To account for their occurrence is a matter of some difficulty, but it seems not unlikely that the compressive strains to which the San Juan region has been repeatedly subjected may be the cause.

The wall rocks.—The fissures are confined to two general types of wall rock—the metamorphic gneisses and schists of Algonkian age and the later intrusive granites, the latter rocks showing some local variation, but in general being readily recognizable as a single group.

The metamorphic rocks intersected by the veins occur along Needle Creek below Chicago Basin. They comprise very prominently banded gneisses, showing in many cases a wavy lamination and composed of biotite, quartz, and orthoclase, the latter usually much crushed and locally altered by dynamic stress into secondary minerals. The other members of the metamorphic series are interbedded bands of hornblende-schist and biotite-mica-schist, apparently derived from the earlier basic eruptives and showing, so far as observed, no traces of sedimentary origin.

Relation of schistosity to fissures.—The veins where they intersect the metamorphic rocks are in all cases independent of the lamination. They cut across the schistosity most commonly at right angles, or less regularly at an angle only slightly athwart this structure.

The laminated structure of the country rock has, however, exercised a much greater effect on the material forming the vein, which in many instances extends for some distance along the planes of schistosity from the original supplying fissures, thus forming ragged and irregular hanging and foot walls.

The granites constitute the country rock in which the fissures are more commonly found. They are in most cases normal biotite-quartz-orthoclase granites containing a little plagioclase and considerable microcline. In some instances they are porphyritic and show evidences of different ages of intrusion; in others they are aplitic.

As seen on the surface they are invariably red in color, owing to the oxidation of a portion of the contained iron, but at some depth a uniform gray tint is to be observed and may be said to characterize the main type of wall rock.

The veins in the granite have more regular walls than those in the metamorphic rocks, show less replacement, and are much more uniform in dip and general direction.

Where more than one variety of granite is intersected by a single fissure the difference in the wall rock has exerted no appreciable effect on either the character of the fissure or the vein material which fills it.

Vein filling.—The material which fills the fissures possesses unusual interest as regards its mineralogy, structure, and genesis. It may be divided into two general classes—ore minerals, or metallic minerals yielding the values sought for in mining, and gangue minerals, or nonmetallic minerals of comparatively worthless character, which make up the balance of the vein filling.

The ore minerals in the deep-seated portions of the veins, where neither oxidation nor secondary sulphide enrichment has exerted any influence, are, in the order of their abundance and development, pyrite, chalcopyrite, galena, and here and there a little sphalerite; the gangue minerals are quartz, rhodochrosite, fluorite, chalcedonic silica, and locally a little barite and calcite.

The minerals, in the manner of their arrangement in the fissures, possess to a remarkable degree the structure called by Posêpny crustification—that is, they are arranged in successive layers on the walls, each layer on the one side corresponding to its prototype on the other until the center is reached. If the fissure is narrow the space is entirely filled; if wide a cavity or vug is left into which the crystals of the last-formed mineral project. In only a few cases, however, is this structure perfect and undisturbed, because the veins have been filled, reopened, their filling material shattered, and the veins filled again as many as three separate times.

The original gangue filling of the veins seems to have been a fine-grained dark- to light-gray silica, cryptocrystalline in character and microscopically showing a considerable admixture of water of crystallization. Disseminated through it and also scattered in large, irregular masses is a fine-grained, velvet-like pyrite containing considerable copper and in some cases grading into chalcopyrite. In this sulphide gold and silver are also present, the latter metal being in large excess and as a rule constituting a slightly greater portion of the actual value than the gold.

After a shattering of these earlier deposited materials had occurred, in the secondary fissures so formed and around the angular fragments of gray silica and pyrite a filling of later gangue minerals was introduced. In most cases these minerals simply filled open cavities, but in some instances a replacement by them of the earlier silica may be detected. The later minerals are, in the order of their deposition, rhodochrosite, white quartz, fluorite, white quartz, fluorite. The layers of white quartz and fluorite are generally repeated several times, at some points the fluorite filling being the last formed and at others the white quartz.

Galena is sometimes found in large bunches, but its relative age is difficult to determine. Barite also occurs locally.

The final product of the mineral deposition is a vein which, though low in commercial value, is of singular beauty. Dark-gray silica in angular, broken fragments, bright-red rhodochrosite, yellow pyrite, and chalcopyrite, with large druses of milk-white quartz, alternating with layers of brilliant green crystalline fluorite, combine to make a vein strikingly varied in color and unusually fascinating to mineral collectors.

The values in the vein where unoxidized and unenriched are uniformly low. If the whole face is broken and no sorting attempted an average of $19 is a fair outside estimate of the grade of ore. Of this $4 to $6 is gold, $5 to $9 silver, and the balance copper. Selected samples may run much higher. Where oxidized and secondarily enriched the veins carry values, as will be later explained, in many cases phenomenally high.

The pay values, except where the irregular bunches of silver-bearing galena occur, are undoubtedly contained in the pyrite as a result of the first period of mineralization. This has been demonstrated in a number of cases by a separation of the various constituents of the veins. For example, in the Bluff and Waterfall group, in Needle Creek, the sulphide ore without concentration carried about $18 in gold and silver. The separated pyrite, on the other hand, carried several ounces in gold and even a larger proportion of silver, while the gangue minerals left were practically worthless.

Alteration.—The oxidation of the ore bodies has produced very marked effects on the surface croppings of the vein. The rhodochrosite, of which there is usually a large amount in the mines, has altered to a jet-black, soot-like mass of manganese oxides, probably pyrolusite or wad, while the iron present, though in places in sufficient amount to give a rusty stain to the gossan, is as a rule obscured by the preponderating black of the manganese.

This black material is mingled with the highly resistant white quartz, which has not become easily stained, so that the croppings of the vein are in many instances readily seen and of an unusually prominent nature. This is especially true on the south side of Aztec Mountain. To the north the iron present in the veins has been larger in amount and has produced the more usual type of iron-stained quartz gossan so familiar to the student of vein phenomena.

Oxidation has not usually proceeded very far below the surface. On steep hillsides it rarely extends more than a few feet underground, and indeed in some cases the sulphides crop almost at the surface. Under the crests of the hills and on slopes of low gradient it has, however, reached much greater depths, often 300 or 400 feet below the outcrop.

Effect of secondary alteration on values.—Between the outcrop and unaltered sulphides a zone of varying vertical range occurs in which rich minerals, often deceptive to the prospector, have been developed. Thus in the upper workings of the Aztec mine brittle and native silver were found, but soon gave place to low-grade ore as depth was attained. Some of the ore is reported to have yielded $1800 per ton, largely in silver.

In like manner in the Mastodon mine irregular crystals and masses of argentite, intermingled with clay and other surface materials, were found in the lower portion of the oxidized zone. In the Bluff and Waterfall groups native wire silver and wire gold were found within reach of the oxidizing surface waters, but gave way in depth to unaltered sulphides.

There is little question that these high-grade minerals are produced by the action of unaltered sulphides on descending surface waters which have leached the values from the upper portions of the veins, and prospectors would do well to exercise caution in regarding such rich croppings as evidence of the continued downward extent of payable ore.

Age of the veins.—There is no available evidence which will serve to determine the age of the fissures and of the introduction of minerals into them, but the fact that they are of limited extent both vertically as well as horizontally indicates that a large amount of erosion has taken place, and that the veins in their present condition are but the remnants of much more extensive fissures whose upper portions have been carried away by erosive action. That such extensive denudation should have occurred within a comparatively limited time seems improbable, though such criteria are of no very positive value in determining geologic age.

Origin of veins.—The veins present features which are in many ways unlike those of other areas in the San Juan region. They carry a higher percentage of fluorite than has been observed in most veins of the region, and are more nearly related to ore deposits usually found in granitic areas. For this reason it seems possible that they may have been produced by pneumatolitic emanations from some one of the varieties of intrusive granites, several of which are present in the region. If such be the case, the veins would resemble in large part a type of pegmatite veins and would present analogies to deposits of tin in granitic regions. It seems not improbable that the prevalence of fluorite and quartz may support this view, but in the absence of any other definite data the writer hesitates to venture an opinion on the question. It is one which is hardly likely to be solved with any degree of satisfaction from the limited number of occurrences now to be observed.

FUTURE OF THE DISTRICT.

In most districts where veins of gold and silver occur the probability of striking other veins of similar character is so strong as to afford much encouragement to the prospector, for where ore bodies of a certain type are found others of similar nature in almost all cases occur in the near vicinity. In the Needle Mountains region, however, the veins already discovered are very numerous and the outcroppings are so prominent in the uncovered granite of the barren summits that it seems improbable that any should have escaped the diligent eye of the prospector. The uniformly low grade of the sulphide ores, moreover, leads one to suppose that new discoveries would not be more promising than those already made. That any of the veins so far opened should constitute the basis of extensive commercial enterprises seems very improbable, but worked on a small scale with proper methods of concentration the ores may yet be made profitable. The high grade of the concentrates as compared with the untreated ore would seem to indicate that concentration on a small scale might prove successful. A consolidation of interest in the many small and irregular veins of the district, coupled with suitable means of treatment on a modest scale, might produce results beneficial alike to the investor and the district.

NORTHEASTERN AREA.

BEAR CREEK DEPOSITS.

The Bear Creek mining camp is located in the northeast corner of the quadrangle, near the head of Bear Creek. It includes also a group of claims at the head of Elk Creek, just over the Continental Divide. It is about 17 miles from Silverton; 9 miles of this distance is over a wagon road by way of Howardsville, up Cunningham Gulch, and the remainder is over a good pack trail. The district may also be reached by wagon road from Creede, a distance of about 40 miles, and in the summer of 1905 a trail was being constructed from Elk Park, on the Denver and Rio Grande Railroad, about 9 miles away. The country is extremely rugged and much of it is above timber line. The region was prospected as early as 1878. The Gold Bug mine was among the first properties located and was sold to Kansas City parties, who, it is said, took out about $50,000 worth of very rich ore. The Good Hope and Sylvanite have also produced considerable amounts and shipments have been made from a number of other properties. The entire district has produced about $200,000, chiefly in high-grade tellurium ores. Nearly all of this was packed out by mule trains.

When the camp was visited in August, 1905, the most largely developed mines had been idle for years, and the portals of several of their tunnels were filled with snow and ice, so that entrance to all the workings was impossible. A number of smaller properties were being developed, and data gained from the examination of these and from the surface workings of the larger properties appear to be in full accord with those reported for the workings then inaccessible.

Geology.—The Bear Creek deposits are located in an area of pre-Cambrian schists, slates, and quartzites, partly covered by San Juan andesite tuffs and later flows. The Archean schists, which are the oldest rocks, have a laminated, streaked appearance and are composed mainly of mica, quartz, and feldspar. Seams or veins of quartz, many of them 3 or 4 inches wide, are quite common. These are known to prospectors as "bull quartz" or "barren quartz." The schists are described more fully under "Descriptive geology."

The slates and the quartzites, though of pre-Cambrian age, are younger than the Archean schists, upon which they rest unconformably, and are the products of metamorphism of shale and sandstone. They belong to the Uncompahgre formation. Certain portions of the shale were sandy, and after metamorphism became a hard, dense, and easily fractured rock, much like the quartzite.

The pre-Cambrian rocks are rather closely folded, the axes of the folds trending generally a few degrees south of east. They are also faulted, the faults running nearly east and west, approximately with the strike of the beds. The andesite tuffs and flows are of volcanic origin and rest upon a very irregular eroded surface of the pre-Cambrian rock. They have suffered little change since their deposition.

A long, narrow fault block of the Uncompahgre quartzite enters the area just south of Beartown and extends nearly due west to the head of Elk Creek. On the north it is in fault contact with the Archean schist, and on the south with other Uncompahgre schist and quartzite. It is partially covered by the Tertiary volcanics. Where it is the surface rock, it stands up conspicuously above the surrounding country and is very generally mistaken for a dike, which form is strongly suggested by its long, narrow, regular outline. A number of claims are located along this fault block, among which are the Good Hope, the New York and Brooklyn, and the Silverton. The lodes cross the block nearly at right angles to the fault; there seems to be no explanation for such a distribution of developments except that the veins are more clearly defined in the quartzite than in the surrounding slate and schists.

Minerals of the ore deposits.—The ore deposits are narrow fissure veins composed chiefly of white quartz, in which are scattered small masses or pockets of gray ore minerals. While quartz is by far the most important gangue mineral, calcite, barite, and a white mud, probably kaolinite, are also present. The metallic minerals are a telluride of gold and silver (probably petzite), tetrahedrite (or gray copper), iron pyrite, marcasite (or white iron pyrite), copper pyrites, bornite (or peacock ore), galena, sphalerite, arsenopyrite, limonite, hematite, malachite, and azurite. None of these minerals have been discovered in sufficient quantities to be of economic importance except the telluride and gray copper. These are very intimately associated. What appeared to be a single mineral from the Good Hope mine gave tests for tellurium, copper, arsenic, antimony, and sulphur. This mineral had the physical properties of gray copper. The tellurium mineral probably occurs also in a much purer state, since roasted specimens which have been taken from the Good Hope mine showed light-yellow globules of considerable size sticking to the white-quartz gangue.

White iron pyrite is found in relative abundance, especially at the Sylvanite and Kankakee properties. Its occurrence is similar to that of the ore minerals, and it has been mistaken for a telluride. It may be distinguished from the tellurium ores by the darker color of its powder, its greater hardness, and its tendency to assume botryoidal or roundish forms.

Pyrite and chalcopyrite (copper pyrites) occur as small masses and crystals in the gangue, and to a certain extent in the country rock. Assays of these minerals show that they carry very low values in gold and silver. The copper, lead, and zinc minerals have not been found in sufficient quantities for profitable exploitation.

Ore deposits.—Some of the veins are well defined and their decomposed outcrops, marked by yellow iron stains, may be followed along the surface for considerable distances. Their usual trend is nearly north and south. Those of an important group run about S. 83° W. The veins are usually vertical or are inclined less than 10° from that position. The fissures do not appear to be closely related to the larger structural features of the country, but cut the faults, the axes of the folds, and the fissility of the rocks at a high angle. The fissures cut all the rocks, but are most clearly defined in the quartzite or in the siliceous portion of the slate. These rocks are strong and brittle and are better adapted to forming and holding open the cavities in which the quartz and ore may be deposited than are the slates. Along the outcrops of the Gold Bug lead there are a number of shallow surface workings. Some of them are said to have produced several hundred dollars' worth of ore. They are all in hard, rather siliceous phases of the slate, and it is reported that in the development of the Gold Bug mine the profitable ore pockets were found in siliceous walls.

The veins vary in width from the thinness of a knife blade to 2 or 3 feet, and the Gold Bug vein is said to reach a maximum of 6 feet. While they usually have well-defined limits, there is often a considerable amount of the country rock contained in the vein matter, so that in certain cases where the country rock is cut by quartz stringers it is impossible to definitely locate the wall. For considerable distances the veins may be entirely barren of the precious metals, while at the end of this barren streak a rich pocket may occur in which are large and profitable quantities of high-grade ores. When this pocket has been removed another barren streak is apt to be encountered. This erratic distribution of the ore has had a tendency to discourage continued effort at exploitation, and while a considerable amount of development work has been done the principal mines are at present idle.

PROSPECTS AT THE HEAD OF THE NORTH FORK OF ELK CREEK.

At the head of the north fork of Elk Creek, near the northern border of the quadrangle, there are a number of small openings in the Archean schist and granite. The Elkora group of claims, which lies north of the head of the gulch, was located and patented in the early nineties, but has been deserted for eight or ten years. At the Eldorado claim, which is about a mile southeast of the Elkora group, a tunnel is being driven to strike a lead which, from surface outcrops, is supposed to run S. 46° E.

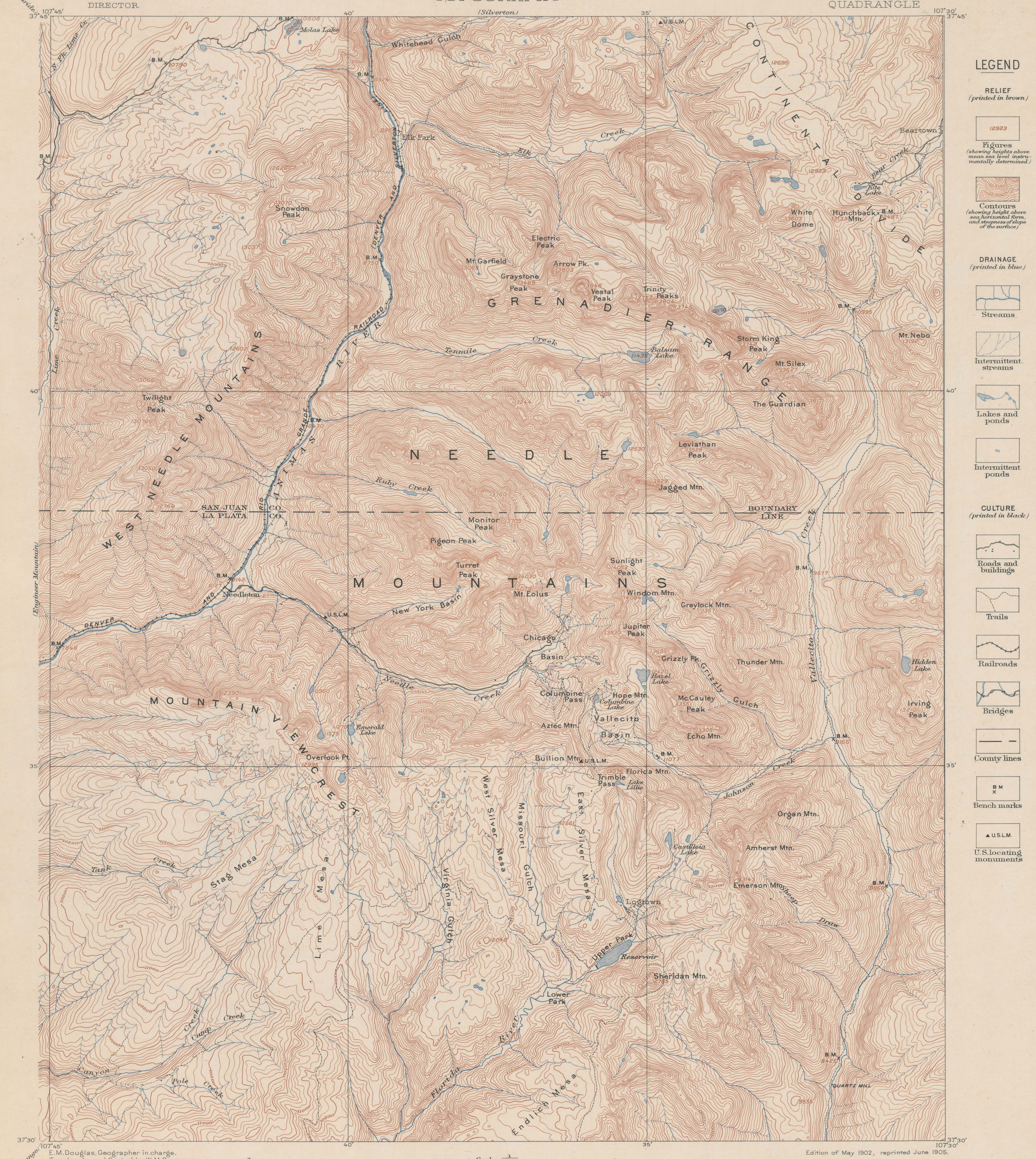
The country rock at the Eldorado is a plicated micaceous chloritic schist containing small quartzitic areas. At the surface a decomposed outcrop of the vein is composed of quartz, calcite, barite, limonite, magnetite, pyrite, chalcopyrite, malachite, azurite, galena, and sphalerite. No tetrahedrite or tellurium minerals have been discovered. The lode has not yet been exposed in depth.

June, 1904.

U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT
DIRECTOR

TOPOGRAPHY

COLORADO
NEEDLE MOUNTAINS
QUADRANGLE



E. M. Douglas, Geographer in charge.
Topography and Control by W. M. Beaman.
Surveyed in 1899 and 1900.

APPROXIMATE MEAN DECLINATION 1900.

Scale $\frac{1}{62500}$

Miles

Kilometers

Contour interval 100 feet.
Datum is mean sea level.
Projection based on U.S.C. and G. Survey data of 1900.
Projection of Engineer Mt. sheet based on earlier data.

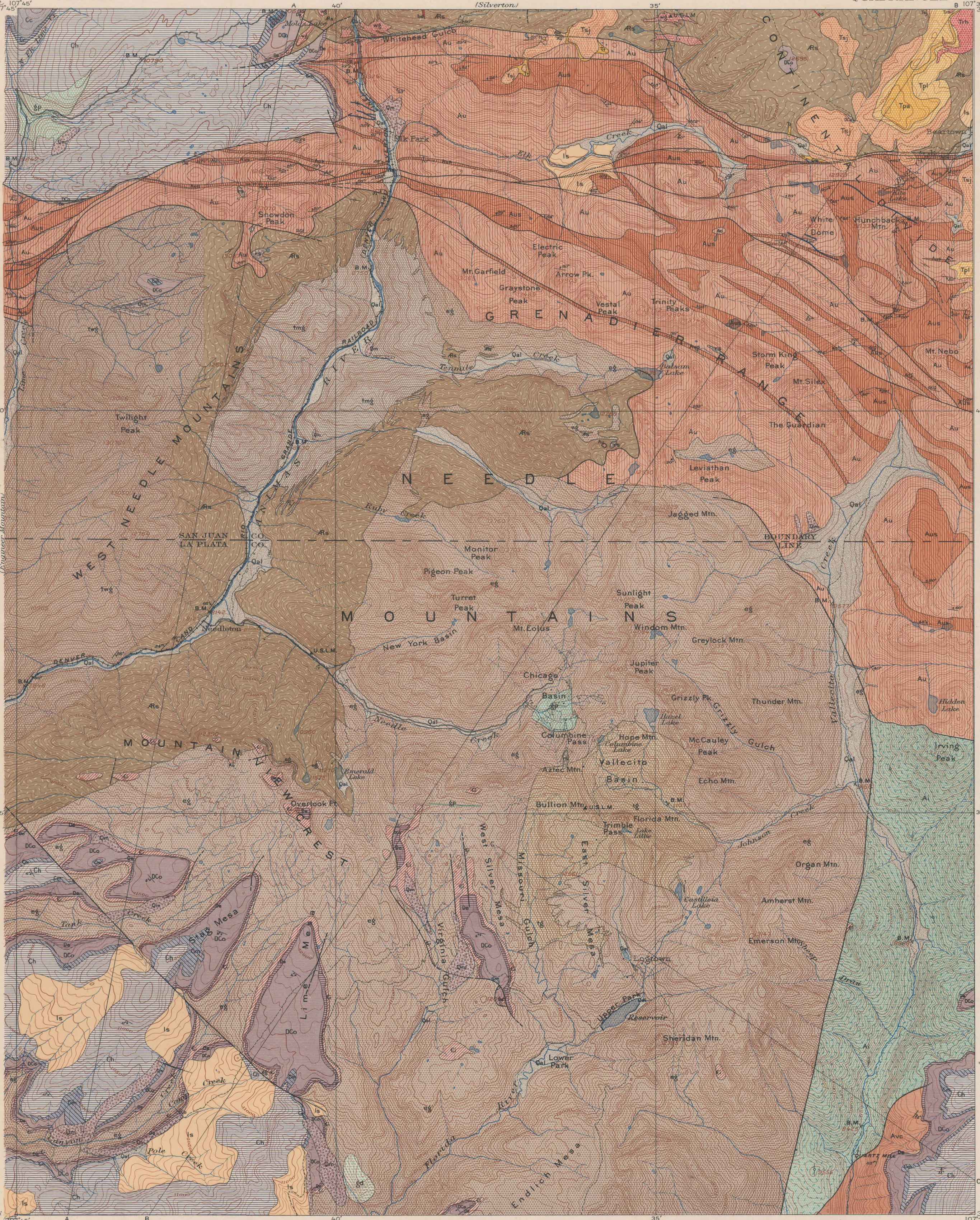
Edition of May 1902, reprinted June 1905.

U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT
DIRECTOR

AREAL GEOLOGY

COLORADO
NEEDLE MOUNTAINS
QUADRANGLE

(Silverton)



E. M. Douglas, Geographer in charge.
Topography and Control by W. M. Beaman.
Surveyed in 1899 and 1900.

TRUE NORTH
MAGNETIC NORTH
$13\frac{1}{2}°$
APPROXIMATE MEAN DECLINATION 1900.

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 100 feet.

Datum is mean sea level.
Projection based on U.S.C. and G. Survey data of 1900.
Projection of Engineer Mt. sheet based on earlier data.

Edition of Sept. 1905

Geology by Whitman Cross and Ernest Howe,
assisted by J. Morgan Clements,
G. W. Stose, and Albert Johannsen.
Surveyed in 1900, 1901, and 1903.

LEGEND

IGNEOUS ROCKS
(continued)

Earlier than Ignacio quartzite — ALGONKIAN OR CAMBRIAN

gp — Granite-porphyry *(dikes, crosscutting bodies, and laccolithic forms)*

l — Lamprophyric dikes *(minette and kersantite)*

bd — Basic dikes *(diabase and greenstone)*

gd — Granodiorite

tg — Trimble granite *(fine-grained, gray biotite-granite)*

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

wg — Whitehead granite *(reddish-pink biotite-granite)*

tmg — Tenmile granite *(pink and gray biotite-granite)*

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

ALGONKIAN *(Engineer Mountain)*

Ai — Irving greenstone *(largely greenstone, massive and schistose, with some granite-gneiss and quartzite)*

Known faults *(doubtful location indicated by dashes)*

Concealed faults *(covered by younger deposits)*

Sections

Strike and dip of stratified rocks
Strike of vertical beds

LEGEND

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

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

SEDIMENTARY ROCKS

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

QUATERNARY

Recent — Qal — Alluvium *(torrential fans and stream gravels)*

Pleistocene — Qm — Moraines *(glacial gravels, unstratified, in mounds and ridges)*

TERTIARY

Eocene? — Tt — Telluride conglomerate *(pebbles and bowlders of schist, quartzite, and limestone)*

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)*

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

UNCONFORMITY

DEVONIAN

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

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

UNCONFORMITY

CAMBRIAN

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

UNCONFORMITY

ALGONKIAN

Needle Mountains group

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

Avc — Vallecito conglomerate *(lower part consists largely of greenstone schist pebbles; upper part contains pebbles of quartzite, jasper, hematite, and magnetite)*

METAMORPHIC ROCKS OF UNKNOWN ORIGIN

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

ARCHEAN

ARs — Schist and gneiss *(quartz-mica-schist and amphibolite with some granite-gneiss)*

IGNEOUS ROCKS

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

TERTIARY

Trh — Intrusive rhyolite *(an irregular, cross-cutting body)*

Potosi volcanic series

Tpl — Quartz-latite *(flows and tuffs)*

Tpa — Andesite *(mainly in flows)*

Tsj — San Juan tuff *(blue to gray andesitic tuff and breccia)*

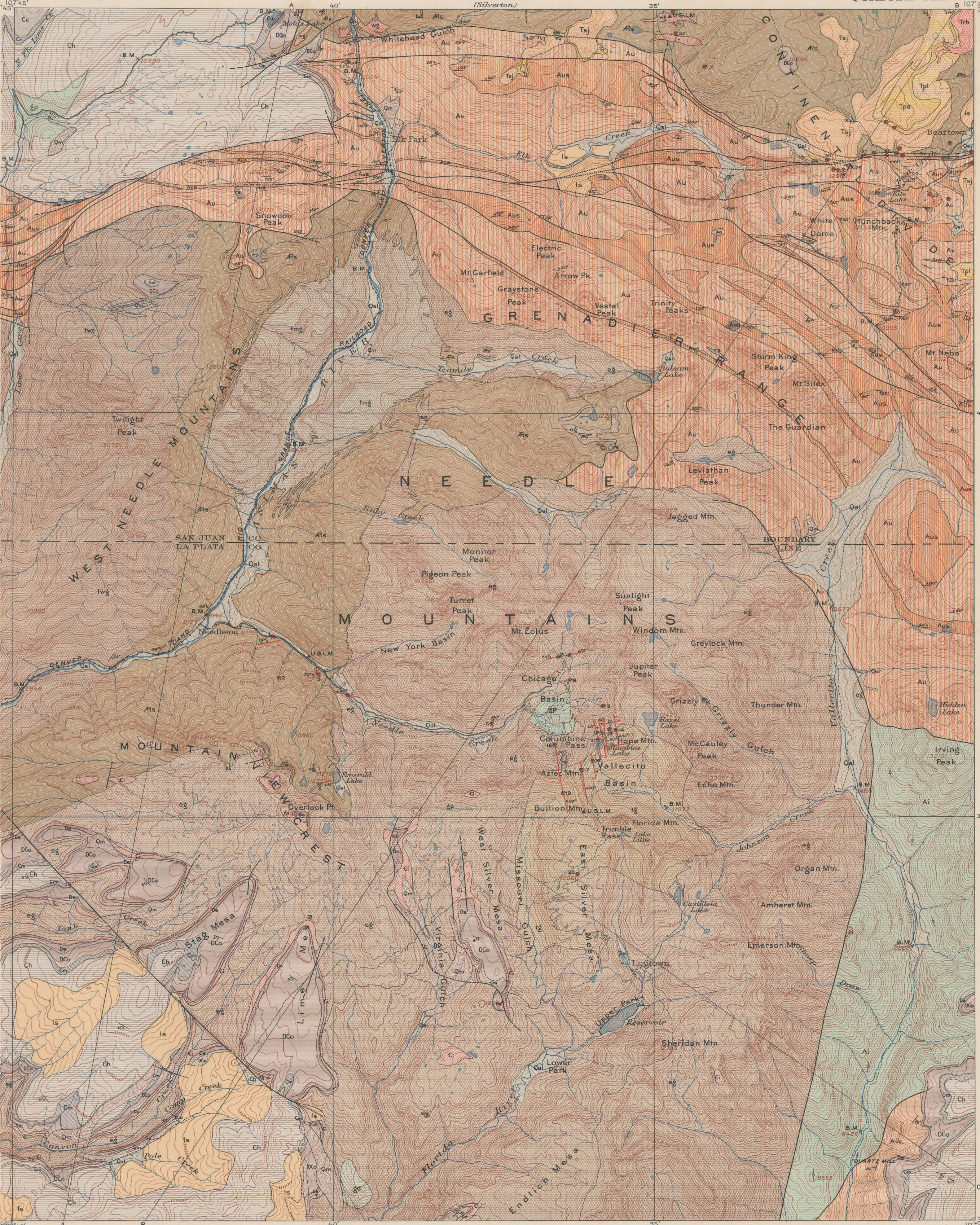
Legend is continued on the left margin.

U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT
DIRECTOR

ECONOMIC GEOLOGY

COLORADO
NEEDLE MOUNTAINS
QUADRANGLE

(Telluride) 107°45' 37°45'   A   40'   (Silverton)   35'   B 107°30' 37°45'



37°30' 107°45' (Durango)   A   B   40'   35'   C   107°30' 37°30'

E.M. Douglas, Geographer in charge.
Topography and Control by W.M. Beaman.
Surveyed in 1899 and 1900.

TRUE NORTH — MAGNETIC NORTH — 13½°
APPROXIMATE MEAN DECLINATION 1900.

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 100 feet.

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Projection based on U.S.C. and G. Survey data of 1900.
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Edition of Sept. 1905.

Geology by Whitman Cross and Ernest Howe,
assisted by J. Morgan Clements,
G.W. Stose, and Albert Johannsen.
Surveyed in 1900, 1901, and 1903.
Economic Geology by J.D. Irving
and W.H. Emmons.
Surveyed in 1904 and 1905.

LEGEND

IGNEOUS ROCKS
(continued)

Earlier than Ignacio quartzite

ALGONKIAN OR CAMBRIAN

gp — Granite-porphyry *(dikes, crosscutting bodies, and laccolithic forms)*

lp — Lamprophyric dikes *(minette and kersantite)*

bd — Basic dikes *(diabase and greenstone)*

gd — Granodiorite

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

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ALGONKIAN

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Known faults *(doubtful location indicated by dashes)*

Concealed faults *(covered by younger deposits)*

Sections

A B C

80° Strike and dip of stratified rocks

Strike of vertical beds

80° Fluoritic gold-bearing quartz veins, showing strike and dip

Gold mines and prospects

NAMES OF MINES.

Location indicated on map by numbers.

1. Mastodon.
2. Waterfall.
3. List.
4. Name unknown.
5. Emerald Lake.
6. Sheridan.
7. Mt. Eolus.
8. Little Jim.
9. Black Giant.
10. Name unknown.
11. Eureka.
12. Eureka.
13. Jennie Hayes.
14. Apache.
15. Name unknown.
16. St. Paul.
17. Republic.
18. Aztec.
19. Pittsburg.
20. Name unknown.
21. Kankakee.
22. Sylvanite.
23. Robinson.
24. Camp Bird.
25. Gold Bug.
26. New York and Brooklyn.
27. Good Hope.
28. Golden Shear.
29. Summit.
30. Little May.
31. Eldorado.
32. Elkora.

LEGEND

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

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

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

QUATERNARY

Recent

Qal — Alluvium *(torrential fans and stream gravels)*

Pleistocene

Qm — Moraines *(glacial gravels, unstratified, in mounds and ridges)*

TERTIARY

Eocene?

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

UNCONFORMITY

CARBONIFEROUS

Permian?

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UNCONFORMITY

DEVONIAN

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UNCONFORMITY

CAMBRIAN

Saratogan?

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UNCONFORMITY

ALGONKIAN

Needle Mountains group

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

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

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Potosi volcanic series

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Tpa — Andesite *(mainly in flows)*

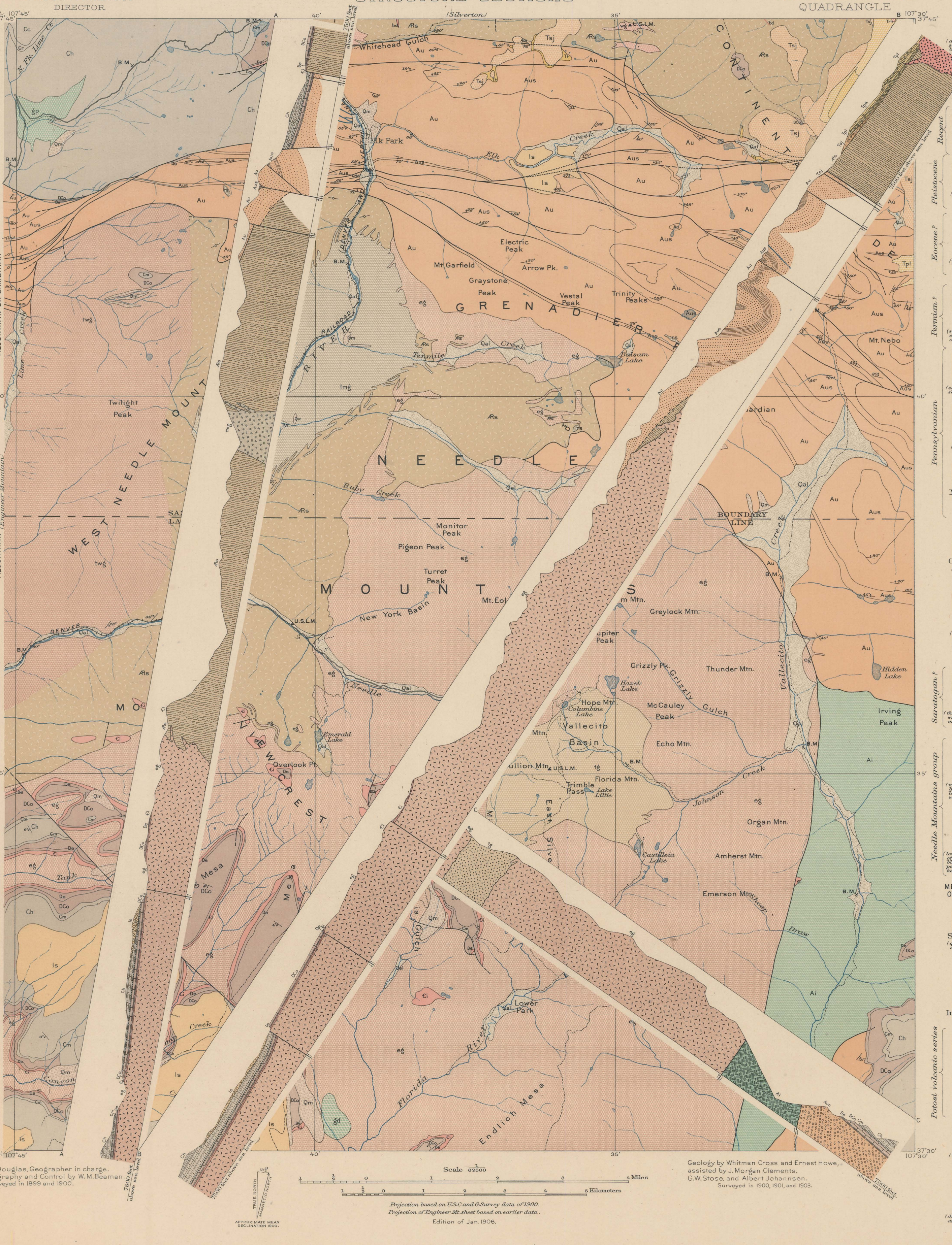
Tsj — San Juan tuff *(blue to gray andesitic tuff and breccia)*

Legend is continued on the left margin.

U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT
DIRECTOR

STRUCTURE SECTIONS

COLORADO
NEEDLE MOUNTAINS
QUADRANGLE



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Topography and Control by W.M. Beaman.
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LEGEND

SHEET SYMBOL / SECTION SYMBOL

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

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SEDIMENTARY ROCKS

QUATERNARY

Recent

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TERTIARY

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UNCONFORMITY

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UNCONFORMITY

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IGNEOUS ROCKS

TERTIARY

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Potosi volcanic series

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Tpa — **Andesite** *(mainly in flows)*

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Legend is continued on the left margin.

LEGEND

IGNEOUS ROCKS *(continued)*

SHEET SYMBOL / SECTION SYMBOL

ALGONKIAN OR CAMBRIAN

Earlier than Ignacio quartzite

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Known faults *(doubtful location indicated by dashes)*

Concealed faults *(covered by younger deposits)*

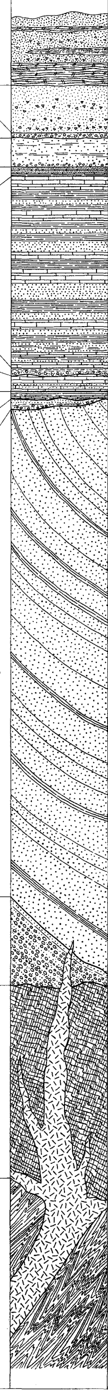
80° Strike and dip of stratified rocks

Strike of vertical beds

COLUMNAR SECTION

GENERALIZED SECTION FOR THE NEEDLE MOUNTAINS QUADRANGLE.

SCALE: 1 INCH = 1000 FEET.



System.	Series.	Formation Name.	Symbol.	Columnar Section.	Thickness in Feet.	Character and Distribution of Formations.
TERTIARY		Potosi volcanic series { Quartz-latite and andesite.	Tpl Tpa		750±	Alternation of quartz-latite and rhyolite flows and tuffs and andesite flows in places. Flows predominate near the base.
TERTIARY		San Juan tuff.	Tsj		500±	Almost exclusively andesitic débris, well stratified near the base, but coarser and less distinctly bedded in upper portion. Thickness variable, reaching 2500 feet in Silverton quadrangle. Fossils not known to occur.
TERTIARY	EOCENE?	Telluride conglomerate.	Tt		0–100	Thin isolated deposits of coarse conglomerate, containing pebbles and bowlders of schist, granite, quartzite, some limestone, and the harder Paleozoic sediments. Thickens westward to nearly 1000 feet.
		UNCONFORMITY				
CARBONIFEROUS	PERMIAN?	Cutler formation.	Cc		300±	Complex of bright-red sandstone, lighter-red or pinkish grits and conglomerate, alternating with sandy shale and earthy or sandy limestone of varying shades of red. Limestone conglomerate fossiliferous.
CARBONIFEROUS	PENNSYLVANIAN	Rico formation.	Cr		100±	Dark reddish-brown sandstone and pink grits, with intercalated greenish or reddish shale and sandy, fossiliferous limestone.
CARBONIFEROUS	PENNSYLVANIAN	Hermosa formation.	Ch		2000	Series of limestones, grits, sandstones, and shales of variable distribution and development. Limestone, in thick, massive beds predominates in the middle and upper parts of the section, the lower portion being mainly sandstone and shale, with a few limestone layers. Numerous invertebrate fossils occur in shales and limestones.
CARBONIFEROUS	PENNSYLVANIAN	Molas formation.	Cm		75±	Red calcareous shale and sandstone, containing pebbles of Mississippian chert and limestone, and limestone lenses with Pennsylvanian fossils.
		UNCONFORMITY				
CARBONIFEROUS	MISS.	Ouray limestone.	DCo		100-250	Buff limestone, compact above, thin-bedded below with shale and quartzitic partings. Mississippian fossils in upper third, Devonian in lower portion.
DEV.		Elbert formation.	De		75±	Thin-bedded limestone, sandstone, and shale containing casts of salt crystals and Devonian fish remains.
		UNCONFORMITY				
CAMB.		Ignacio quartzite.	€i		0-200	Massive quartzite, conglomerate near base, thin-bedded with shaly partings in middle portion. One fossil of Cambrian type found.
		UNCONFORMITY				
ALGONKIAN	NEEDLE MOUNTAINS GROUP	Uncompahgre formation, with shale members.	Au (Aus)		5000	Massive and some thin-bedded quartzites and occasional bands of shale. Quartzites vary in color from white through pink, brown, and purple to black. Shales are rusty brown or black.
ALGONKIAN	NEEDLE MOUNTAINS GROUP	Vallecito conglomerate.	Avc		1000±	Coarse conglomerate consisting of pebbles and bowlders of greenstone and quartzite with occasional fragment of jasper and magnetite. Portions near Irving greenstone contact are often schistose.
		UNCONFORMITY				
ALGONKIAN		Irving greenstone.	Ai		10000	Greenstone, greenstone-porphyry, and greenstone-schist, with subordinate quartz-mica-schist and granite-gneiss. In association with the greenstones are a few bands of quartzite, often mashed and schistose, whose structural relations and origin are obscure.
ARCHEAN		Schist and gneiss. Granite, intrusive in pre-Cambrian rocks.	Æs			Quartz-mica- and amphibole-schists, and granite-gneiss less prominent, much crumpled and contorted.

WHITMAN CROSS,
ERNEST HOWE,
Geologists.

ILLUSTRATIONS I

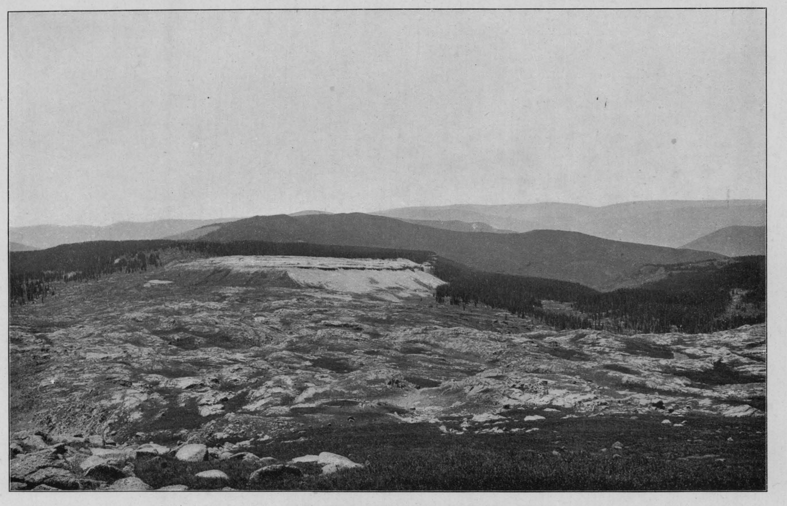


Fig. 1.—LIME MESA, FROM NEAR OVERLOOK POINT.

Ignacio quartzite rests on the granite at foot of talus from Lime Mesa; the prominent escarpment is formed by Ouray limestone. To the left is a small glacial lake in the Ignacio; to the right of Lime Mesa is the upper portion of Canyon Creek; a branch of Florida River is to the extreme left. Valleys of the Animas and the Florida appear in the distance.

Fig. 2.—STAG MESA, FROM NEAR OVERLOOK POINT.

Débris of Ignacio quartzite on the right; rough surface beyond the foreground is formed by Eolus granite, on which, in the middle distance, rest the older Paleozoic rocks of Stag Mesa. In the distance is the escarpment of the Hermosa formation on the west side of the Animas Valley, while in the far distance rise the La Plata Mountains, composed in part of Cretaceous rocks.

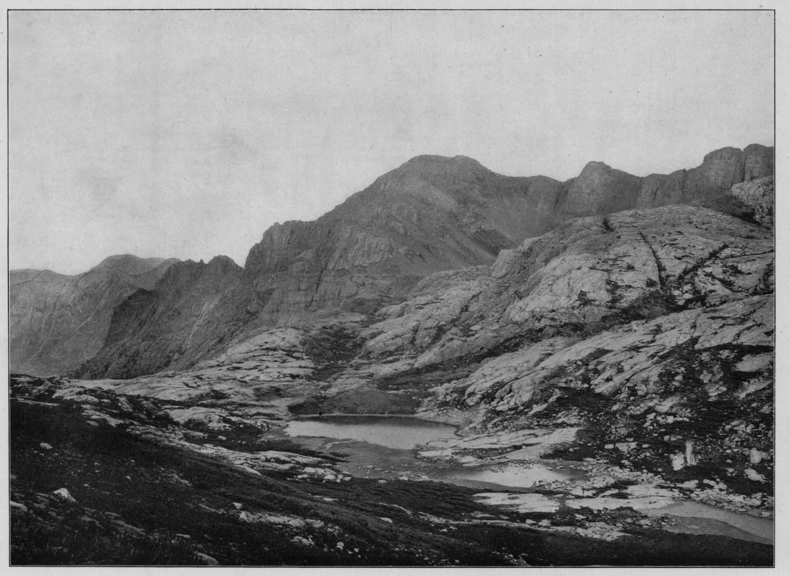


Fig. 3.—GRANITE CLIFFS OF AMHERST MOUNTAIN, FROM NEAR CASTILLEIA LAKE.

A typical view of the higher glaciated region of Needle Mountains. The polished ridge to the left of the small lake is the divide between the Florida and a branch of the Vallecito.

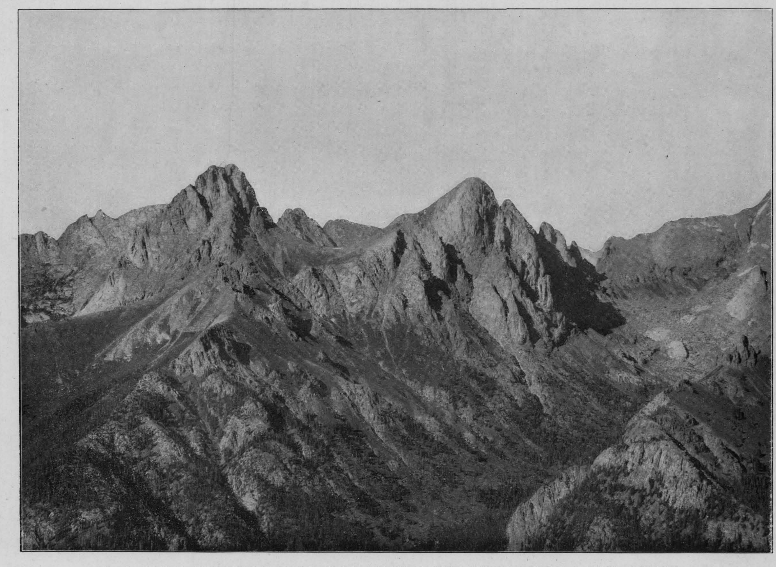


Fig. 4.—PIGEON AND TURRET PEAKS, FROM MOUNTAIN VIEW CREST, NEARLY 4 MILES DISTANT.

New York Basin is to the right. These are two of the highest and most conspicuous summits of the Needle Mountains, and are composed entirely of Eolus granite.

Fig. 5.—CLOSED AND OVERTURNED FOLDS OF UNCOMPAHGRE QUARTZITES AND SLATES IN REGION ABOUT HEAD OF VALLECITO CREEK.

White Dome is in the middle; Grenadier Range and the west fork of the Vallecito are on the left; Hunchback Mountain is slightly to the right of White Dome. From a point just north of Mount Nebo.

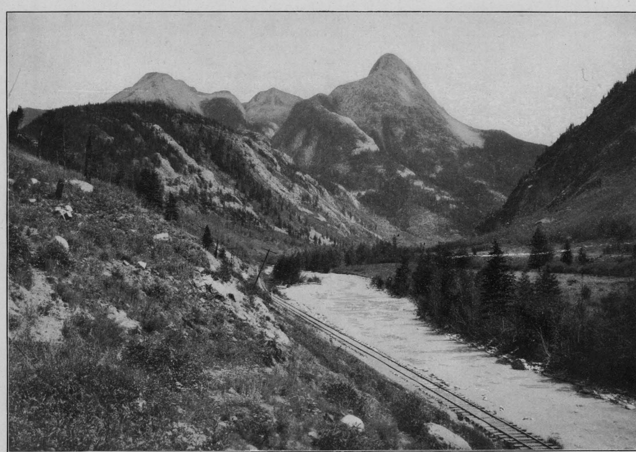


Fig. 6.—MOUNT GARFIELD, FROM THE NORTHERN END OF ELK PARK, ANIMAS CANYON.

Near center of picture the vertical strata of Uncompahgre quartzites are shown. The well-defined ravine below and to left of Mount Garfield marks the fault which bounds the quartzites at the river. The peak of Mount Garfield itself consists of northward-dipping quartzites, which have been thrust over the Archean schists.

Fig. 7.—THE VALLECITO AND THE GUARDIAN, FROM A POINT NOT FAR ABOVE MOUTH OF JOHNSON CREEK.

Stream gravels and terraces in the foreground; the cliffs to the left are Eolus granite, all else being within the area of Uncompahgre quartzites and slates.

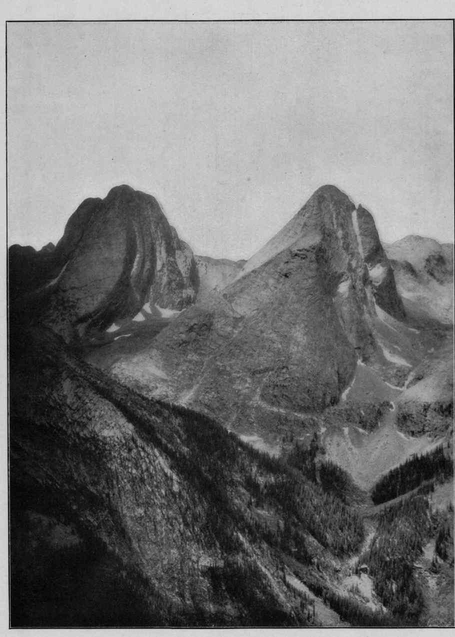


Fig. 8.—ARROW AND VESTAL PEAKS, SEEN ACROSS ELK CREEK FROM DIVIDE NEAR HEAD OF WHITEHEAD CREEK.

In Vestal Peak, to the left, are shown the upturned strata of Uncompahgre quartzite, characteristic of the whole Grenadier Range.

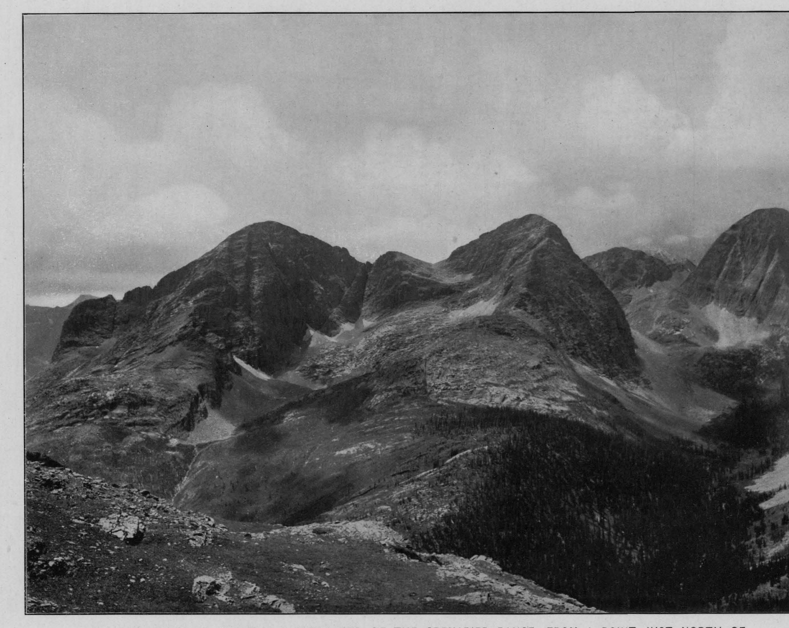


Fig. 9.—THE GUARDIAN AND THE EASTERN END OF THE GRENADIER RANGE FROM A POINT JUST NORTH OF MOUNT NEBO.

Fig. 10.—A GLACIATED SURFACE IN ANIMAS CANYON.

Shows light-gray Twilight gneissose granite cutting dark amphibolites.

Fig. 11.—INCLUSIONS OF AMPHIBOLE-SCHIST IN TWILIGHT GNEISSOSE GRANITE.

Illustrates manner in which the gneissose banding follows the irregular outlines of included schist fragments.

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