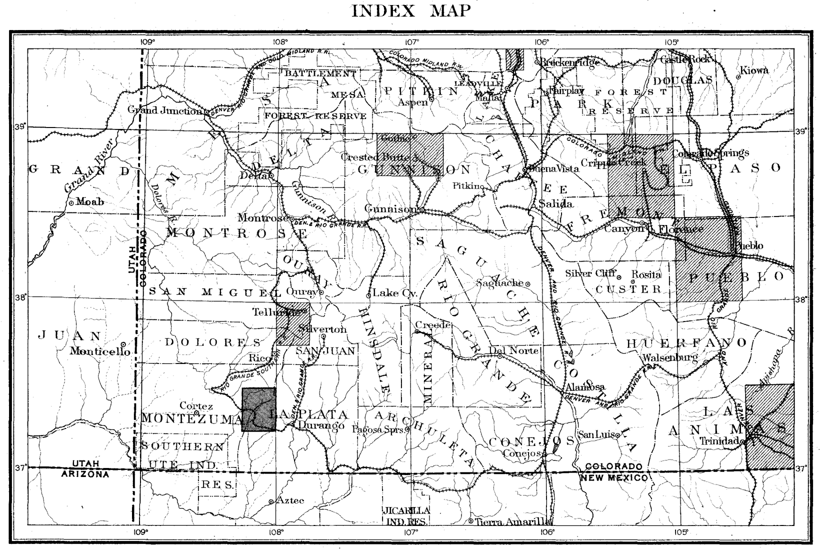
DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

GEOLOGIC ATLAS OF THE UNITED STATES

LA PLATA FOLIO

COLORADO

INDEX MAP



SCALE: 40 MILES-1 INCH

AREA OF THE LA PLATA FOLIO

AREA OF OTHER PUBLISHED FOLIOS

LIST OF SHEETS

DESCRIPTION   TOPOGRAPHY   HISTORICAL GEOLOGY   ECONOMIC GEOLOGY   STRUCTURE SECTIONS

COLUMNAR SECTION   SPECIAL ILLUSTRATIONS

FOLIO 60   LIBRARY EDITION   LA PLATA

WASHINGTON, D. C.
ENGRAVED AND PRINTED BY THE U. S. GEOLOGICAL SURVEY
GEORGE W. STOSE, EDITOR OF GEOLOGIC MAPS   S. J. KÜBEL, CHIEF ENGRAVER
1899

EXPLANATION.

The Geological Survey is making a geologic map of the United States, which necessitates the preparation of a topographic base map. The two are being issued together in the form of an atlas, the parts of which are called folios. Each folio consists of a topographic base 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 horizontal outline, or contour, of all slopes, and to indicate their grade or degree of steepness. This is done by lines connecting points of equal elevation above mean sea-level, the lines being drawn at regular vertical intervals. These lines are called *contours*, and the uniform vertical 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:

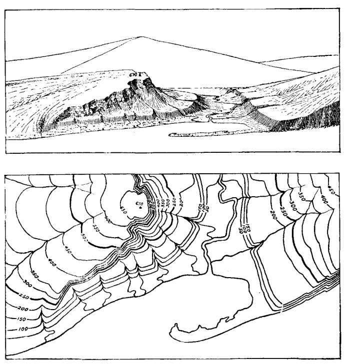


Fig. 1.—Ideal sketch and corresponding contour map.

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 in a precipice. Contrasted with this precipice is the gentle descent of the left-hand slope. 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 approximately a certain height above sea-level. In this illustration the contour interval is 50 feet; therefore the contours are drawn at 50, 100, 150, 200 feet, and so on, above sea-level. Along the contour at 250 feet lie all points of the surface 250 feet above sea; and similarly with any other contour. In the space between any two contours are found all 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 nearly all the contours are numbered. Where this is not possible, certain contours—say every fifth one—are accentuated and numbered; the heights of others may then be ascertained by counting up or down from a numbered contour.

2. Contours define the forms of slopes. Since contours are continuous horizontal lines conforming to the surface of the ground, they wind smoothly about smooth surfaces, recede into all reentrant angles of ravines, and project in passing about prominences. The 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 vertical 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 used 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 the stream flows the year round 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, and artificial details, are printed in black.

Scales.—The area of the United States (excluding Alaska) is about 3,025,000 square miles. On a map with the scale of 1 mile to the inch this would cover 3,025,000 square inches, and to accommodate it the paper dimensions would need to be 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 $\frac{1}{63,360}$. Both of these methods are used on the maps of the Geological Survey.

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 and corresponds nearly to 1 square mile; on the scale $\frac{1}{125,000}$, to about 4 square miles; and on the scale $\frac{1}{250,000}$, to about 16 square miles. At the bottom of each atlas sheet the scale is expressed in three different ways, one being a graduated line representing miles and parts of miles in English inches, another indicating distance in the metric system, and a third giving the fractional scale.

Atlas sheets and quadrangles.—The map is being published in atlas sheets of convenient size, which are bounded by parallels and meridians. The corresponding four-cornered portions of territory 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-quarter 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, respectively.

The atlas sheets, being only parts of one map of the United States, are laid out without regard to the boundary lines of the States, counties, or 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 sheet.—Within the limits of scale the topographic sheet is an accurate and characteristic delineation of the relief, drainage, and culture of the district represented. Viewing the landscape, map in hand, every characteristic feature of sufficient magnitude should be recognizable. It should guide the traveler; serve the investor or owner who desires to ascertain the position and surroundings of property to be bought or sold; save the engineer preliminary surveys in locating roads, railways, and irrigation ditches; provide educational material for schools and homes; and serve many of the purposes of a map for local reference.

THE GEOLOGIC MAP.

The maps representing areal geology show by colors and conventional signs, on the topographic base map, the distribution of rock formations on the surface of the earth, and the structure-section map shows their underground relations, as far as known, and in such detail as the scale permits.

KINDS OF ROCKS.

Rocks are of many kinds. The original crust of the earth was probably composed of *igneous rocks*, and all other rocks have been derived from them in one way or another.

Atmospheric agencies gradually break up igneous rocks, forming superficial, or *surficial*, deposits of clay, sand, and gravel. Deposits of this class have been formed on land surfaces since the earliest geologic time. Through the transporting agencies of streams the surficial materials of all ages and origins are carried to the sea, where, along with material derived from the land by the action of the waves on the coast, they form *sedimentary rocks*. These are usually hardened into conglomerate, sandstone, shale, and limestone, but they may remain unconsolidated and still be called "rocks" by the geologist, though popularly known as gravel, sand, and clay.

From time to time in geologic history igneous and sedimentary rocks have been deeply buried, consolidated, and raised again above the surface of the water. In these processes, through the agencies of pressure, movement, and chemical action, they are often greatly altered, and in this condition they are called *metamorphic rocks*.

Igneous rocks.—These are rocks which have cooled and consolidated from a liquid state. As has been explained, sedimentary rocks were deposited on the original igneous rocks. Through the igneous and sedimentary rocks of all ages molten material has from time to time been forced upward to or near the surface, and there consolidated. When the channels or vents into which this molten material is forced do not reach the surface, it either consolidates in cracks or fissures crossing the bedding planes, thus forming dikes, or else spreads out between the strata in large bodies, called sills or laccoliths. Such rocks are called *intrusive*. Within their rock enclosures they cool slowly, and hence are generally of crystalline texture. When the channels reach the surface the lavas often flow out and build up volcanoes. These lavas cool rapidly in the air, acquiring a glassy or, more often, a partially crystalline condition. They are usually more or less porous. The igneous rocks thus formed upon the surface are called *extrusive*. Explosive action often accompanies volcanic eruptions, causing ejections of dust or ash and larger fragments. These materials when consolidated constitute breccias, agglomerates, and tuffs. The ash when carried into lakes or seas may become stratified, so as to have the structure of sedimentary rocks.

The age of an igneous rock is often difficult or impossible to determine. When it cuts across a sedimentary rock, it is younger than that rock, and when a sedimentary rock is deposited over it, the igneous rock is the older.

Under the influence of dynamic and chemical forces an igneous rock may be metamorphosed. The alteration may involve only a rearrangement of its minute particles or it may be accompanied by a change in chemical and mineralogic composition. Further, the structure of the rock may be changed by the development of planes of division, so that it splits in one direction more easily than in others. Thus a granite may pass into a gneiss, and from that into a mica-schist.

Sedimentary rocks.—These comprise all rocks which have been deposited under water, whether in sea, lake, or stream. They form a very large part of the dry land.

When the materials of which sedimentary rocks are composed are carried as solid particles by water and deposited as gravel, sand, or mud, the deposit is called a mechanical sediment. These may become hardened into conglomerate, sandstone, or shale. When the material is carried in solution by the water and is deposited without the aid of life, it is called a chemical sediment; if deposited with the aid of life, it is called an organic sediment. The more important rocks formed from chemical and organic deposits are limestone, chert, gypsum, salt, iron ore, peat, lignite, and coal. Any one of the above sedimentary deposits may be separately formed, or the different materials may be intermingled in many ways, producing a great variety of rocks.

Sedimentary rocks are usually made up of layers or beds which can be easily separated. These layers are called *strata*. Rocks deposited in successive 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 over wide expanses, and as it rises or subsides the shore-lines of the ocean are changed: areas of deposition may rise above the water and become land areas, and land areas may sink below the water and become areas of deposition. If North America were gradually to sink a thousand feet the sea would flow over the Atlantic coast and the Mississippi and Ohio valleys from the Gulf of Mexico to the Great Lakes; the Appalachian Mountains would become an archipelago, and the ocean's shore would traverse Wisconsin, Iowa, and Kansas, and extend thence to Texas. More extensive changes than this have repeatedly occurred in the past.

The character of the original sediments may be changed by chemical and dynamic action so as to produce metamorphic rocks. In the metamorphism of a sedimentary rock, just as in the metamorphism of an igneous rock, the substances of which it is composed may enter into new combinations, or new substances may be added. When these processes are complete the sedimentary rock becomes crystalline. Such changes transform sandstone to quartzite, limestone to marble, and modify other rocks according to their composition. A system of parallel division planes is often produced, which may cross the original beds or strata at any angle. Rocks divided by such planes are called slates or schists.

Rocks of any period of the earth's history may be more or less altered, but the younger formations have generally escaped marked metamorphism, and the oldest sediments known, though generally the most altered, in some localities remain essentially unchanged.

Surficial rocks.—These embrace the soils, clays, sands, gravels, and bowlders that cover the surface, whether derived from the breaking up or disintegration of the underlying rocks by atmospheric agencies or from glacial action. Surficial rocks that are due to disintegration are produced chiefly by the action of air, water, frost, animals, and plants. They consist mainly of the least soluble parts of the rocks, which remain after the more soluble parts have been leached out, and hence are known as residual products. Soils and subsoils are the most important. Residual accumulations are often washed or blown into valleys or other depressions, where they lodge and form deposits that grade into the sedimentary class. Surficial rocks that are due to glacial action are formed of the products of disintegration, together with bowlders and fragments of rock rubbed from the surface and ground together. These are spread irregularly over the territory occupied by the ice, and form a mixture of clay, pebbles, and bowlders which is known as till. It may occur as a sheet or be bunched into hills and ridges, forming moraines, drumlins, and other special forms. Much of this mixed material was washed away from the ice, assorted by water, and redeposited as beds or trains of sand and clay, thus forming another gradation into sedimentary deposits. Some of this glacial wash was deposited in tunnels and channels in the ice, and forms characteristic ridges and mounds of sand and gravel, known as osars, or eskers, and kames. The material deposited by the ice is called glacial drift; that washed from the ice onto the adjacent land is called modified drift. It is usual also to class as surficial rocks the deposits of the sea and of lakes and rivers that were made at the same time as the ice deposit.

AGES OF ROCKS.

Rocks are further distinguished according to their relative ages, for they were not formed all at one time, but from age to age in the earth's history. Classification by age is independent of origin; igneous, sedimentary, and surficial rocks may be of the same age.

When the predominant material of a rock mass is essentially the same, and it is bounded by rocks of different materials, it is convenient to call the mass throughout its extent a *formation*, and such a formation is the unit of geologic mapping.

Several formations considered together are designated a *system*. The time taken for the deposition of a formation is called an *epoch*, and the time taken for that of a system, or some larger fraction of a system, a *period*. The rocks are mapped by formations, and the formations are classified into systems. The rocks composing a system and the time taken for its deposition are given the same name, as, for instance, Cambrian system, Cambrian period.

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

Strata often contain the remains of plants and animals which lived in the sea or were washed from the land into lakes or seas or were buried in surficial deposits on the land. Rocks that contain the remains of life are called fossiliferous. By studying these remains, or fossils, it has been found that the species of each period of the earth's history have to a great extent differed from those 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 formations are remote one from the 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 rocks of different areas, provinces, and continents, afford the most important means for combining local histories into a general earth history.

Colors and patterns.—To show the relative ages of strata, the history of the sedimentary rocks is divided into periods. The names of the periods in proper order (from new to old), with the color or colors and symbol assigned to each, are given in the table in the next column. The names of certain subdivisions of the periods, frequently used in geologic writings, are bracketed against the appropriate period name.

To distinguish the sedimentary formations of any one period from those of another the patterns for the formations of each period are printed in the appropriate period-color, with the exception of the first (Pleistocene) and the last (Archean). The formations of any one period, excepting the Pleistocene and the Archean, are distinguished from one another by different patterns, made of parallel straight lines. Two tints of the period-color are used: a pale tint (the underprint) is printed evenly over the whole surface representing the period; a dark tint (the overprint) brings out the different patterns representing formations.

Period.	Symbol.	Color.
Pleistocene	P	Any colors.
Neocene { Pliocene / Miocene }	N	Buffs.
Eocene (including Oligocene)	E	Olive-browns.
Cretaceous	K	Olive-greens.
Juratrias { Jurassic / Triassic }	J	Blue-greens.
Carboniferous (including Permian)	C	Blues.
Devonian	D	Blue-purples.
Silurian (including Ordovician)	S	Red-purples.
Cambrian	Ꞓ	Pinks.
Algonkian	A	Orange-browns.
Archean	AR	Any colors.

Each formation is furthermore given a letter-symbol of the period. In the case of a sedimentary formation of uncertain age the pattern is printed on white ground in the color of the period to which the formation is supposed to belong, the letter-symbol of the period being omitted.

The number and extent of surficial formations of the Pleistocene render them so important that, to distinguish them from those of other periods and from the igneous rocks, patterns of dots and circles, printed in any colors, are used.

The origin of the Archean rocks is not fully settled. Many of them are certainly igneous. Whether sedimentary rocks are also included is not determined. The Archean rocks, and all metamorphic rocks of unknown origin, of whatever age, are represented on the maps by patterns consisting of short dashes irregularly placed. These are printed in any color, and may be darker or lighter than the background. If the rock is a schist the dashes or hachures may be arranged in wavy parallel lines. If the rock is known to be of sedimentary origin the hachure patterns may be combined with the parallel-line patterns of sedimentary formations. If the metamorphic rock is recognized as having been originally igneous, the hachures may be combined with the igneous pattern.

Known igneous formations are represented by patterns of triangles or rhombs printed in any brilliant color. If the formation is of known age the letter-symbol of the formation is preceded by the capital letter-symbol of the proper period. If the age of the formation is unknown the letter-symbol consists of small letters which suggest the name of the rocks.

THE VARIOUS GEOLOGIC SHEETS.

Historical geology sheet.—This sheet 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 particular colored pattern and its letter-symbol on the map 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 symbols and names are arranged, in columnar form, according to the origin of the formations—surficial, sedimentary, and igneous—and within each group they are placed in the order of age, so far as known, the youngest at the top.

Economic geology sheet.—This sheet represents the distribution of useful minerals, the occurrence of artesian water, or other facts of economic interest, showing their relations to the features of topography and to the geologic formations. All the formations which appear on the historical geology sheet are shown on this sheet 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 symbol for mines is introduced at each occurrence, accompanied by the name of the principal mineral mined or of the stone quarried.

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 name 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 the formation of rocks, and having traced out the relations among beds on the surface, he can infer their relative positions after they pass beneath the surface, draw sections which represent the structure of the earth to a considerable depth, and construct a diagram exhibiting 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:

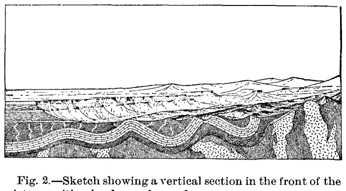


Fig. 2.—Sketch showing a vertical section in the front of the picture, with a landscape beyond.

The figure represents a landscape which is cut off sharply in the foreground by a vertical plane that cuts a section so as to show the underground relations of the rocks.

The kinds of rock are indicated in the section 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:

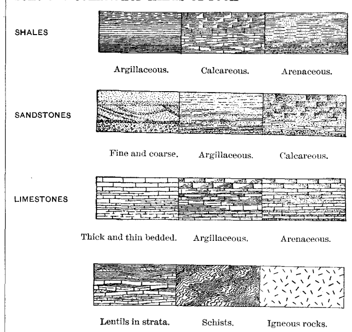


Fig. 3.—Symbols used to represent different kinds of rock.

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 beds of sandstone that rise to the surface. The upturned edges of these beds form the ridges, and the intermediate valleys follow the outcrops of limestone and calcareous shales.

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.

When strata which are thus inclined are traced underground in mining, or by inference, it is frequently observed that they form troughs or arches, such as the section shows. But these sandstones, shales, and limestones were deposited beneath the sea in nearly flat sheets. That they are now bent and folded is regarded as proof that forces exist which have from time to time caused the earth's surface to wrinkle along certain zones.

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

In fig. 2 there are three sets of formations, distinguished by their underground relations. The first of these, seen at the left of the section, is the 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 swelled upward 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 strata thus rest upon an eroded surface of older strata 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 this pressure and intrusion of igneous rocks have not affected the overlying strata of the second set. Thus it is evident that an interval of considerable duration 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, marking a time interval between two periods of rock formation, is another unconformity.

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

Columnar-section sheet.—This sheet contains a concise description of the rock formations which occur in the quadrangle. The diagrams and verbal statements form a summary of the facts relating to the character of the rocks, to the thicknesses of the formations, and to the order of accumulation of successive deposits.

The rocks are described under the corresponding heading, and their characters are indicated in the columnar diagrams by appropriate symbols. The thicknesses of formations are given under the heading "Thickness in feet," in figures which state the least and greatest measurements. The average thickness of each formation 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 is placed at the bottom of the column, the youngest at the top, and igneous rocks or other formations, when present, are indicated in their proper relations.

The formations are combined into systems which correspond with the periods of geologic history. Thus the ages of the rocks are shown, and also the total thickness of each system.

The intervals of time which correspond to events of uplift and degradation and constitute interruptions of deposition of sediments may be indicated graphically or by the word "unconformity," printed in the columnar section.

Each formation shown in the columnar section is accompanied by its name, a description of its character, and its letter-symbol as used in the maps and their legends.

CHARLES D. WALCOTT,
Director.

Revised June, 1897.

DESCRIPTION OF THE LA PLATA QUADRANGLE.

General Geology by Whitman Cross, assisted by Arthur Coe Spencer.
Economic Geology by Chester Wells Purington.

GEOGRAPHY AND PHYSIOGRAPHY.

GENERAL RELATIONS.

Geographic position.—The La Plata quadrangle is situated in southwestern Colorado, near the State line, as is shown by the index map on the title page of this folio. It is bounded by meridians 108° and 108° 15′ west longitude and parallels 37° 15′ and 37° 30′ north latitude, embracing 237.22 square miles. Within its borders are the headwaters of the La Plata and Mancos rivers and of Bear Creek, an important tributary of the Dolores River. All of this drainage is tributary to the Colorado River.

Extent and drainage.

Relations to San Juan Mountains and the Plateau country.—The quadrangle lies some 20 miles southwest of the San Juan Mountain front. In the intermediate space is a heavily timbered, hilly country occupied by Paleozoic and lower Mesozoic formations. Westward the level expanse of the Dolores Plateau stretches far toward the canyon of the Colorado. On the southwest, and rising nearly 2000 feet above that plateau, is the famous Mesa Verde, dissected by the deep canyons of the Mancos River and its tributaries, the favorite fastnesses of the cliff dwellers. The quadrangle is thus situated on the border between the well-watered and forest-clad mountain region of the San Juan and the arid mesa, plateau, and canyon country which extends far into Utah, Arizona, and New Mexico. These relations are brought out by figs. 1, 2, and 3 of the Illustration sheets, to which further reference will be made.

Border line between mountains and plateaus.

Physical features.—By virtue of its position, described above, the La Plata quadrangle presents varied physical features, typical of the broad, level, canyon-dissected plains to the west, and of the foothills of the San Juan Mountains, but the most prominent element in the topography is the rugged La Plata Mountain group, occupying the greater part of the northeastern section of the area. These peaks form one of a number of isolated groups, rising high above the general plateau level, which are scattered over the adjacent portions of Colorado, Utah, Arizona, and New Mexico. From the western summits of the La Platas may be seen the Rico, El Late, Carriso, Abajo, La Sal, and, in the far distance, the Henry Mountains, all mountains of analogous origin.

La Plata Mountains one of a number of isolated groups.

The general characteristics of these plateaus and local mountain groups must be familiar to all who are acquainted with the masterful sketches by W. H. Holmes presented in the annual reports of the Hayden survey for 1875 and 1876 and in the Hayden Geological Atlas of Colorado. Many of these matchless drawings were reproduced in Part II of the Fourteenth Annual Report of the United States Geological Survey, in an article by the writer upon the igneous problems of these mountain groups (Laccolitic Mountain Groups of Colorado, Utah, and Arizona).

Published drawings and sketches of the region.

On the western side of the La Plata Mountains there is a rapid descent of 4000 to 5000 feet to the gently sloping plain known as the Dolores Plateau, into which the West Mancos River has cut a steep-walled canyon several hundred feet deep, as shown by the topographic map. While the intermediate foothills of the mountains occupy the greater space, the extreme northwest corner of the quadrangle presents a bit of the Dolores Plateau, of the character prevailing for many miles to the west.

Rapid descent from mountains to plateau.

The southern third of the quadrangle exhibits the general topographic features of the northern border of the Mesa Verde as it changes from the typical level plain to one of gentle southerly inclination, with a pronounced scarp on the north, crossing the quadrangle from Menefee Mountain on the west to Hesperus on the east. The La Plata River and several of its branches have cut into or across the broken mesa, causing much diversity in the topography.

Topography of southern portion.

Culture.—The La Plata Mountains have been found to contain metalliferous deposits, and in the development of mining operations a small town, named La Plata, has grown up in the heart of the mountains. The Rio Grande Southern Railroad crosses the quadrangle south of the mountains. Hesperus, situated at the crossing of the La Plata River, is the main station within the area for the traffic from the mountains and the valley below. Coal mining is carried on in the immediate vicinity of Hesperus on either side of the river. Agricultural lands, developed through irrigation, extend down the La Plata Valley from Hesperus, while in Thompson Park and on the East Mancos are a number of ranches.

Towns, agricultural lands, and ranches.

On the La Plata River at the entrance to the mountains is Parrott, once the county seat of La Plata County, when it embraced the whole southwest corner of Colorado, but the town is now reduced to a single inhabited house. The present boundary of La Plata and Montezuma counties traverses the quadrangle, following the watershed between the Mancos and La Plata rivers.

Geographic names.—In the course of work in the La Plata Mountains it became desirable to have names for various peaks and ridges hitherto nameless. In a few other cases it was found that local usage was conflicting or for some reason undesirable. Since in these instances there were names already applied in earlier publications concerning the La Platas, these older terms have been revived.

Revival of earlier names.

The name Rampart Hills, applied to the prominences due to the porphyry sheet on the eastern bank of the West Mancos Canyon, needs no explanation. As seen from the west these porphyry cliffs present the aspect of an outlying breastwork of the mountains. The long ridge leading north from the La Platas to the Rico Mountains was the course of an old Indian trail, which in several places has been worn deep in the soft sandstones of the La Plata formation. This line of communication appears to have been a favorite one for the Indians of the region, and the name Indian Trail Ridge is applied to the divide followed. The names "Sliderock" and "Owen," applied to basins on either side of Hesperus Peak, have been adopted from a local map of the mountains. Rush Basin, at the head of the East Mancos, has been named after one of the earliest prospectors of the district. Two points upon the crest between the East Mancos and the La Plata have been named, respectively, Gibbs and Burwell peaks, for the well-known surveyors.

The name Diorite Peak speaks for itself. The name Baker Peak has been applied to the summit at the north end of the Silver Mountain porphyry mass on account of its position directly above the well-known "Baker contact."

Jackson, Ohlwiler, and Bragdon are names applied to ridges in the mountains after men who have been prominent in the mining developments of the region.

Babcock and Spiller are terms used in the Hayden survey report for two prominent peaks of the monzonite mass south of Mount Moss. The summit to which the name Spiller is applied is variably known to prospectors and miners of the La Platas as Helmet or Hayden Peak. As the former name belongs to the lesser summit east of the Hogback, and as Hayden is a name which has been applied to many mountains in Colorado, it seems best to restore the term Spiller, used in the Hayden report, although it has not as yet been locally adopted.

Sharkstooth is a name readily suggested by its form for the sharp point of porphyry on the ridge west of Bear Creek, seen in fig. 5.

Banded Mountain is a term used in one or two places by Holmes as an alternative for Hesperus Peak, but as the latter was finally placed upon the Hayden map and was generally used throughout the Hayden reports, the other name is applied to the summit of similar character north of Mount Moss.

The other names on the map are those of local usage as far as that could be ascertained.

LA PLATA MOUNTAINS.

Size and form of the group.—The La Platas form a compact group of high peaks, all the principal summits lying within a circle 9 miles in diameter, the center of which is situated in the La Plata Valley near the mouth of Tirbircio Creek. The lesser summits and outlying ridges all come within an oval area 12 to 15 miles in diameter. Nearly all the peaks of the inner circle are situated within the La Plata quadrangle, but a few lie beyond its eastern border, in the Durango quadrangle.

Many of the summits rise to more than 12,000 feet above sea level, and the highest, Hesperus Peak, reaches an altitude of 13,225 feet. The general character of the mountains and of the valleys dissecting them may be seen on the Topographic, Structure Section, and Illustration sheets of this folio.

Height of peaks.

Drainage system.—The La Plata Mountains are the result of a domal uplift which has been dissected by erosion. Consequently the drainage system of the mountains has a general radiate arrangement. But the work accomplished by the various streams has not been equal. The master stream is the La Plata, which, flowing south, has cut back at its head almost to the northern rim of the group, dividing the mountains into nearly equal parts. The main northern stream, Bear Creek, has also penetrated the inner circle of peaks, overlapping the La Plata, a narrow divide separating the basins at the heads of these streams.

Dome dissected by radial streams.

On the west side two forks of the Mancos have cut slightly into the core of the group, leaving but a jagged crest between their headwaters and the La Plata drainage. On the east the attack of the radial streams has been less effective, but several branches of Lightner and Junction creeks head on the slopes of the highest peaks. These streams are tributary to the Animas River.

La Plata Valley.—The character of the La Plata Valley within the mountains is shown by fig. 8, a view looking into the heart of the group from the entrance above Parrott. In fig. 9 is presented the view from the divide at the head of the valley. In both views the broad U-shaped section and the steep slopes on either side are well exhibited.

From the entrance to the mountains for 3 miles up the valley the rise of the stream bed is about 500 feet. For the next 3 miles it amounts to 1200 feet. In the lower 3 miles within the mountains the fall is nearly the same as for the first 3 miles below. From about the mouth of Madden Creek downward the La Plata flows on a flood plain.

From its head to Parrott the La Plata receives nearly twenty lateral tributaries of importance, half of which have a length of from 2 to 3 miles and rise in the amphitheaters under the higher peaks. All of these streams enter the La Plata with a steep grade, and all of the principal ones have a greater fall in their short courses than has the La Plata itself above their mouths in a much greater distance. This is due to the fact that the divide at the head of the main stream is nearly 1000 feet lower than the divides on either side under which the lateral streams have their basin heads. Erosion is naturally going on very vigorously in the side gulches and in the upper reaches of the La Plata. In fig. 6 is shown a ravine at the head of Bedrock Gulch which has been recently cut through a forest covering into brecciated rock, in which erosion is now proceeding at a rapid rate.

Tributaries of the La Plata.

Bear Creek.—The basin head of this stream overlaps the extreme head of the La Plata for $1\frac{1}{2}$ miles and is excavated in the stocks of Diorite Peak and Mount Moss and of the indurated and metamorphosed strata between them. Polished and striated areas in the upper part of the basin show that this was the source of a local glacier, but no considerable morainal accumulations exist in the lower valley. Bear Creek enters the Dolores River in the Rico quadrangle, 8 miles from the La Plata line, at an elevation of 7900 feet. Fig. 5 represents the Sharkstooth, on the west side of Bear Creek, the most northerly summit of the La Platas.

Branches of Mancos River.—The entire western slope of the mountains is drained by the three forks of the Mancos River, two of which penetrate at their heads within the inner circle of peaks. Of these branches the West Mancos is the longer, rising in Owen Basin under Mount Moss and Hesperus, Babcock, and Spiller peaks, all of which exceed 13,000 feet in height. The extreme head of the West Mancos is shown in fig. 11.

The East Mancos heads in Rush Basin, under Spiller Peak, an amphitheater corresponding to that at the source of the west fork of the river. The Middle Mancos is practically a branch of the East Mancos, heading in minor streams on either side of the Hogback.

Eastern drainage.—As shown by the topographic sheet, the two principal branches of Lightner Creek rise on the eastern side of the higher peaks of the La Platas. From Eagle Pass north to Cumberland Peak, which is just beyond the eastern margin of the quadrangle, are a number of small branches of Junction Creek. But while Lightner and Junction creeks have cut back to the main eastern divide of the mountains, there is but a single summit of importance isolated by this erosion from the other high summits of the group. This is Bald Knob (11,600+ feet), situated east of Baker Peak, about one-half mile east of the quadrangle line. While Lightner and Junction creeks have but short courses within the physiographic limits of the La Plata Mountains, they have done a greater amount of work than the forks of the Mancos in carving the La Plata dome. At 5 miles from the mouth of Tirbircio Gulch their stream beds are lower than that of the La Plata at the same distance.

Great erosion by Lightner and Junction creeks.

The greater cutting power of these streams is due to the fact that they are branches of the Animas River, a large stream whose valley bottom 9 miles east of the quadrangle line is at 6600 feet, or nearly 2000 feet lower than the La Plata at its exit from the mountains.

The inner circle of peaks.—The principal summits of the La Platas are nearly all situated upon the narrow divide on either side of the La Plata River. A few, like Hesperus Peak and Banded Mountain, are upon spurs from this divide and near to it. Since many of the peaks rise above timber line a thousand feet or more, and are carved from hard rocks, they have the characteristics of rugged form modified by talus slopes common at this altitude throughout the Rocky Mountains. The western peaks average somewhat higher than the eastern and are of bolder outline, both facts being due to the resistant rock masses from which they have been sculptured.

Ruggedness of peaks above timber line.

In fig. 10 may be seen the forms and relations of the highest peaks of the group, while in fig. 11 are details of Hesperus Peak and Mount Moss. Lewis Mountain, the highest summit east of the river, is shown in fig. 1.

Outlying summits.—The slopes from the inner peaks to the surrounding country are interrupted in a few places by lesser summits to be included in the La Plata group. Of these, Helmet Peak and the Hogback are the main ones on the west. On the north Sharkstooth is the only one of note, and Bald Knob has a similar distinction to the east, while southward there are no outliers. In all cases these outer peaks are due to large masses of igneous rock extending beyond the usual line of their prominent occurrence.

Forest growth and timber line.—The altitude of the La Platas causes them to precipitate an abundant rain from the moisture-laden currents coming over the arid plateaus which lie west and south. Their slopes are thus in general heavily timbered by spruce, fir, and aspens in the zones usual at these elevations in Colorado. The Illustration sheets show the character of the forest-clad slopes and the line, varying between 11,500 and nearly 12,000 feet, at which the forest gives way to a scant vegetation of alpine character. Downward there is a transition to the commonly sparse growth of white pine, piñon pine, scrub oak, and cedar, which covers large areas of the adjacent plateau country, as shown in fig. 3.

Heavily timbered slopes.

Mining operations in the La Platas have not yet caused great havoc on the wooded slopes, but forest fires have in places destroyed much of the natural beauty of the mountains. Burnt Timber Gulch is a name bearing melancholy testimony to one of the earlier devastations of this character.

Timber destroyed by forest fires.

Rock coloration.—The coloration of the mountains in rock exposures varies from the gray tones of the igneous masses and of the La Plata sandstone to the brilliant red characteristic of the Dolores formation, into which most of the igneous rocks are intruded. In the center of the group this red color has in most places been destroyed by metamorphism, being replaced by dull brown or green, but on many of the outer peaks and ridges the red color of the Dolores assumes its normal hue. Brilliant discoloration of both igneous and sedimentary formations occurs locally where the pyrite which had been disseminated through the rocks has suffered decomposition.

Color variation from gray to brilliant red.

AREA WEST OF THE MOUNTAINS.

Transition slopes.—Were the La Plata Mountains due to erosion of an uplifted dome of sedimentary rocks only, it may be safely said that the western slope of the mountains would now be much more regular than is actually the case and would correspond closely to the dip of the Dakota sandstone. But on the western and northwestern sides of the mountains intrusive igneous rocks in the soft shales overlying that sandstone have hindered the uniform removal of the shales by erosion. Where the porphyry masses are large enough they have caused peaks or ridges, like The Hogback, which are outliers of the mountains. The lesser masses cause minor inequalities on the slopes, either from the presence of the porphyry bodies, as in the Rampart Hills, or from the protection afforded to underlying shales, as on the divide between Bear Creek and the West Mancos, and in a hill north of The Hogback.

Erosion of shales hindered by igneous rocks.

Were it not for the intrusives the entire western and northwestern slopes of the La Platas would have presented a character much like that seen on the southwest, where the dip slope of the Dakota is uninterrupted from an elevation of more than 10,000 feet down to the level of the gently inclined plateau at somewhat below 8000 feet.

The Rampart Hills present a cliff to the westward, reaching 400 feet in height in places, making a feature which is very prominent in the view from the plateau, but insignificant from the mountains. Since the porphyry sheet causing this rampart has been nearly denuded of its overlying shales the effect is that of an elevated block of the plateau.

Rampart Hills.

The Dolores Plateau.—Beyond the West Mancos River and in the area where the Middle and East Mancos unite, the very gently sloping surface may be considered the eastern border of the Dolores Plateau, itself the eastern extension of the Great Sage Plain. Fig. 3 gives a better idea of this fact than could be obtained from a description in words, and also brings out the relation to the higher plateau of the Mesa Verde.

In fig. 3 may be seen the monotonous and generally arid waste lying beyond the borders of the La Plata quadrangle. The white pines, piñons, and cedars, growing sparsely over portions of the plain near the point of view, save it from the appearance of utter desolation. Yet, where irrigation is possible, in the vicinity of the main streams, this desert may be transformed into valuable farm lands. This has been done on a large scale in the wide Montezuma Valley, which is shown in fig. 3, in front of the El Late Mountains.

Arid waste west of the quadrangle.

The plateau surface in and adjacent to the La Plata quadrangle has a gentle dip, due to the influence of the mountain uplift on the Dakota sandstone, which is the floor of the plateau over a large area, as shown by the Hayden geological map.

Canyons.—While the portion of the Dolores Plateau embraced in the quadrangle is small the gorges of the West Mancos and of Chicken and Turkey creeks are characteristic of the canyons found in the wide area to the west. The smaller canyons that are cut in the sandstone floor of the plateau have vertical cliffs or very steep slopes. The larger canyon has a similar character, since the Dakota sandstone is of sufficient thickness to maintain the bounding scarp and the lower formations are themselves favorable to the perpetuation of the canyon form.

Character of plateau canyons.

SOUTHERN PORTION OF QUADRANGLE.

Extension of Mesa Verde.—The southern third of the La Plata quadrangle belongs physiographically to the eastern extension of the Mesa Verde, a plain normally some 2000 feet above the level of the Dolores Plateau. This high level is maintained as a plateau by the preservation of massive Cretaceous sandstones which have been entirely removed over the large area of the Dolores and Great Sage plains. The northern rim of that part of the Mesa Verde lying west of the Mancos River is shown in fig. 3 in its relation to the Montezuma Valley, which is really the plain of the Dolores Plateau as it abuts against the slopes from the higher plain.

Difference in level of Mesa Verde and Dolores Plateau.

Passing eastward from the Mancos River the formations to which these two great plateau levels owe their existence come more and more under the influence of the La Plata and San Juan uplifts. With increasing dip the vertical distance between the rim of the mesa and the level of the Dakota sandstone floor at its northern base naturally decreases, until in Menefee Mountain, on the western border of the La Plata quadrangle, it amounts to only about 1200 feet. Between the sandstones forming the floors of the Dolores and Mesa Verde plains occurs the soft Mancos shale, and a broad transverse depression naturally appears in the zone of this shale between the two sandstones, south of the La Platas. The greater part of this depression is occupied by the upper course of Cherry Creek.

Effect of La Plata uplift on the plateaus.

The Mesaverde sandstone presents a bold cliff to the north along the front of the mesa proper and in the western part of the La Plata quadrangle, as expressed by the contours of the topographic map. Nearer the La Plata River this scarp is less pronounced, as is clear from the map and fig. 7. But farther east it again becomes notable, as may be seen in fig. 2, which shows the more steeply inclined strata near Durango.

While the dissection of the mesa between Menefee Mountain and the La Plata River is such as to obscure its character as a plain near its northern border, the map shows that on the southern line of the quadrangle the mesa level is much more prominent, and it becomes still more so farther south.

Dissection of the mesa.—East Canyon, a branch of the Mancos, has much of the usual character of the gorges cut in the Mesa Verde, and so have the eastern branches of Cherry Creek between Spring and Hay gulches. The main valley of Cherry Creek also assumes the canyon form near the border of the quadrangle, but the creek has cut back at its head beyond the rim of the mesa and has excavated a broad valley in the soft shales. As will be more fully discussed in a later section, there are grounds for believing that East Canyon was once the course of the East Mancos River.

Character of gorges in southern portion.

The La Plata Valley is a broad, shallow depression from Hesperus downward and scarcely assumes the canyon form, yet according to the Hayden map the stream cuts into the level of the Mesa Verde for 20 miles below the quadrangle line. It never has high walls, however.

It will be seen by the map that all the western tributaries of the La Plata cross the south border of this quadrangle at considerably lower levels than the river itself. This is most striking in the case of Hay Gulch, which at 4 miles from its head and the same distance west of the La Plata has cut 500 feet deeper into the Cretaceous than has the main stream. This difference of level is the more remarkable since Cherry Creek is a branch of the La Plata, its mouth lying about 15 miles southwest of Hesperus, according to the Hayden map. The conditions of erosion by which this result has been reached are discussed by Mr. Spencer in the section on "General geologic problems."

Striking difference of stream levels.

SEDIMENTARY ROCKS.

The sedimentary formations of the La Plata quadrangle belong to the Mesozoic group, and the section resembles in detail that of the Plateau country to the westward rather than that of the Rocky Mountain system. As the area is situated in the border zone between these geological provinces, the formation units of the quadrangle are naturally seldom identical with those of distant regions on either side and can not in all cases be closely correlated with them. The formations apparently succeed one another in an unbroken series, but as there are no recognized equivalents of the lower Cretaceous as developed in Texas, it appears either that there is an undiscovered gap in the section or that certain formations have been wrongly assigned to the Juratrias. The formations distinguished on the map are those demanding such recognition by their local development, and the age assignments have been made in accordance with the fossils obtained or by comparison with the best established sections of Colorado. All but the two highest Cretaceous formations are identical with the beds of the Telluride quadrangle and have been described in the Telluride folio. So far as the known Mesozoic group of the region is concerned, the section displayed in the La Plata quadrangle is nearly complete, only the highest and lowest members being wanting, the former because erosion has removed them from this area, the latter because erosion has not cut quite deeply enough to reveal them.

Nearly complete Mesozoic section.

JURATRIAS PERIOD.

Subdivision into three formations.—The sedimentary rocks of southwestern Colorado occurring between the uppermost recognizable Carboniferous and the Dakota Cretaceous have been referred to three divisions, the Dolores, La Plata, and McElmo formations. All of these are developed in the Telluride quadrangle, and the general grounds for this subdivision as well as the individual characteristics of each formation are presented in the Telluride folio (No. 57, Geologic Atlas of the United States, 1899) somewhat more fully than in the following description.

The three divisions of the Juratrias thus far established are founded mainly upon stratigraphic position and lithologic character, with which the scanty fossil evidence is in full accord. The lowest formation, the Dolores, embraces the greater part of the "Red Beds" of this region, and although the known fossils are few in number they furnish better proof of Triassic age than has been obtained in many other localities where reddish strata have been assumed to belong to that period. The other two formations, the La Plata and the McElmo, possess lithologic characters making their correlation with the strata of assumed Jurassic age, elsewhere developed in Colorado, a most natural one.

The formations here assigned to the Juratrias were variously designated on the Hayden map of this portion of Colorado. In the Dolores and San Miguel valleys of the Plateau country W. H. Holmes distinguished three formations between the Carboniferous and the horizon of the Dakota sandstone as defined in this folio. These three divisions were called Trias, Jura, and Lower Dakota on the Hayden map. Their boundaries can not now be closely compared with those of the Dolores, La Plata, and McElmo formations. To the east of the Animas Valley F. M. Endlich distinguished no Triassic or Jurassic beds, including the former in the Carboniferous and the latter in the Dakota Cretaceous. The Hayden map of the vicinity of the La Plata Mountains represents a necessary adjustment between the usages of Holmes and Endlich. The apparent dying out of the Trias, Jura, and Lower Dakota shown by the map expresses no fact or theory of distribution. In fact, the continuity of all formations distinguished by Holmes is clear as far eastward beyond the Animas as recent observations have been made.

Trias, Jura, and Lower Dakota of Hayden map.

The La Plata and McElmo formations are subdivisions of what was called the Gunnison formation by Eldridge in the Anthracite-Crested Butte folio (No. 9, Geologic Atlas of United States, 1894). Their distinction is due entirely to the desirability of recognizing the individual character of the two divisions as developed on the flanks of the San Juan, especially the strongly marked La Plata horizon.

Gunnison formation of Eldridge.

DOLORES FORMATION.

Definition.—The name Dolores formation was first applied in the Telluride folio "to the Triassic strata of southwestern Colorado and of adjacent territory so far as a direct correlation may prove to be practicable." The formation was so called on account of the excellent exposures along the banks of the Dolores River in the Rico quadrangle, which lies next north of the La Plata. The definition is intended to provide for the contingency arising in the event of the discovery of Permian or Permo-Carboniferous fossils in the lower part of the complex of beds referred to the Dolores.

The Dolores formation is now assumed to embrace a complex of about 2000 feet of predominantly reddish sandstone, grits, conglomerates, and shales, all highly calcareous, limited below by the Rico formation, containing a typical Permo-Carboniferous fauna, and above by the La Plata sandstone, of assumed Jurassic age. The Rico formation is also reddish in color and is otherwise similar to the Dolores in lithologic constitution, and its upper limit has been arbitrarily drawn for the present at the highest horizon observed to contain its characteristic fauna (Geology of the Rico Mountains, Colorado, by Whitman Cross and Arthur Coe Spencer: Twenty-first Ann. Rept. U. S. Geol. Survey, Part II, 1900). It is evident that future discoveries may not only place the upper boundary of the Rico formation at a higher horizon but may also establish an intermediate Permian formation between the Rico and the Dolores. Until such discoveries have been made it seems best to assume that above the Rico horizon the apparently indivisible section of the "Red Beds" in this geological province belongs to the Dolores.

Lower boundary of the Dolores.

Vertebrate, invertebrate, and plant remains have been found in the upper half of the complex referred to the Dolores, and although these fossils are as yet few in number they agree in indicating the Triassic age of the beds containing them.

General description.—The Dolores formation has in general the characteristics commonly found in the "Red Beds" of the Rocky Mountain region. It consists of series of interbedded calcareous sandstones, grits, conglomerates, and sandy shales, the latter often grading into earthy limestones. Individual beds of sandstone or conglomerate of uniform texture are seldom more than 25 or 30 feet in thickness, although fine-grained and thin-bedded sandstones with slight textural variations may exceed 100 feet in thickness. Many strata can be traced laterally for long distances, but local variations in constitution and thickness are so great that detailed sections made at points not widely separated can not always be closely correlated.

The "Red Beds".

The reddish color of the formation is due partly to pink grains of feldspar in the coarser layers, but chiefly to a ferritic pigment in minute

Cause and variation of red color.

particles. This color is dark or dull red in the lower portion, and a brighter red in the upper part; but gray or pinkish sandstones appear here and there, and efforts to distinguish divisions in the formation by shades of color have been unsuccessful. The red color is, moreover, not strictly limited to the Dolores formation in this region. The Rico beds are dull reddish brown in color, and various brilliant hues of red and orange locally appear in the lower sandstone of the overlying La Plata.

A calcareous cement is present in abundance throughout the Dolores formation, emphasizing the lithologic similarity between the Triassic and the underlying Carboniferous, and contrasting with the purely siliceous sandstones common in the Jurassic and Cretaceous.

Thin limestones, almost free from sand grains, are found locally. These may be white, mottled, or pinkish in color and are quite different in appearance from the common sandy or marly strata of strong reddish color, which are often 10 feet or more in thickness and occur throughout the formation. The latter beds have the habit of fine-grained massive sandstones, break with irregular fracture, and from the wide variation in the ratio between arenaceous and calcareous material they are at times called sandy limestones and again calcareous sandstones.

The clastic materials of the Dolores beds are derived chiefly from granites, gneisses, schists, and the ancient quartzitic sediments of the San Juan, like those now seen in the Animas Canyon and the Needle Mountains. The finer-grained strata are rich in quartz and the coarser ones in feldspar. Limestone pebbles characterize certain conglomerates in the upper part of the complex, but may be found occasionally in lower strata.

Members of Dolores formation.

While there is no evidence indicating that the series of strata now referred to the Dolores should be further subdivided into formations, there is nevertheless a broad lithologic distinction which may be drawn between an upper and a lower portion. It is the upper of these two divisions, moreover, which contains all of the fossils thus far obtained, so that if in future the whole complex is split up into different formations it may be predicted that the line to be mentioned will in all probability be the most feasible one for such a purpose.

The studies thus far made on the southern and western flanks of the San Juan Mountains show that the series of beds referred to the Dolores may be divided into a lower, coarser-grained member, unfossiliferous as far as known, characterized by conglomerate strata containing granite, gneiss, quartzite, and, rarely, limestone pebbles; and an upper, predominantly fine-grained member, characterized by limestone conglomerate, often fossiliferous. This division is plain in the region thus far examined, except in the eastern part of the Telluride quadrangle. On the South Fork of Mineral Creek in that area the conglomeratic layers of the upper part of the formation contain an unusual amount of granitic and schistose material, and limestone pebbles are not uncommon in strata of the lower member. A prevailing coarseness in the beds also tends to obliterate the distinction elsewhere applicable for the subdivision in question and suggests approach to the shore line of the Dolores sea.

The lower member.—The strata comprising the lower member of the Dolores are so metamorphosed in the La Plata Valley that the primary character of the complex can not there be well studied, but in the adjacent Rico and Durango quadrangles the formation is perfectly exposed. All but the lowest beds are well shown in Bear Creek and in Lightner Creek near the La Plata quadrangle line.

In this region the two principal features of the lower division are on the one hand the heavy grits and conglomerates, and on the other rather crumbling, strong-red, calcareous sandstones, free from pebbles, grading into sandy marls or impure limestones, of conchoidal or irregular fracture. The bedding of these layers is often inconspicuous in small fragments. Other reddish sandstones are thin bedded, with clay or micaceous partings, and exhibit ripple and current markings often resembling fucoidal traces. Mud flakes, molded to resemble shells, are found at various horizons.

Grits and conglomerates of granite, schist, and quartzite fragments.

The grits and conglomerates occur in massive beds reaching a maximum thickness of 40 feet. Their alternation with finer-grained and softer beds causes a succession of benches and ledges on the longer slopes and ridges made up of this complex. The grits are generally rich in pink feldspar and white quartz and are either gray in color or have a much lighter pink tone than the average of the formation. Pebbles are scattered sparingly through all grit layers, causing transitions to conglomerate, and a gravel matrix is abundant in the latter strata. Bowlders a foot and more in diameter occur in the coarser conglomerates in some places, but the average size is only a few inches.

Boundary between the two members of the Dolores.

The most prominent grit and conglomerate beds are in the lower few hundred feet of the formation, but two very persistent layers occur, one at the summit and the other 100 feet or more below the top of the lower member. These two beds permitted the drawing of a provisional line separating the two members here under discussion throughout the La Plata quadrangle. The upper of these conglomerates has an abundant arkose matrix and its pebbles are small. White and pink quartz are the most prominent materials, but quartzite and limestone pebbles were found even in the uppermost layer of this lower division. A dull altered porphyry is one of the constituents. Thin limestones of reddish or gray color, which appear to be homogeneous on freshly fractured planes but look rather like conglomerate on weathered faces, are locally present. In some cases there appears to be a gradation from a massive limestone to a layer with rounded fragments of limestone in a scanty matrix of sand, as though a soft calcareous stratum had been partially broken up by wave or current action.

The upper member.—The upper member of the Dolores has within itself a bipartite character. Succeeding the conglomerate noted as the top of the lower division comes an alternation of sandstones, sandy shales, and fine conglomerates, the last characterized by small pebbles of a peculiar limestone. Following this series is a fine-grained reddish sandstone, more or less shaly, which continues to the La Plata formation above. The limestone conglomerates and the fine-grained sandstones associated with them form the most noteworthy portion of the formation, as they carry the only fossils yet found in it and are in general the most distinctive beds in the series.

Bands of limestone conglomerate.

The limestone conglomerate characterizes several bands, within which it has a variable development. In places a ledge 20 feet thick may consist chiefly of conglomerate, with numerous sandy partings, while a few yards away the same beds may be composed mainly of sandstone with numerous thin layers of conglomerate, some of them less than an inch in thickness. Other bands of conglomerate are more persistent, but observations to the present time indicate that possibly no stratum of the limestone conglomerate is continuous throughout the entire area between the Animas and San Miguel rivers. These conglomerates are more common in association with a series of thin-bedded gray sandstones or greenish-gray sandy shales, a complex 50 to 75 feet in thickness, which can be traced for long distances by reason of its contrast in color with the prevalent red of the formation. Plant stems are common in this series, but determinable leaves have not been found.

The limestone of the pebbles in the conglomerate is usually very fine grained and seldom resembles the strata of the Carboniferous as seen in the Animas Valley. No fossil-bearing pebbles have been found and the material resembles the thin limestones occasionally developed in this part of the Dolores itself rather than those known from any other formation.

Origin of the limestone pebbles.

Commonly the pebbles of limestone are very small, and they are of such uniform shot-like appearance as to suggest that they are pisolitic, but gradations occur to pebbles several inches in diameter and then usually unsymmetrical in form. Similar limestone also appears sporadically in the lower conglomerates of the formation. Observations have not extended far enough to warrant general statements as to the origin of these limestone pebbles. Owing to the common occurrence of teeth of dinosaurs in the conglomerate, it has been found convenient to speak of them as the "Saurian conglomerates," as explained in the Telluride folio.

The distance between the uppermost "Saurian conglomerate" and the base of the La Plata sandstone above varies with the increasing thickness of the red sandstone which occupies this interval in the area between the San Miguel River and the Animas. This is 30 feet on the San Miguel in some places and nearly 500 feet in Lightner Creek.

These upper sandstones and shales are even and fine grained and grade into one another so regularly that the entire thickness from the La Plata to the first limestone conglomerate appears as one member of the section. There is a variable amount of shale, some localities presenting this complex as a sandstone. The bands of massive sandstone are often 20 feet or more in thickness, the bedding being indistinct in small blocks.

The color of this sandstone is usually a bright brick red, shading sometimes into purplish above and a darker duller red below. Where the overlying La Plata sandstone is also highly colored the two formations seem sometimes inseparable, but the hue of the higher formation is commonly orange or yellow.

Probable unconformity between the La Plata and Dolores.

The varying thickness of the beds in question is supposed to be due to an unconformable overlap of the La Plata sandstone, but the friable nature of the Dolores sandstone and the gradual transgression of the upper formation have thus far prevented a demonstration of the assumed unconformity. No beds of different character have as yet been detected between the two sandstones.

The variation in thickness of this uppermost member of the Dolores formation is considerable even within the La Plata quadrangle. It is not more 250 feet thick on the East Mancos, but reaches 500 feet on the northern border of the quadrangle, east of Indian Trail Ridge and in Lightner Creek.

Vertebrate remains.

Age and correlation.—The Triassic age of the fossiliferous portion of the beds referred to the Dolores formation is fairly well proved. The evidence consists of scanty vertebrate, invertebrate, and plant remains found in the limestone conglomerates or the associated strata in the upper part of the formation. As stated above, the limestone conglomerates are characterized by the presence of teeth of crocodiles and dinosaurs. F. A. Lucas has determined the former as belonging to the genus *Belodon* and the latter as belonging to a megalosauroid dinosaur, *Palæoctonus*. Both of these are Triassic types. The jaw of a crocodile found by H. S. Gane in the Dolores formation at Clay Hill in Utah has been described by Mr. Lucas as belonging to a new genus having decided Triassic affinities, to which he gave the name *Heterodontosuchus ganei* (Am. Jour. Sci., 4th series, Vol. VI, 1898, p. 399).

Invertebrate fossils.

A small gasteropod shell, poorly preserved, has been found at localities in both the Rico and La Plata quadrangles. According to T. W. Stanton it belongs to *Viviparus*, or some closely related genus, and it is stated by him that the earliest previous record of this genus is from the Jurassic. A unio of specifically undeterminable character was found in the highest exposed conglomerate of the Cataract Creek section in the Telluride quadrangle. This is thought by Mr. Stanton to be in all probability one of the forms obtained by Cope from the Trias on Gallinas Creek, New Mexico. A single specifically determinable plant has been found in the Rico quadrangle, just below the limestone conglomerate series. This has been determined by David White as resembling *Pachyphyllum münsteri*, a Triassic plant.

Fossils from the Dolores formation in Colorado were found by R. C. Hills and first announced, with some provisional determinations, in 1880 and 1882 (Am. Jour. Sci., 3d series, Vol. XIX, 1880, p. 490; Vol. XXIII, 1882, p. 243). Vertebrate remains found by Mr. Hills were the teeth of *Belodon* and the remains of a fish regarded by him as a ganoid, similar to *Catopterus gracilis*. He also found a small gasteropod shell and eleven or twelve apparently determinable species of plants. Unfortunately these fossils were lost before they could be identified.

Correlation with the Trias of New Mexico.

The fossils found in the Dolores indicate a general correlation with the Triassic of Gallinas Creek on the western side of the Sierra Madre in New Mexico, from which E. D. Cope obtained crocodilian and dinosaurian remains similar to those of the Dolores. Probably the strata of the Abiquiu copper mines of New Mexico, from which J. S. Newberry collected several Triassic plants, belong to the same horizon. The tooth-bearing horizon of the Dolores has been found by R. C. Hills on the north side of Grand River, near Red Dirt Creek, but, so far as the writer is aware, this fossiliferous horizon has not been traced farther north.

Equivalency of "Red Beds" and Dolores.

While much of what has been called the "Red Beds" in Colorado and adjacent territory is doubtless the equivalent of the Dolores formation, it appears that the continuity must be traced, or fossils found, to establish identity, since the Carboniferous, Permo-Carboniferous, and Jurassic beds are in many localities characterized by a reddish color and may be similar in lithologic character to the Dolores strata.

LA PLATA SANDSTONE.

Name and definition.—This formation was first named in the Telluride folio from its prominence in the La Plata Mountains. It is defined to include a marked lithologic unit consisting principally of two massive sandstones with a variable calcareous member between them, lying at the base of the fresh-water complex thus far assigned to the Jurassic in Colorado. The sandstones are usually white and quartzose and in thickness greatly exceed the calcareous beds between them, which in the Telluride quadrangle were locally reduced to a single blue-gray, massive limestone, 6 to 8 feet in thickness. The base of the formation is the well-known plane of unconformity by which the lower sandstone overlaps all older sedimentary rocks to the Archean, as shown north of the San Juan Mountains and elsewhere. This angular unconformity is not distinct in or near the La Plata quadrangle, but is thought to be the cause of the gradual increase in thickness of the uppermost sandstones of the Dolores, as described above. The upper limit of the La Plata is drawn at the base of a marked clay shale of green or reddish color, which signalizes the beginning of the alternating shales and sandstones grouped in the McElmo formation. No determinable fossils have been found in the La Plata formation adjacent to the San Juan Mountains.

Great unconformity at base of La Plata formation north of San Juan Mountains.

Very white and massive sandstone forming sheer cliffs.

Description.—The total thickness of the La Plata is from 250 to 500 feet in this quadrangle, becoming less northward to a minimum of 100 feet in the Telluride quadrangle, but increasing to the east and west. The limestone occurs here below the middle of the formation and varies from 8 to 30 feet in thickness. The sandstones are very white, massive, fine and even grained, presenting in some places bands 75 feet or more in thickness, within which stratification is hardly discernible except in large exposures. Outcrops of such beds often form sheer cliffs or smooth, rounded faces of bare rock. The normal sandstone is rather friable, but in the mountains is in many places changed to dense quartzite, as at the head of the East Mancos River and on the divide to the east. A very marked cross bedding appears in some of the more massive layers, being brought out by lines of shading rather than by change in the sandy particles. Occasionally an intricate and delicate veining by secondary white quartz appears in the more massive layers.

The two sandstone members are usually of similar character, but the upper one is more likely to be thinly or regularly stratified and to have thin shale partings. The sandstones are normally white or light gray, but at some localities north of the mountains, and especially in the western plateau country, the lower member may be in part brilliantly colored in varying shades of orange or yellow. This coloration ordinarily extends irregularly from the base upward and it is in most places clearly different from that of the underlying Dolores sandstone.

The limestone is often bluish black, of conchoidal fracture, and destitute of fossils. The shales which replace it are also dark, some sandy, others grading into limestones. Adjacent to these shales the sandstones are inclined to become thinly bedded, and so the complex between the more massive sandstones sometimes exceeds 50 feet in thickness. These calcareous strata are not often well exposed, for they naturally weather away more rapidly than the sandstones, and on the bench thus formed the softer strata are more or less concealed by débris from above.

Distribution.—The La Plata formation extends in almost connected outcrops from the northern line of the quadrangle, in Indian Trail Ridge, through the western summits and thence in steeply upturned position across the southern slope of the mountains. It is locally cut through by erosion or interrupted by the monzonite and diorite stocks, as illustrated on the map. In the higher points and ridges it forms cliffs and débris slopes greatly resembling those of the intrusive porphyry sheets which occur in many places throughout the mountains, and a close inspection is necessary to determine the distribution of these two rocks. To this fact is probably due the erroneous representation on the Hayden map of the La Plata Mountains, where porphyry is shown in a considerable area occupied in fact by the sandstone. Fig. 4 shows the light outcrops and talus slopes of the La Plata at the southern end of Indian Trail Ridge.

The domal structure carries the La Plata formation down the valleys of the East and West Mancos, the white bands being very noticeable wherever the contrasting natural red color of the Dolores is preserved.

Age and correlation.—The age of the La Plata formation is more definitely indicated by its stratigraphic position than by any other criterion. The only fossils thus far obtained from it in the region adjacent to the San Juan Mountains were some small fish scales and vertebræ found north of Engineer Mountain, northeast of the La Plata quadrangle. These were lost before they could be identified. Minute fresh-water shells referred to *Limnea*, *Valvata*, and *Cypris* were discovered by G. H. Eldridge in the limestone occurring near the base of the Gunnison formation in the Elk Mountains, a horizon probably identical with the calcareous zone between the sandstones of the La Plata. Certain crocodilian or dinosaurian teeth found in a local conglomerate at the base of the formation in the Telluride quadrangle rest under the suspicion of having been derived from the Dolores "Saurian conglomerate," since this horizon is but a few feet below the La Plata in the San Miguel Valley.

Fish scales and vertebræ in the La Plata sandstone.

McELMO FORMATION.

Name and definition.—The alternating series of sandstones and shales described under this heading was called the McElmo formation in the Telluride folio, from an important tributary of the San Juan River heading about 10 miles west of the La Plata quadrangle, on the Dolores Plateau. In the main McElmo Valley and in its side canyons the strata of the formation are well exposed below the Dakota. The formation does not appear to be divisible in this region, as the individual beds are too thin to be mapped separately.

Description.—The McElmo varies considerably in the ratio of sandstone to shale in different localities, and also in total thickness. The sandstone beds are much like those of the La Plata and Dakota. They are fine grained, quartzose, friable, and gray or yellowish in color. The lateral variation in thickness is marked, as are also the transitions to shaly sandstones by increase of argillaceous matter. A characteristic of many sandstones is the abundance in them of green shale flakes or scales, a diagnostic of value in distinguishing the McElmo from the Dakota or the La Plata where exposures are poor. Few sandstones exceed 20 feet in thickness in this area.

Similarity of the McElmo, La Plata, and Dakota sandstones.

The lithologic similarity between the McElmo and Dakota formations is emphasized by a conglomerate containing white and dark quartz pebbles as much as an inch in diameter, occurring frequently at 50 or 60 feet below the basal conglomerate of the Dakota. This lower stratum is sometimes 10 or 15 feet thick. The distinctly shaly strata of green or red color above this conglomerate make its reference to the McElmo necessary upon the criterion adopted. A similar conglomerate appears more locally at other horizons.

The shales of this series are predominantly green in the La Plata quadrangle. The color is pronounced and has led many prospectors to search for copper ore in this formation. Pink, dark-red and chocolate-brown shales occur, and occasionally the variegated coloring approaches that characteristic of the formation in many other regions. The shales are seldom free from sand, and a gradation to sandstone is more common than are sharp lines of division.

Pronounced green and variegated shales.

The total thickness of the McElmo in this quadrangle is 400 to 500 feet, formed of approximately equal parts of sandstone and shale. The thickness increases northward to a maximum of 900 feet in the Telluride quadrangle, largely through greater thickness of the sandstone members of the series. The highest and lowest beds assigned to the McElmo are shales that are strongly marked and highly colored, contrasting with the Dakota and La Plata sandstones.

Distribution.—The McElmo formation naturally has a distribution similar to that of the La Plata. By its greater thickness and higher position it covers larger areas upon the mountain slopes, and the canyons of the West Mancos and Chicken Creek display it beneath the Dakota. The crumbling beds cause less prominent ledges than do the more massive strata above and below, and on dip slopes the presence of the McElmo is often determinable only by the abundant fragments of sandstone with green shale flakes.

Age and correlation.—The strong lithologic resemblance between the Gunnison beds of the Elk Mountains and the celebrated dinosaur-bearing beds of Morrison was evident to Eldridge, who described the Morrison strata in the monograph on the Denver Basin (Monograph XXVII, U. S. Geol. Survey). This resemblance, which has also been noted by the writer, seems to him quite sufficient to warrant a general correlation of the McElmo division of the Gunnison with the complex at Morrison, Oil Creek near Canyon, and other localities along the Front Range where *Atlantosaurus* and other huge dinosaurs have been found. The name Morrison was given by the writer to the vertebrate-bearing formation of the eastern foothills because it seemed best not to correlate it too closely with the Gunnison beds of the Elk Mountains, in which no fossils were known (Pikes Peak folio, No. 7, U. S. Geol. Survey). No fossil remains have as yet been described from the McElmo beds, as here defined.

Correlation of the McElmo with the Morrison formation.

The Jurassic age of the Morrison formation has been maintained by Marsh and other vertebrate paleontologists on account of the numerous dinosaurs and other vertebrates contained in it, but, as has already been pointed out, the reference of these strata to the Jurassic involves the assumption of a great stratigraphic break or hiatus between them and the Dakota. No such break is indicated by the stratigraphy, but there is, in fact, one of the most extensive unconformities known in the Rocky Mountains occurring between the Triassic and the so-called Jurassic at the horizon represented by the base of the La Plata sandstone. Until the vertebrate remains known to exist in association with invertebrate fauna in the lower Cretaceous of Texas have been compared with the fauna of the Morrison beds, there must remain some doubt in the minds of stratigraphers as to the true position of the latter.

CRETACEOUS PERIOD.

SECTION OF SOUTHWESTERN COLORADO.

As has already been stated, no strata of lower Cretaceous age corresponding to the section so well developed in Texas have been recognized in Colorado. The upper Cretaceous is represented in southwestern Colorado by an important series of formations, some of which clearly correspond to members of sections in other parts of the State, while others are more provincial in character. The fossils which have been found in the La Plata and adjacent quadrangles show that the faunas of the period were here similar in character and succession to those known in other regions, but the strata in which they occur are not lithologically divisible, for purposes of mapping, into the same formation units which have been adopted elsewhere. In consequence of this unusual character of the upper Cretaceous section it has been necessary to establish certain new formations. Three of these formations are represented in the La Plata quadrangle, and the whole section from the Dakota upward to the post-Laramie, inclusive, is characteristically developed in the adjoining Durango quadrangle on the east. While a thorough discussion of these formations is reserved for the Durango folio, an analysis of the section is here presented. It is very similar to the generalized section for the San Juan Valley given by Holmes (Ann. Rept. Hayden Survey, 1875, Pl. XXXV).

Absence of lower Cretaceous strata.

Establishment of new formations in the Cretaceous.

The lowest Cretaceous formation recognized is the Dakota, which alone, of all the divisions, has the lithologic character common in other parts of the Rocky Mountain region.

Succeeding the Dakota comes a very homogeneous clay-shale formation more than 1000 feet thick, which from the invertebrate fossils found at several horizons must be supposed to represent the Benton, Niobrara, and a part of the Pierre formations as distinguished at the eastern base of the Front Range in Colorado. But the fossil-bearing strata are neither sufficiently numerous nor well enough developed to serve as horizons for a satisfactory subdivision of this shale formation, which was named the Mancos shale in the Telluride folio.

The next higher distinguishable series in the Cretaceous section is the variable complex whose more massive sandstones cause the principal scarps of the Mesa Verde. Holmes named this series after the Mesa Verde in the Hayden reports and his designation is here accepted. It was not used, however, on the Hayden map. The Mesaverde formation consists of alternating sandstones and shales with several seams of excellent coal. The invertebrate fossils, which are not uncommon at several horizons in the shales and sandstones, range throughout the Montana group, and hence give no ground for a reference of the Mesaverde strata to the Fox Hills, as was done on the Hayden map.

The Mesa Verde formation of Holmes.

Above the Mesaverde formation occurs another formation of clay shale, reaching an observed thickness of nearly 2000 feet, which is very much like the Mancos shale, but contains fewer fossils. The only identifiable form thus far found in this shale occurs also in the Mancos shale, so that this division is still apparently below the true Fox Hills. This formation is called the Lewis shale. Holmes designated it the "Sand Shale Group."

"Sand Shale Group" of Holmes.

Still above the Lewis shale is a second series of sandstones, shales, and coals, bearing some resemblance to the Mesaverde formation, but differing in detail. The lowest member of this complex is the "Pictured Cliff Sandstone" of Holmes's San Juan section, which he placed in the Fox Hills upon the evidence of invertebrate remains. The remainder was referred by Holmes to the Laramie, but without fossil evidence. The present survey has also failed to bring to light valid ground for assigning any of the beds in question to the Laramie, while there is some reason to believe that more than the lower sandstone belongs to the Montana group.

The "Pictured Cliff Sandstone" of Holmes.

Between the uppermost quartzose sandstones of the Cretaceous and the Puerco marls (Eocene), which are well developed below Durango on the Animas, there occurs a series of beds not recognized by Holmes. These strata are composed mainly of andesitic débris, tuffs, or conglomerates, and it has been proposed by the writer to call them the Animas beds or formation. The fossil plants obtained from the tuff layers clearly indicated that the beds may be correlated with the Denver, Middle Park, Livingston, and other post-Laramie formations, which paleontologists refer to the Mesozoic, although they are stratigraphically shown to be later than the great revolution which terminated the conformable succession of Cretaceous sediments.

Animas formation of andesitic débris.

DAKOTA SANDSTONE.

Description.—The lowest member of the Cretaceous, succeeding the McElmo formation with apparent conformity, is the Dakota formation. It is here, as commonly in Colorado, a series of extremely variable gray or brownish quartzose sandstones, often cross bedded, with a peculiar conglomerate at or near the base and several shale layers at different horizons. Its thickness in this quadrangle ranges from less than 100 to 300 feet.

Conformity of the Cretaceous on the Juratrias.

The basal conglomerate, carrying small chert pebbles of white, dark-gray, or reddish colors, which is so persistent over large areas elsewhere in the Rocky Mountains, is here very variable in development, being absent in some places and of unusual thickness or coarseness in others. Conglomerate of this character is not, moreover, strictly confined to the base of the section.

Basal conglomerate of the Dakota.

The shale members are strongly developed near the middle and again near the top of the series. These are dark, strongly carbonaceous, with abundant indistinct plant remains, and in many places one or both of the shale horizons has a thin coal seam, sufficient to induce prospecting on its outcrops, but nowhere of economic importance in comparison with the neighboring coal measures of the Mesaverde formation. The upper shale bed has a thickness varying from 25 to 50 feet. Above its coal seam there is sometimes a transition to the great shale series above by alternation of thin sandstone and shale strata.

Thin coal seams in the Dakota.

The variability of the sandstones in thickness and in purity makes close correlations of sections in different parts of the quadrangles difficult. The general character of the formation remains most clearly the same over this entire section of Colorado.

The Dakota sandstone is, as a rule, much more highly indurated than the La Plata or McElmo sandstones, largely owing to its containing hydrous iron oxide as a cementing substance. It therefore resists erosion and becomes very prominent in scarps facing the canyons which cut below it in the plateau country. It is, in fact, the floor of the Dolores Plateau over hundreds of square miles, with thin remnants of the Mancos shales resting upon it and producing minor undulations. No determinable fossils have been discovered in the Dakota of this region, but indistinct plant stems and occasional leaves occur in the shale horizons.

MANCOS SHALE.

Name and definition.—The Mancos shale, which lies above the Dakota sandstone, was so named in the Telluride folio on account of its characteristic development in the Mancos Valley, especially about the town of Mancos, which is situated a few miles west of the La Plata quadrangle line. This locality is near the center of the area through which the shale has been traced in the resurvey of the region. The whole formation is well exposed along the north face of the Mesa Verde near Mancos, upon the slope shown in fig. 3, below the scarp of sandstone. The thickness of the Mancos shale within the La Plata quadrangle is about 1200 feet. Throughout this thickness it is an almost homogeneous body of soft, dark-gray or nearly black, carbonaceous clay shale, varied only by the presence of a few thin bands or concretions of impure limestone. These bands are fossiliferous, but are too few and too discontinuous to serve as practical guides in subdivision of the great shale series in which they occur. The Mancos is therefore a lithologic unit which it is necessary to recognize in the mapping of this region. It is limited below by the Dakota sandstone and above by the lowest sandstone of the Mesaverde formation of alternating sandstones and shales. As explained below, this lithologic unit embraces the Colorado group and a part of the Pierre division of the Montana group.

Great thickness of homogeneous, soft, dark shale.

Description.—The Mancos shale is very similar to the most typical clay shales found commonly in the Colorado group elsewhere in the State. It is seldom so highly bituminous as the Benton shale may be along the foothills of the Front Range, but it has much less sand mixed with it than is commonly found in the Pierre shales of the Denver region.

The calcareous and occasionally sandy layers containing fossils occur most frequently near the base of the formation or else well up toward the top. Yet sometimes fossils are found nearer the middle of the section. The lower fossil-bearing beds have long been known. They were noted by Newberry during the Macomb expedition in 1859 at many places along the Santa Fe trail. Holmes traced them from the La Plata around the west side of the Mesa Verde and across the San Juan River. Stanton collected from them near the town of Mancos and elsewhere (The Colorado formation: Bull. U. S. Geol. Survey No. 106, 1893, p. 32). In the course of mapping the Telluride, Rico, La Plata, and Durango quadrangles, and in reconnaissance work in adjoining areas, the various fossiliferous horizons have been seen and, as will appear below, persistent faunas have been found. With increasing experience it has become more and more clear that the fossil layers do not afford practical horizons for the subdivision of the Mancos shale for purposes of mapping.

Areas occupied by the Mancos shale have, naturally, no bold relief except on steep slopes below some more massive protecting formation, as on the slope of the Mesa Verde or the inclined mesas near Durango. In these localities there is a typical bad-land sculpturing at numerous points. Where the overlying formation has been removed, as over the area of the Dolores and corresponding plateaus, the Mancos shale often forms low ridges or mounds of very gentle outline. Valleys cut into the Mancos between the La Plata Mountains and the Mesa Verde scarp have broad and simple features, like the valley of Cherry Creek.

Fossils and correlation.—The invertebrate fossils thus far obtained from the Mancos formation of southwestern Colorado have all been determined by T. W. Stanton, and the following application of that fossil evidence in correlation is in accord with his views.

Benton fossils in the lower Mancos formation.

The Mancos shale formation has yielded two groups of fossils, the one characteristic of the Benton shale and the other less distinctly so of the Pierre division of the Montana. The Benton forms obtained are the following:

Gryphæa newberryi.	Prionocyclus macombi.
Ostrea lugubris.	Baculites gracilis.
Ostrea congesta.	Scaphites warreni.
Inoceramus labiatus.	Anatina sp?
Inoceramus fragilis.	Plicatula n. sp.
Inoceramus dimidius.	

Of these forms *Gryphæa newberryi* and *Ostrea congesta* were commonly found in the Telluride quadrangle characterizing layers at about 125 and 225 feet respectively above the Dakota sandstone, but these layers are not so prominent in the La Plata quadrangle. The greater number of the species named occur in association at distances varying from 100 to 300 feet above the Dakota, in the La Plata and Rico quadrangles and near the town of Mancos, where they were obtained by Mr. Stanton. This fauna, according to Mr. Stanton, indicates a horizon near the top of the Benton shale.

Pierre fossils from the Mancos.

The middle shales of the Mancos carry little evidence of fossils, but within the upper few hundred feet of the formation there are various thin discontinuous bands or lenses of impure limestone which often carry a few fossils. The following forms have been identified by Mr. Stanton:

Inoceramus cripsii, var. barabini.	B. sp?, a large form resembling B. ovatus or B. compressus.
Inoceramus undabundus.	Arca sp?
Inoceramus sagensis.	Ptychoceras (or Hamites).
Syncyclonema rigida.	Turritella sp?
Scaphites nodosus.	
Baculites asper.	

The forms of this list show that the upper part of the Mancos shale must be considered as of Pierre age. No distinctive fauna of the Niobrara division of the Colorado has yet been found.

MESAVERDE FORMATION.

Name and definition.—The name "Mesa Verde Group" was applied by W. H. Holmes to the series of sandstones and shales forming the Mesa Verde (U. S. Geol. and Geog. Surv. Terr., 1875, Pl. XXXVm, facing p. 244). He included in the group three divisions, viz: the "Lower Escarpment Sandstone," 120 feet in thickness; the "Middle Coal Group," of sandstone, shale, marl, and coal, 800 to 900 feet; and the "Upper Escarpment," massive sandstone, 190 feet; a total of about 1200 feet. This complex included the variable series, largely of sandstones occurring between two strong shale formations—clearly the Mancos and Lewis shales as here designated. It is probable that the development of sandstone and shale varies locally both at the base and at the top of the Mesaverde, but the boundaries assigned to the group by Holmes are certainly very near those which are natural in the La Plata quadrangle and vicinity. The name is particularly appropriate.

Three members of the Mesaverde formation.

The fossil evidence to be presented shows that the Mesaverde formation is but a part of the Pierre division of the Montana group.

Description.—The Mesaverde formation is to be characterized as a succession of alternating sandstones and shales, with occasional marls or thin limestones and a number of coal seams, some of which are of excellent quality. The greater number of coal beds now worked in southwestern Colorado belong to this formation. The Mesaverde is thus lithologically quite distinct from the thick shale formations above and below it. In the La Plata quadrangle the maximum thickness of the formation is about 1000 feet. Westward Mr. Spencer found a somewhat greater thickness, agreeing with the observations of Holmes in the Mesa Verde, while there is a thinning eastward. The actual base of the formation in the La Plata quadrangle is a thin quartzose sandstone, 6 inches thick, succeeding the homogeneous Mancos shale. From this stratum upward there is a succession of thin sandstone and shale beds for 250 feet, sandstones continually increasing in thickness, coarseness, and amount, relative to the shales. This increase in sandstone culminates in a massive, cross-bedded stratum of coarse quartz sand, 100 to 150 feet in thickness, which corresponds to the "Lower Escarpment Sandstone" of Holmes. In this vicinity, and even on the north side of the Mesa Verde, this sandstone fails to cause a distinct lower scarp, as it does in some places in the San Juan Valley. Even there, however, Holmes notes that the greater part of the formation occasionally appears in one continuous cliff nearly 1000 feet in height. In the La Plata quadrangle the lower heavy sandstone is in some places divided into two ledges by a thin fossiliferous shale stratum.

"Lower Escarpment Sandstone" of Holmes.

Above the "Lower Escarpment Sandstone" there is in the La Plata area a complex of about 600 feet of shales, sandstones, and coal beds, corresponding to Holmes's "Middle Coal Group." These beds are not very well exposed along the northern edge of the mesa in the La Plata quadrangle, but are fairly shown in Hay and Alkali gulches and in East Canyon. In this vicinity the shales predominate over sandstones, but they are arenaceous, and sandstone is more conspicuous in the Mesa Verde, according to Holmes. From the general section given below the relative development of shales and sandstones may be seen.

"Middle Coal Group" of Holmes.

Coal beds occur at intervals all through this intermediate member of the formation. The variability of the coal seam is very pronounced as a rule, and careful prospecting is necessary to demonstrate the extent of individual beds. Within the lower 150 feet of this complex there were observed by Mr. Spencer in Menefee Mountain eight coal seams, each under a more or less prominent outcrop of sandstone. At several other horizons below the "Upper Escarpment Sandstone" coal beds also appear. They were found by Holmes in the Mesa Verde proper, but according to the statements of those who have looked into the matter the quality is poorer and the aggregate amount of the coal decreases westward from the La Plata River, while the economic importance increases eastward. The greater number of productive coal mines in the Durango quadrangle, as well as the openings near Hesperus on either side of the La Plata River, are in the seams of the Mesaverde formation.

Eight coal seams observed.

The upper sandstone member of the Mesaverde in the La Plata region is but 25 feet thick as seen in Hay Gulch and vicinity. It is yellowish and rather massive and often carries fossils in its upper part. Below this sandstone is a series of sandy shales and thin sandstones, and above it a similar succession forming a rapid transition to the Lewis shale. There is little doubt that the 25-foot bed of sandstone, possible together with the sandy strata above and below, corresponds to the "Upper Escarpment Sandstone" of Holmes, which has a thickness of 200 feet in the Great Hogback, on the banks of the San Juan River, south of the Mesa Verde.

"Upper Escarpment Sandstone" of Holmes.

Invertebrate fossils occur at many horizons throughout the Mesaverde formation, in both shales and sandstones. Fossil plants are also known at various horizons, though few have thus far been collected in a sufficiently good state of preservation to permit of identification. The discussion of the fauna given below shows that the Mesaverde belongs to the Montana group of the Cretaceous, and, further, that it is, in all probability, but a part of the Pierre division.

General section.—From the partial sections of the formation secured by Mr. Spencer in various places the section given below may be considered as a general representation of its development in the La Plata quadrangle.

	Feet.
Upper massive sandstone, carrying fossils in upper part	25
Shales with thin layers of sandstone	250
Shales with coal at top	45
Sandstone, from 10 to 20 feet thick	15
Gray shales, carrying two coals	100
Sandstone 15 to 25 feet	20
Coal-bearing shales, 125 to 200 feet thick	170
Lower massive sandstone, bipartite in places	125
Alternating sandstones and shales	250
Total	1000

Fossils and correlation.—Invertebrate fossils are found at many horizons in sandstones or shales, most of the species occurring throughout the formation. The following fossils have been found in the La Plata quadrangle or adjacent districts:

Leda.	Callista pellucida.
Ostrea pellucida	Corbicula.
Ostrea inornata.	Baculites anceps var. obtusus.
Cardium speciosum.	Baculites compressus.
Cardium bellulum.	Placenticeras placenta var. intercalare.
Inoceramus cripsii var. barabini.	Pinna.
Mactra alta.	

According to T. W. Stanton, these forms range through both the Pierre and Fox Hills formations of the Montana group of the Cretaceous. The list does not contain any exclusive Fox Hills species and there is, therefore, no ground from this fossil evidence to assign the Mesaverde formation to the Fox Hills, as was done by the Hayden survey.

Absence of exclusive Fox Hills species.

LEWIS SHALE.

Name and definition.—The heavy shale formation succeeding the Mesaverde is here named the Lewis shale from its occurrence at Fort Lewis, in the La Plata Valley a few miles south of the quadrangle line. Like the Mancos shale, this formation is distinguished as a lithologic unit of marked character. It occurs as a band between the Mesaverde and Piedra formations as far as these divisions of the Cretaceous have been traced in this part of Colorado. Only a few hundred feet of the shale are now preserved within the La Plata quadrangle, but the entire thickness is well exposed in the adjacent Durango quadrangle on either side of the Animas River. There the Lewis shale was found by Mr. Spencer to have a thickness of 2000 feet and to be comparable to the Mancos shale in its purity.

The Lewis shale corresponds to a division of Holmes's general section of southwestern Colorado which he designated as "Sand Shale Group" and assigned a thickness of 400 to 800 feet (U. S. Geol. and Geog. Surv. Terr., 1875, facing p. 244) as developed south of the Mesa Verde on the San Juan River.

Description.—The Lewis shale is a body of more or less sandy shales and clays with occasional thin layers of impure limestone, or of concretionary masses at several different horizons. As far as examined, it has even less tendency than the Mancos shale to become sandy. But Holmes's designation of it seems to indicate a lesser degree of homogeneity in the San Juan Valley than it possesses in the Durango quadrangle.

The only fossil of identifiable character as yet obtained from the Lewis shale is *Baculites asper*, a form which ranges through the Montana group, and was found in the Mancos shale. There is thus no known ground for placing this shale higher than the Pierre division of the Montana.

Age of the Lewis shale.

Only the lower 200 to 300 feet of the Lewis shale occurs within the La Plata quadrangle, and exposures of these beds are rare. They appear, as shown by the map, in the southeast corner of the quadrangle and are generally masked by river or terrace gravels. Some exposures were found in ravines, and calcareous concretions carrying baculites are characteristic of some of the observed outcrops.

SURFICIAL ROCKS.

PLEISTOCENE PERIOD.

Some of the events of Pleistocene time are recorded within the La Plata quadrangle by gravel-covered terrace and glacial débris. Terraces are found along all of the more important streams below their mountain canyons, where the valleys broaden. Glacial deposits of a well-marked character are, however, not common.

Scattered bowlders of small size are found lying upon the surface of the Mesaverde formation in the region north of the Ute coal mine, but they do not form anything like a veneer. They are probably remnants of gravel beds which were once more conspicuous. Whether these gravels record a stage of erosion when the streams had not yet cut their present deep channels, or are evidence of the previous extension of glacial ice, is not apparent. The rounded character of the gravels would indicate that they had suffered attrition by running water, and would therefore favor the first hypothesis.

Terrace gravels.—Well-marked deposits of gravel at a considerable height above the present drainage are found along the La Plata River in the vicinity of Hesperus and on the divide between East Mancos River and Cherry Creek. Since the deposition of these gravels erosion has taken such directions that they are now left upon the tops of ridges, but there can be little doubt that they were formed in the valleys of rather voluminous streams. The gravels in both these localities form a continuous wash over the areas represented on the map. They contain bowlders, always very smoothly rounded, a foot or more in diameter, but the thickness is not considerable, not more than 4 feet having been observed. These two high terraces and their gravels, being about equally elevated above the streams of their neighborhood, presumably represent the same period. Possibly small gravel remnants on the tops of two knolls on the west side of the West Mancos Canyon should also be correlated with these higher terraces.

High terrace gravels.

On the west side of the La Plata River the elongated knoll south of Parrott above 8800 feet elevation has a remnant of gravel, and as a topographic feature can be seen to correspond to the terrace ridge southeast of Hesperus, on the east side of the river.

All these high terrace gravels are supposed to be auriferous, but have not yet been found rich enough to be of economic value.

Between the high terrace and the present flood plain an intermediate bench is usually to be found. This low terrace is especially well marked in the vicinity of Hesperus on the La Plata, where the equivalence of the terrace north of Hesperus on the west side of the river and the low terrace south of Hesperus is very evident. Also on the south side of the East Mancos east of Menefee ranch the low terrace is well marked. In Thompson Park the low terrace is represented by a double bench covered with

Low terrace gravels.

scattered gravel, the upper of which is not more than 25 or 30 feet above the stream.

Glacial débris.—The only deposit of distinctly glacial material which has been recognized is a small terminal moraine that lies partly across the valley of the La Plata at old Parrott City, three-quarters of a mile south of Parrott post-office.

Landslide débris.—The principal area in which slipping of large masses of rock has given character to the topography lies between the two forks of the West Mancos. The sliding has taken place, as is usual throughout this region, on the Mancos shale. The materials which now lie in an irregular mixture upon the shale comprise the igneous rock occurring in the ridge above, the Dakota sandstone, and fragments from the McElmo formation. This anomaly is explained by the great fault which crosses the landslide area. The eastern part of the area is characterized by almost complete lack of drainage, little ponds being formed by crescent-shaped dams. Here large blocks are of infrequent occurrence. To the west of this there is an area where the whole surface is covered by huge blocks of Dakota in confused relation. On the north side of the ridge west of Mount Hesperus the talus covers the lower part of the Dakota sandstone.

Numerous small ponds in the landslide area.

IGNEOUS ROCKS.

The igneous rocks of the La Plata quadrangle have all consolidated at considerable depths below the surface which existed at the time of eruption. No remnant of the San Juan volcanic series now exists in the vicinity, although it must be assumed that some members of that series once extended over the site of the present La Plata Mountains.

The La Plata intrusives are similar in structure and composition to rocks known in many parts of the Rocky Mountains, especially in Colorado. This is particularly true of the porphyries, which may be said to be typical of the laccolithic and sheet intrusions described from numerous localities within the last twenty years. The stock rocks are in part of somewhat unusual composition, though the types in question are closely related to common facies. The dark rocks of the later periods of eruption embrace a considerable variety, and some of the more basic types are rare, yet as a whole the group comprises rocks similar to those often found in Colorado in association about centers of eruption.

General characteristics of the La Plata intrusives.

The later stocks of the La Plata Mountains are all composed of granular rocks, but the older conduits, through which the magmas ascended to spread out in sheets, are apparently occupied by porphyries. The descriptions will follow under the heads "Granular stock rocks," "Porphyries," and "Basic dikes and sheets."

GRANULAR STOCK ROCKS.

The granular rocks belong to three large divisions, which are only partially connected in this region by transition forms. The most highly feldspathic rock is a syenite, that richest in ferromagnesian silicates a diorite, and between these there is a group to be called monzonite, though more closely related to diorite than to syenite.

AUGITE-SYENITE.

Description.—The two large masses of syenite occurring in the heart of the La Plata Mountains are nearly identical in character and are presumably nearly contemporaneous intrusions of the same magma. It is evident at a glance that the rocks are strongly feldspathic, although the ferromagnesian constituent is so frequently quite decomposed that its former rôle is not easily estimated.

The large igneous mass at La Plata.

As now seen the syenite is gray or pinkish, and, while plainly crystalline, the dullness of the feldspars obscures the individual grains. Where augite remains it can be seen on close examination to be dark green. Its irregular prisms are greatly subordinate to the feldspars in amount. In many places ocherous spots or darker-brown limonite represents the augite. A very small amount of biotite or green hornblende may be associated with augite.

As microscopical examination and chemical analysis show, the feldspars of these rocks are very largely alkali feldspars, and orthoclase, anorthoclase, and microperthite are variably developed in the different specimens examined. Albite or soda-rich oligoclase may be present in some cases, but they have not been positively determined. In general anorthoclase tends to a development in large grains and rudely automorphic crystals surrounded by microperthite and orthoclase zones. The latter varieties are usually more abundant, and where a transition to porphyritic structure appears they form the granular groundmass for anorthoclase phenocrysts.

The augite of these rocks is very pale green in thin sections, and the light-brown biotite is occasionally intergrown with it. Titanite (sphene) is present in many minute crystals. Apatite occurs in few clear large prisms, and magnetite is very subordinate. Quartz is present in small amount throughout the masses and assumes a more conspicuous place in certain aplitic modifications.

Variations in composition are frequent and usually orthoclase and microperthite increase at the expense of anorthoclase and the ferromagnesian minerals. Some aplitic facies were found in which quartz, orthoclase, and microperthite constituted nearly the whole mass. But anorthoclase may also become prominent, and in one place, on the ridge between Schurman and Spencer gulches, a porphyry was found with flat anorthoclase crystals, very similar to those of the well-known "Rhombenporphyr" of the Christiania region in Norway. The aplitic and porphyritic facies seem to occur in dike-like bodies confined to the stocks. They certainly were not observed beyond the limits of the stocks.

Chemical composition.—The freshest and most even-grained syenite of the region, from the ridge between Tirbircio and Schurman gulches (No. 3201), was subjected to quantitative analysis by H. N. Stokes of the Survey, with the following result:

Analysis of augite-syenite.

SiO_2	59.79
Al_2O_3	17.25
Fe_2O_3	3.60
FeO	1.59
MgO	1.24
CaO	3.77
Na_2O	5.04
K_2O	5.05
H_2O (110°+)	.39
H_2O (110°—)	.19
TiO_2	.67
CO_2	.72
P_2O_5	.35
SO_3	.04
Cl	trace.
MnO	.20
BaO	.14
SrO	.11
Li_2O	trace.
	100.14

No Cr_2O_3 or NiO. Sp. gr., 2.704 at 25° C.

An accurate calculation of the mineral composition from this analysis is difficult because of the decomposition represented by the calcite present. It appears, however, that nearly 80 per cent of the mass consists of feldspar and that alkali feldspar is strongly preponderant. There must be 5 or 6 per cent of quartz. The rock is to be characterized as quartz-bearing augite-syenite.

MONZONITE.

Description.—The granular rock of the long and irregular stock within which are located Mount Moss and Babcock and Spiller peaks belongs to the group termed monzonite, intermediate in composition between syenite and diorite. In this rock the feldspars predominate over the dark ferromagnesian silicates, but not so strongly as in the augite-syenite. As a consequence it is grayish in tone, often with a pinkish tinge due to the color of the orthoclase, which, as in many granites, derives this color from minute particles of hydrous iron oxide. Where the pink or flesh tint of the orthoclase is strong it affords a rude means of estimating the relative amounts of the alkali and lime-soda feldspars, for the latter are white. In the freshest parts of the mass the feldspars are not distinguishable in this way.

The granular rock of Mount Moss.

As a rule, alkali and lime-soda feldspars are nearly equal in amount. Of the ferromagnesian constituents augite is the most abundant, with hornblende and biotite in variable development and sometimes absent. The usual accessory minerals are present, with titanite relatively abundant and magnetite uncommonly subordinate.

The alkali feldspar is apparently always orthoclase, the lime-soda feldspar mainly labradorite of the composition ab_1 an_1, as determined by the Michel Lévy method upon many Carlsbad twins in different specimens. More highly calcic labradorite is occasionally found in the core of some crystals.

The augite of these rocks is the common pale-green variety, similar to that of the syenite. It is usually fresh and is developed in imperfect prisms. Hornblende and biotite are of the varieties common in diorite and monzonite. Occasionally they are intergrown with augite in the manner well known in such rocks.

A small amount of interstitial quartz is of common occurrence, but there is no observed facies of the mass sufficiently rich in this mineral to make it comparable with the quartz-monzonite found in large stocks in the western San Juan Mountains. (See the Telluride folio.)

A medium-fine and even grain prevails in this monzonite mass, but locally there is a marked poikilitic structure, due to the development of orthoclase in grains which may be as much as half an inch in diameter, inclosing numerous small grains of the other constituents. The lustrous cleavage faces of these grains are conspicuous on freshly fractured surfaces of the rock.

Chemical composition.—The very fresh rock of Babcock Peak was quantitatively analyzed by H. N. Stokes, with the result stated below:

Analysis of monzonite from Babcock Peak.

SiO_2	57.42
Al_2O_3	18.48
Fe_2O_3	3.74
FeO	2.10
MgO	1.71
CaO	6.84
Na_2O	4.52
K_2O	3.71
H_2O 110°+	.28
H_2O 110°—	.08
TiO_2	.86
P_2O_5	.36
Cl	.03
MnO	.09
BaO	.15
SrO	.08
Li_2O	trace.
	100.45

No CO_2, SO_3, Cr_2O_3, or NiO.
Sp. gr., 2.767 at 26° C.

Calculations from this analysis show that about three-fourths of the rock must be feldspar, and that if the lime-soda species be assumed to be labradorite (ab_1 an_1) there is considerable of the albite molecule remaining to combine with the potash molecule in orthoclase. Probably the labradorite slightly exceeds the orthoclase in amount.

Variations in composition.—The mass referred to above is certainly monzonitic in very large degree, but at two observed points there is a tendency to grade into a diorite, by increase in lime-soda feldspar and decrease in orthoclase. One of these is just south of Banded Mountain, the other at the head of the West Mancos, where a wedge-like arm of the stock upturns the strata and intercalated porphyry sheets of Hesperus Peak, as seen in fig. 11. Only at the former locality is the even grain maintained with this change. But there too, as elsewhere, a porphyritic structure is more common. Hornblende is more abundant than augite, and quartz becomes more important than in any of the monzonitic rocks of the stock. The two places where this dioritic character is seen are on opposite sides of the stock, in apophyses from the main mass.

Complementary dikes.—At several places aplitic veins or dikes were observed in the monzonite. These are almost wholly composed of orthoclase, microperthite, and quartz, with small amounts of hornblende or biotite. The rock which seems complementary to these was seen only on the slope east from Banded Mountain. Here some narrow dikes of a dark-green heavy rock were observed. The material of this dark dike is principally green augite and magnetite, with grains of orthoclase and plagioclase quite subordinate.

Drusy veins.—Occasionally the narrow veins traversing the monzonite have irregular cavities lined by crystals of alkali feldspar and quartz, with other minerals, such as epidote, magnetite, hematite (specular iron), and apatite, in variable abundance. Apatite was found in one of these drusy veins developed in beautiful transparent green prisms, reaching nearly half an inch in length by 0.2 inch in diameter. Several such crystals were grouped upon a surface 3 inches square.

DIORITE.

Description.—The stock extending from Diorite Peak to Basin Gulch is of very similar appearance to the fine-grained monzonite, but is richer than the latter both in ferromagnesian minerals and in lime-soda feldspars. There is in fact within this mass a transition from monzonite to diorite bearing some orthoclase, and from the evidence at hand it appears that diorite strongly predominates. However, the mass as a whole has not been examined in sufficient detail to show accurately the distribution of the two facies. Small stocks of diorite occur in Lewis Peak and near the end of the ridge between Bedrock and Madden Gulches.

The stock of Diorite Peak.

In appearance the diorites are typical of that rock. They are somewhat darker gray than the monzonite, because of a slightly larger amount of the ferromagnesian minerals and because they are finer-grained in most places. In composition all the diorite bodies agree in having the total of the feldspars much greater than that of the dark minerals. Lime-soda feldspar is considerably but variably in excess of the alkali feldspar, orthoclase. Augite is more abundant than either biotite or hornblende, except very locally, when hornblende may assume a rôle at least equal to that of augite.

The characteristics of the minerals in the diorite are the same as in the monzonite, and quite agree with those considered as normal to such rocks elsewhere, It is notable that quartz is present in greater abundance than in any monzonite examined from the mountains.

The accessory minerals magnetite, titanite, and apatite have the common appearance. Titanite is rather more abundant than usual in such rocks, and magnetite less so.

Chemical composition.—A considerable portion of the stock crossing La Plata Valley north of Basin Creek is somewhat richer in orthoclase than the western part about Diorite Peak. Below is given an analysis, by W. F. Hillebrand, of this orthoclase-rich rock from the little canyon of the river not far above the mouth of Basin Creek.

While the alkalies are present in this rock in nearly the same amount as in the monzonite of Babcock Peak, there is a notable increase in the magnesia and iron, representing a decided increase in the percentage of augite, hornblende, and biotite.

From rough calculations it appears that the feldspars constitute about two-thirds of the rock analyzed, and that labradorite is much more abundant than orthoclase. There must be a considerable amount of the albite molecule in the orthoclase.

Analysis of monzonitic facies of diorite mass.

SiO_2	55.53
Al_2O_3	16.78
Fe_2O_3	4.06
FeO	3.35
MgO	3.00
CaO	6.96
Na_2O	4.31
K_2O	3.57
H_2O 110°+	.55
H_2O 110°—	.09
TiO_2	.95
CO_2	.09
P_2O_5	.47
V_2O_3	.02
NiO, CoO	trace
MnO	.16
BaO	.13
SrO	.11
Li_2O	trace
FeS_2	.04
	100.17

Sp. gr., 2.79 at 21° C.

PORPHYRIES.

The porphyries of the intrusive sheets and associated dikes or irregular masses of the La Plata Mountains nearly all belong to one or the other of two groups which are distinguished on the map. One of these groups is the predominant one in all the so-called laccolithic groups of the adjoining plateau country, and is also common in the Rocky Mountains, especially in Colorado. The second group is certainly much less abundant than the first in the districts that have been closely studied, but its distribution is not well known at the present time.

DIORITE-PORPHYRY AND MONZONITE-PORPHYRY.

Introductory.—The map shows distinctly how large a share of the porphyries of the La Plata Mountains has been placed in one group for purposes of mapping. The group includes diorite-porphyry and monzonite-porphyry, no distinction being made on the map, because the rocks are, for the most part, intermediate between these two extremes. They also resemble each other so closely that a distinction would seem to the local student extremely artificial. It is indeed difficult to assign many of these rocks to one or the other of these types on account of the mode of development of the constituents, which will be described.

Reason for grouping porphyries on the map.

Description.—All of the rocks of the group are distinctly porphyritic in structure. They exhibit very plainly many crystals of white feldspar and of hornblende embedded in a gray, dense-looking groundmass. Occasionally folia of biotite are found, and still more rarely rounded phenocrysts of quartz may be seen.

Rocks with distinctly porphyritic structure.

From microscopical examination it appears that the rocks consist of lime-soda feldspar, potash feldspar, hornblende, biotite, and quartz, with magnetite, titanite, and apatite as accessory constituents in their common development. The feldspars together greatly exceed all other minerals in amount. The proportion of the feldspars to the ferromagnesian silicates varies, however, but in no case do the latter equal the feldspars. As to the latter, there is commonly much more plagioclase than orthoclase, and many of the rocks are to be characterized as orthoclase-bearing diorite-porphyries. The fact that the plagioclase is usually developed in distinct phenocrysts, and orthoclase as uniformly confined to the groundmass, gives the rock the appearance of containing the former mineral in great abundance, while the rôle of the latter is disguised. From the optical determination of numerous crystals, it is probable that labradorite of ab_1 an_1 is the characteristic plagioclase of these rocks.

Aside from the accessory elements the groundmass is characteristically composed of a granular mixture of orthoclase and quartz. In some cases the hornblende constituent grades uninterruptedly from the larger individuals to smaller grains, corresponding in size to the orthoclase and quartz of the groundmass. But as a rule the hornblende is in distinctly larger individuals, and thus may be said to occur chiefly in phenocrysts. Of the ferromagnesian minerals, hornblende is the only prominent one in most of the rocks.

Variations in composition.—The chief variations in composition among these rocks are in the relative abundance of the feldspars and in the amount of hornblende present. As to the feldspathic constituent, the variation is from rocks in which the soda-lime species and the alkali feldspar (orthoclase) are about equal in amount—monzonitic—to those in which the former strongly predominates—dioritic. The amount of amphibole in the rock is not easily estimated from a megascopical study, because of the great variation in the development of this mineral. Where it appears in a great many small needles the rock is much darker and gives the impression of a greater amount of amphibole than is really present, while the same amount of amphibole concentrated in a few crystals causes the rock to have a lighter shade. In a few cases pale-green augite replaces the hornblende in large degree, and in one case entirely. The latter rock occurs on the ridge between Shaw and Boren gulches, where it cuts a hornblendic porphyry. The rocks containing augite are not different in general appearance from the hornblendic forms.

Variations in texture.—While the porphyritic structure is so common through these masses, there is great variation in texture. This variation is not distinctly connected with the size of the sheets or the horizon of their intrusion. In certain cases the porphyritic structure is so fine grained that there is an apparent transition to the granular structure. Microscopical study, however, clearly shows that in these cases the phenocrysts, though small, are distinctly different from the groundmass grains, even where the latter are comparatively coarse. The most prominent phenocryst is plagioclase. In some rocks these crystals are nearly all of approximately the same size. At other times there is a gradation from unusually large crystals to very small phenocrysts. Certain masses, like that of Baldy Peak, are characterized by a few plagioclase phenocrysts of unusual size without a distinct gradation to the average. The hornblende also varies in its development. In the thin sheet on the west side of the La Plata between Snowslide and Bay City gulches, this constituent is so uniformly developed in rather large prisms that the groundmass of the rock is unusually distinct. This rock exhibits the typical development of the porphyritic structure. Orthoclase is almost never present in phenocrysts, and quartz but very rarely.

Chemical composition.—The chemical composition of rocks varying as described can be readily comprehended from the basis of an analysis of one of the most typical diorite-porphyries of the mountains; namely, one occurring in dike form on the western slope of Deadwood Gulch. This analysis, which follows, was made by W. F. Hillebrand;

Analysis of diorite-porphyry.

SiO_2	60.44
Al_2O_3	16.67
Fe_2O_3	2.31
FeO	3.09
MgO	2.18
CaO	4.22
Na_2O	5.18
K_2O	2.71
H_2O	1.43
TiO_2	.60
CO_2	.48
P_2O_5	.29
MnO	.13
BaO	.12
SrO	.11
Li_2O	trace
	99.96

Sp. gr., 2.677 at 24° C.

SYENITE-PORPHYRY AND ALLIED ROCKS.

General description.—There occurs in the La Plata Mountains a series of rocks ranging from syenite-porphyry to monzonite-porphyry which deserves to be distinguished from the monzonite-diorite-porphyry series above described. The rocks in question belong to a later period of eruption than those of the larger group and have certain mineralogical peculiarities, though in general terms the monzonitic extremes of the two series are not far apart. This later series has been designated syenite-porphyry in the legend.

The rocks referred to are plainly porphyries, but as a rule the groundmass greatly predominates over the phenocrysts, and they are more strongly feldspathic rocks than the diorite-monzonite-porphyry series. It is a singular fact that, although these types are similiar in composition to the principal porphyries of the mountains, they usually have a more decomposed appearance. This is largely due to ferritic and other indistinct dusty particles in the feldspars. But the ferromagnesian silicate is also almost wholly decomposed.

Porphyries with predominant groundmass.

The phenocrysts of feldspar are mainly plagioclase, similar to those of the diorite-porphyries; a pink orthoclase in tabular form is not rare in many instances. The plagioclase crystals frequently have an oriented orthoclase rim about them. The phenocrysts of plagioclase are seldom determinable as to composition, but are presumably rather rich in the albite molecule. In all of these rocks pyroxene is more common than amphibole; biotite is rare. Several of the occurrences are characterized by titanite in honey-yellow tablets which are very distinct to the naked eye.

The groundmass of these rocks was found, on microscopical study, to be trachytic in structure, composed of laminæ or microlites, and in the narrower dikes the groundmass laminæ are arranged so nearly parallel to the walls that a notable structure is produced in the rock. The groundmass feldspar is usually impregnated by pyritic dust to a degree which obscures its character. It is presumably an orthoclase rich in soda, or possibly in part anorthoclase. The assumption that soda is abundant in feldspars is supported by the character of the pyroxene in these rocks. It is usually very strongly green in color, and distinctly pleochroic, but has in all cases a large extinction angle, and is hence to be called ægirite-augite. The amphibole associated with this pyroxene is generally olive green in color and exhibits resorption rims.

If plagioclase is restricted to the development in phenocrysts, as appears to be the case, the rocks are, as a rule, much richer in alkali feldspar than in plagioclase. None of these porphyries were obtained in sufficiently fresh condition to warrant complete quantitative analysis.

Occurrences.—The small laccolithic body of syenite-porphyry in the McElmo formation on the southwest slope of Parrott Peak is almost identical with the dike shown crossing the ridge northeast of Helmet Peak. These rocks are ashen gray in color and have a strongly predominant feldspathic groundmass. The pyroxene in these two occurrences is very well developed in prismatic crystals and is a typical ægirite-augite. There are a few large, dark hornblende phenocrysts. According to determinations by W. F. Hillebrand this rock contains 6.13 per cent Na_2O and 4.68 per cent K_2O. Both the soda percentage and that of the two alkalies is higher than in any other type analyzed.

Igneous sheet on Jackson Ridge.

The rock of the sheet on Jackson Ridge is much nearer to a monzonite-porphyry, as it has more abundant plagioclase phenocrysts. Its occurrence so near the dike rock suggests that they represent the same magma. But the Jackson Ridge sheet is so much decomposed that close comparison is impossible.

There are several small dikes of syenite-porphyry not represented on the map. These are usually characterized by pink or reddish color, strong predominance of very fine-grained groundmass, and they possess a pronounced lamellar structure, parallel to the dike walls. These narrower dikes of syenite-porphyry were seen on Helmet Peak, crossing Tirbircio Gulch near its mouth, in Deadwood Gulch, and cutting the large porphyry body of Silver Mountain. Other dikes related to these were noted in the adjacent portions of the Rico and Durango quadrangles, which undoubtedly belong to the La Plata center of eruption.

INCLUSIONS IN PORPHYRY.

Many of the porphyry sheets and dikes are characterized by numerous inclusions of apparently foreign rocks, these inclusions varying greatly in abundance. In some cases the sheets are spotted with inclusions quite uniformly. The small sheet in the northwestern branch of Cumberland Basin contains the largest number of inclusions. These range in character from granitic rocks, or rocks of granitic composition and gneissic structure, to dark granular amphibole masses, or to schistose rocks consisting very largely of hornblende. Inclusions of the same character are found also in the more basic porphyries described in the following section, and there is no observable relation between the size of the porphyry body and the size or number of inclusions which may be contained in it. Thus, some of the narrow lamprophyric dikes of Snowstorm Peak contain a great many inclusions of granite, or of amphibolic rocks of the same types which occur most commonly in the diorite and monzonite porphyries. Considering the great number of fissures traversing the sedimentary formations, it is somewhat remarkable that fragments of these formations are so rare in the intrusive bodies. Apparently the granitic rocks, at least, represent the composition of the pre-Paleozoic floor upon which the sedimentary section of this region rests. From what is known of the Archean complex in the Animas Valley, it must be considered that the amphibolic inclusions may also be derived from this fundamental formation. At the same time, it is so characteristic of dioritic masses almost everywhere that they should contain inclusions very rich in hornblende that it is natural to infer that the fragments and the rock containing them are genetically related. Until a large number of these inclusions have been collected and carefully studied it will be impossible to affirm or deny such a connection for the inclusions of the La Plata Mountains. The amphibolic fragments vary considerably in appearance. They are sometimes rather dense and schistose, but in certain dikes and sheets upon the southwest face of Hesperus Peak a number of fragments were observed which, although several inches in diameter, consisted mainly of a single individual of hornblende, as shown by the continuous cleavage. Pyroxenic masses occur in some of the sheets containing numerous inclusions, but they are nowhere so abundant as those characterized by hornblende.

Pre-Paleozoic granite fragments included in intrusive bodies.

BASIC DIKES AND SHEETS.

In and about the La Plata Mountains occurs a series of dark and usually fine-grained aphanitic rocks, most of which appear in dikes, though some are sheets and one has a laccolithic form. These rocks have been designated basic dikes and sheets in the legend of the geologic map. The classification and naming of these rocks is difficult in the present stage of systematic petrography. Genetically considered, they may be grouped plausibly under the unsystematic term "lamprophyre" to indicate their supposed origin and relationship as differentiation products of the La Plata magmas, erupted in the later stages of igneous activity at this center. In this view they belong in the *melanocratic* division of *diaschistic* rocks proposed by W. C. Brögger. The corresponding or complementary magmas, the *leucocratic* division of Brögger, may be considered as represented in the La Platas by the rocks already described as augite-syenite and syenite-porphyry. One of the masses to be described exhibits such clear evidence of further differentiation in situ that this genetic problem becomes one of the most important developed in the study of these mountains. The further discussion of this question is, however, reserved for the section on "General geologic problems."

"Lamprophyre" dikes.

General character.—The rocks in question may be broadly characterized as made up of the same minerals as the more abundant rocks already described but possessing the dark silicates in more or less decided preponderance. The feldspars are, however, less markedly subordinate than one may infer from megascopical examination. Many of these rocks are fine grained throughout, and then both the minute size of the dark constituents and the dissemination of decomposition products tend to obscure the feldspar. Where a porphyritic structure is prominent it is hornblende which assumes the leading rôle and the contrast with the diorite- and monzonite-porphyries is strong.

The difficulty in classifying these rocks under existing schemes is twofold. Giving to the feldspars the great importance assigned them in modern systems, the lamprophyric rocks fall in two series: the orthoclastic and the plagioclastic, related respectively to syenite and diorite. But most of these rocks are related in this respect to monzonite; that is, the alkali and lime-soda feldspars are both present and may be nearly equal. As yet no set of terms for monzonitic lamprophyres has been proposed. That there has been hesitation in doing so seems natural and is amply justified by such a series as the rocks under discussion. In this series the larger number possess the feldspars in an amount not far below that of the ferromagnesian silicates. With respect to the character of the feldspars these rocks logically fall into three groups: the syenitic, the monzonitic, and the dioritic lamprophyres. No purely orthoclastic or plagioclastic rocks have been found, and the majority are monzonitic lamprophyres, for which special names are wanting.

Classification of the lamprophyric dikes difficult.

Some of the rocks are rich in amphibole and pyroxene, and in these the classifactory value of the feldspars plainly decreases. Rocks so basic that the feldspar is negligible do not occur in the La Plata Mountains, and yet those richest in amphibole and pyroxene clearly belong together, whatever the character of the feldspar.

The problem in classification presented by the lamprophyric rocks of the La Plata Mountains is that of expressing in system the quantitative importance of the chemically and physically contrasting mineral groups, the feldspars and the ferromagnesian silicates. Further discussion of so broad a question is clearly out of place in this text. The rocks observed vary so greatly that no two seem quite alike in composition. Their description will therefore proceed by localities, specific names being in most cases avoided.

Occurrence on Indian Trail Ridge.—The sheet or thin laccolith occurring in the McElmo formation in one of the knolls on Indian Trail Ridge, as shown by the map, is the largest mass of lamprophyric character in this quadrangle. It lies in nearly horizontal position, conformable with the strata inclosing it, and has a thickness of about 150 feet. The mass is not homogeneous in character, but exhibits important differences in composition in zones parallel to the upper and lower contacts respectively.

The inner portion of this body is a rather fine-grained and evenly granular, grayish-green rock in which the feldspars nearly equal the ferromagnesian constituents in amount. These two classes of minerals are so distinct in the rock that the rôle of each is very clear. Of the dark silicates, augite is far more important than hornblende, which occurs only in a few short prisms. Biotite was also formerly present in subordinate quantity. The augite throughout the mass is very pale green or colorless in thin sections. There is but very little magnetite present in the rock. The feldspars are so much sericitized and obscured that their character is not perfectly certain. While some soda-lime feldspar is undoubtedly present, orthoclase is apparently greatly predominant. The transitions toward the contact zone are very gradual. The feldspar decreases and both augite and hornblende increase in amount, but variably. Hornblende tends to appear in larger crystals of prismatic form, and augite ranges down to minute grains that mingle with the feldspar to form a groundmass which is much more distinct as seen under the microscope than it appears to the naked eye. Chlorite, epidote, and calcite as decomposition products obscure the feldspars and make the contact facies appear much more basic than is actually the case. As the amount of augite and hornblende increases the feldspar becomes more and more predominantly orthoclase. In the contact zone, several feet in width, feldspar has become much subordinate and is difficult of specific determination, for it is greatly obscured by the finer particles of augite and the alteration products of the dark silicates. A part of the rock is characterized by hornblende phenocrysts, which may exceed 1 centimeter in length, but the adjoining zones are very apt to be almost entirely augitic rocks. The rocks of this mass seem more nearly related to vogesite than to any other recognized type of the lamprophyres.

On the ridge north of the mass just described is a small irregular dike of a very dark porphyry crowded with hornblende and augite phenocrysts, the former being much the more conspicuous. From its situation this dike might be suspected to represent the channel through which the magma of the adjacent laccolith ascended. But the rock is much richer in dark silicates than is the laccolith. Its feldspars are confined to the subordinate groundmass, and a plagioclase in microlites is more abundant than the presumable orthoclase of the irregular interstitial grains. The decomposition of augite and feldspar is considerable. An analysis of this rock was made by W. F. Hillebrand, with the result given below:

Analysis of basic dike rock.

SiO_2	43.98
Al_2O_3	13.30
Fe_2O_3	3.67
FeO	6.92
MgO	7.03
CaO	10.66
Na_2O	2.15
K_2O	1.64
H_2O	1.94
TiO_2	1.18
CO_2	6.46
P_2O_5	.32
NiO and CoO	.03
MnO	.22
BaO	.06
SrO	.05
FeS_2	.54
	100.15

Sp. gr., 2.912 at 19.5° C.

The presence of nearly 15 per cent of calcite and the partially decomposed state of the dark silicates prevent any satisfactory calculation of the mineral components of this rock. The K_2O found represents 9 45 per cent of orthoclase, and there is probably twice as much plagioclase present.

Thin sheet on North Fork West Mancos River.—The thin sheet intruded above the Dakota sandstone north of Hesperus Peak is a greenish-gray, aphanitic rock, with numerous small biotite leaves megascopically present and showing parallel streaks of the feldspathic constituents. The microscope shows augite and orthoclase to be the chief constituents, the former predominating. There is no hornblende in this rock, and the biotite is present only in the leaves which are visible to the naked eye. The augite appears in small rounded prisms of very pale green color. This rock is considerably altered, chlorite, calcite, and muscovite being the chief products.

Dike on divide at head of La Plata River.—The dike cutting the western part of the prominent knoll on this divide is much richer in amphibole and pyroxene than the rocks above described. Hornblende decidedly predominates over augite. It is, indeed, the only prominent megascopic constituent, occurring in prisms which reach 1 centimeter in length, most of them rather slender, but a few short and stout. Augite is also quantitatively important in the rock, as shown by the microscope, but occurs uniformly in very small grains. No biotite was observed. The matrix for the larger hornblende prisms is composed mainly of feldspar with minute grains of augite and magnetite. Feldspar appears to be chiefly orthoclase, in irregular grains. Decomposition products of augite, chlorite, calcite, etc., greatly obscure the feldspathic constituent. But there is a little magnetite in the rock, and some of it is titaniferous. This rock appears to be a hornblendic vogesite considerably more basic in chemical composition than the preceding rocks.

Dikes of Snowstorm Peak.—Near the summit there are several small dikes of a strongly marked porphyry with many hornblende phenocrysts in a dark or greenish aphanitic groundmass. The hornblende crystals vary from 1 centimeter in length downward, but most of them are megascopically visible. Augite is also present, but in much smaller grains than hornblende. Possibly it is nearly equal to the hornblende in amount. The rock is megascopically very similar to the type described from the Indian Trail Ridge, but its feldspar is chiefly a soda-lime species in microlitic form with subordinate granular orthoclase. The following quantitative analysis of the freshest rock obtained, from the dike just south of the summit, was made by W. F. Hillebrand;

Analysis of lamprophyre from Snowstorm Peak.

SiO_2	47.25
Al_2O_3	15.19
Fe_2O_3	5.05
FeO	4.95
MgO	6.87
CaO	9.98
Na_2O	2.39
K_2O	2.60
H_2O	2.52
TiO_2	1.22
CO_2	1.87
P_2O_5	.25
NiO and CoO	.02
MnO	.17
BaO	.08
SrO	.05
	100.46

This rock is plainly richer in feldspar than the one from Indian Trail Ridge the analysis of which was given above. The potash corresponds to about 15.5 per cent of orthoclase, and nearly one-half of the rock is feldspar.

Rocks similar to this type from Snowstorm Peak occur on the southwest slope of Lewis Peak and in the saddle between Snowstorm and Cumberland peaks. Certain zones of the laccolithic mass of Indian Trail Ridge are also of this type.

Aphanitic rock in West Mancos Canyon.—The dark aphanitic rock intruded as a sheet above the Dakota sandstone and below the larger porphyry mass on the north side of this canyon is somewhat different from the preceding in composition. Augite, biotite, and plagioclase are the chief constituents. Orthoclase is very subordinate. The augite is pale green and the biotite dark reddish brown. There are a few phenocrysts of biotite. The rock is now far from fresh. This type seems nearly related to augite-kersantite.

A very similar rock occurs as a dike of small dimensions on the west side of Deadwood Gulch.

DESCRIPTIVE GEOLOGY.

OUTLINE SKETCH.

The La Plata quadrangle lies where the geologic structures of the San Juan Mountains and of the Great Plateau country meet and blend. The position of the area may be easily understood by a glance at the Hayden atlas of Colorado, the general structure there represented being in the main correct, though many of its details are faulty.

Southerly dip of Cretaceous along southern front of the San Juan.

The broader structures of the region, controlling the distribution of the sedimentary formations, may also be comprehended by the aid of figs. 2 and 3. In the former is shown the gentle southerly dip of the Cretaceous formations about Durango, an attitude prevailing for many miles along the southern front of the San Juan, with steeper dips nearer the mountains. The prominent hills of this view are isolated portions of a sloping mesa, the floor of which is the Mesaverde sandstone. The same formation, which traverses the La Plata quadrangle and connects directly with the Mesa Verde, is seen in fig. 3.

In fig. 3 may also be seen the comparatively level floor of the Dolores Plateau, underlain by the Dakota sandstones — the plain which is represented in the northern part of the western border of the La Plata quadrangle. The general structure of the southwestern slopes of the San Juan Mountains, including the area of the La Plata quadrangle, has been more fully discussed in the Telluride folio, and in a report on the geology of the Rico Mountains, to which the reader is referred ("Geology of the Rico Mountains, Colorado," by Whitman Cross and Arthur Coe Spencer: Twenty-first Ann. Rept. U. S. Geol. Survey, Pt. II).

While the San Juan and Plateau structures are prominent in the La Plata quadrangle, an element of far more local importance is the domal uplift of the La Plata Mountains. This movement and other phenomena of the same center have led to the formation of the rugged mountain group containing many features of interest to the geologist.

Domal uplift of the La Plata Mountains.

The domal uplift of the La Platas has elevated the lower Mesozoic formations, which would otherwise have remained buried on the site now occupied by the mountains. Simultaneously with the uplift, and to an unknown extent causing it, numerous masses of molten magma were injected between strata at many horizons, and these are now visible as sheets or small laccoliths of porphyry, which have been described in a preceding section. Later intrusions of igneous material forced their way more directly across the sedimentary beds and the intercalated sheets of porphyry, forming stocks, within the mass of which are several of the highest peaks of the group.

Igneous intrusions and metamorphism.

The igneous intrusions of the La Platas, and especially the stock eruptions, were accompanied by agents of metamorphism, and the heart of the group exhibits such extensive alteration of the more or less calcareous sediments that the geologists of the Hayden Survey, in their necessarily hurried observations, failed to trace out the structure of the inner portions of the mountains and grouped as "Metamorphic Paleozoic" several formations elsewhere distinguished by them.

Period of ore deposition.

At a period later than any igneous intrusion of this region the La Plata uplift became the seat of extensive deposition of ores of the heavy metals, iron, copper, lead, and zinc, with variable accompaniment of silver and gold. The ore deposits are of several types and will be described in the section on "Economic geology," by Mr. Purington.

Late uplift and great erosion.

The later geologic history of the region is involved in that of an extended area of almost continental dimensions within which there was orogenic uplift succeeded by enormous erosion beginning early in Cenozoic time and continuing to the present. Of this great erosion the La Plata quadrangle exhibits little evidence aside from the local dissection and sculpturing of the dome. For broader facts bearing on this period of denudation the study of a larger area is necessary, especially of the San Juan Mountains and the adjacent slopes. Certain gravel terraces of the La Plata quadrangle undoubtedly belong to epochs in which similar deposits were formed over large areas, but their close correlation has not yet been made out.

From the concise outline above given it is clear that a detailed description of the quadrangle can best be carried through by considering separately the mountain area, the slopes toward the Plateau, and the southern portion of the dissected section of the Mesa Verde.

LA PLATA MOUNTAINS.

STRATIGRAPHY AND STRUCTURE.

Formations represented. — The stratigraphic units which enter into the make-up of the mountains, as now exhibited, are the Dolores (Triassic); the La Plata and McElmo (Jurassic); the Dakota and Mancos (Cretaceous). The character of these formations and many facts of distribution have already been given. From the section displayed in the Animas Valley and at Rico, we can assume the presence of other sedimentary formations below the Dolores in the La Plata dome. These embrace the Rico and Hermosa (Carboniferous), the Ouray (Devonian), and the Ignacio (Cambrian), all in apparent structural conformity.

Carboniferous, Devonian, and Cambrian rocks in the La Plata dome.

Archean complex and possibly Algonkian quartzites present.

The floor upon which the Cambrian quartzites rest beneath the La Plata Mountains is either an Archean complex of gneiss or schists with granite intrusives, or a great series of Algonkian quartzites. The east-west strike exhibited by the steeply upturned Algonkian quartzites of the Needle Mountains and their appearance at Rico in the line of that strike make it probable that the zone of their westward extension passes to the north of the La Plata Mountains. The inclusions of granite and of several kinds of schist in some of the porphyry masses of the La Platas also indicate the presence of schist and granite below.

The upper formations which originally took part in the La Plata dome doubtless included the remainder of the Cretaceous section, the Animas or post-Laramie beds, the Puerco (Eocene), and possibly other Tertiary formations. It is also probable that some, at least, of the surface volcanics of the San Juan complex were present at the time of the La Plata uplift.

Present distribution of Dolores formation.

The present distribution of formations is dependent upon structure and erosion and is represented by the geologic map. The deep valley of the La Plata brings to light the Dolores formation, in nearly its entire thickness at the heart of the mountains. It is shown in most normal development in Bear Creek and the Hermosa drainage to the east of Indian Trail Ridge. Throughout the mountains proper the formation is generally metamorphosed or bleached, but at many places remote from the stocks of granular rocks the reddish color reappears.

Distribution of La Plata sandstone.

The La Plata sandstone deserves the name which has been given to it by reason of its prominence in the peaks of the mountains. It is present at or near the summits of all the points on the divide between the La Plata and Mancos rivers from Madden Peak northward and on Indian Trail Ridge. It is thought that a small remnant caps Deadwood Mountain, but with this exception it has been removed by erosion from the eastern peaks of the group. The La Plata sandstone is massive enough to form prominent outcrops, even where not especially indurated, but wherever it has been metamorphosed in the center of the group it becomes a hard quartzite causing jagged pinnacles or cliff exposures.

Distribution of McElmo, Dakota, and Mancos formations.

The McElmo, Dakota, and Mancos formations appear principally upon the outer slopes of the mountains, dipping away from the main circle of peaks. The only notable irregularity in their distribution appears in Hesperus Peak, where the naturally soft Mancos shales have been greatly indurated in the metamorphic zone about the monzonite stock of Mount Moss. Their preservation has also been aided by the presence of numerous thin intrusive sheets of porphyry, as represented by the map in a generalized way.

Structural features of the mountains. — The most notable structural feature of the mountains is the local uplift of sedimentary beds which may in general be characterized as a domal uplift. With this local structure the more general dips of the same strata away from the San Juan center have blended on the northern and eastern slopes of the mountains. The quantitative relation of the two structures is difficult to determine, and will be discussed in some detail in a later section. Faulting has modified in some degree the simple structure of the domal uplift, but is confined to a few localities, as represented by the map. There has also been much disturbance of the sedimentary beds by a large number of intrusions of molten magma. The geologic map shows the local dome structure by the areal distribution of the sedimentary formations and of the intercalated porphyry sheets. The strike and dip signs indicate the same structure as determined in definite localities. Further illustration of the domal structure appears in the profiles of the Structure Section sheet.

La Plata dome.—The geologic map does not perfectly exhibit a domal structure because on the north and east all the formations above the Dolores have been removed by erosion, and on these sides the blending with the broader San Juan structure takes place. The actual distribution of formations north and east of the mountains beyond the present quadrangle limits brings out the domal structure somewhat more plainly. The La Plata sandstone extends northward on the east as far as Sandstone Mountain, a hill on the divide between Junction and Hermosa creeks situated 5 miles directly east of Lewis Mountain.

Conditions which modify the regularity of dome structure.

On the north the Dakota sandstone comes almost to the crest of Indian Trail Ridge at a point a little north of the quadrangle line. The dip signs of the map show many irregularities in details of structure which are often due to the igneous intrusions. The faults, which will be referred to below, the influence of the San Juan structure, and the apparently elliptical form of the uplift, all modify the regularity of the structure. The profile sections illustrate the fact that the dome at its maximum was very flat. The La Plata sandstone remnant at the summit of Diorite Peak is now about 5000 feet above the level of the same horizon at a point some 6 miles westward, as represented in section B B. The remnant of the same formation on the summit of Deadwood Mountain is also about 5000 feet above the horizon it occupies on the line of section C C, where the steeper dips die out, some 4 miles to the southwest of the mountain. These instances represent an amount of doming in which visible eruptives have had little share.

Apex of the dome.

The apex of the original dome would appear to have been a little west of Lewis Peak, but at this point there is apparently a local steepness of dip in various directions, which may possibly be interpreted as due to a buried laccolith of porphyry.

Uplift increased by intrusive bodies.

In all the central part of the mountains the intrusive beds are very numerous below the horizon of the La Plata sandstone, and hence must have increased the uplift of the latter to a considerable amount above the elevation of 5000 feet indicated in Deadwood Mountain and Diorite Peak.

Section B B shows a steep dip on the east side of the dome, which quickly brings the sedimentaries down to the general level found on the western and southern slopes. This is a more or less local irregularity and is possibly due entirely to a buried laccolith, mentioned above.

The diameter of the domal dislocation of the La Plata sandstone may be estimated at approximately 10 to 15 miles. The blending with the San Juan structure on the north and east makes any close estimate impossible.

Upthrust along faults usually on side nearer dome.

Faults.—The faults of the La Plata Mountains are neither numerous nor important. The principal ones were traced out and mapped across the northwest slopes of the mountains from the West Mancos to Indian Trail Ridge. These approximately parallel fissures are connected by several cross fractures. The other more important fractures are an east-west fault near the Menefee ranch and one crossing the saddle between Parrott and Madden peaks. There are many smaller fractures, as on Ohlwiler Ridge and in the divide at the head of the La Plata River. The latter fractures were not represented on the map, it being impossible to trace them for any considerable distance. The dislocation of the faults is commonly upward on the side nearer the center of the dome, but instances are not lacking of the reverse movement, as shown in profile sections A A and B B.

The faults crossing the West Mancos are clearly exhibited upon the ground, since they affect strongly marked formations, such as the Dakota sandstone and the intrusive porphyry sheet above it. Their effect and the amount of their dislocation are so clearly expressed by the map and the sections A A, B B, that little description is necessary. To the southwest these faults can not be traced in the shale area, and they seem to die out before reaching the Dakota exposures of the lower course of the West Mancos. To the northeast they are also lost on the shale slopes and beneath landslide débris, but may reasonably be assumed to connect, at least in some cases, with similar faults observed to cross Bear Creek and the ridges on either side.

The fault crossing the saddle south of the Sharkstooth is very distinctly marked by its effect upon sandstone horizons and a thick porphyry sheet. Its curving course, as represented by the map, is due to a change in direction and not to dip. Whether the fault passing north of the Sharkstooth is, as represented on the map, the same as that crossing Indian Trail Ridge north of the porphyry sheet in the McElmo formation was not definitely determined. If they are the same, there is a change in the throw, since the displacement is in different directions on the two ridges.

Fault at Parrott Peak 1000 feet.

The fault between Madden and Parrott peaks is very noticeable, since it cuts off the porphyry sheet of the latter and lifts the La Plata sandstone to the summit of the former peak. The dislocation of this fault on the line C C is represented on the section as about 1000 feet. This is so considerable that it might be expected that this fracture could be traced eastward across the La Plata River. A careful search failed to discover any trace of it on the eastern bank of the stream. It also appears to die out in a westerly direction very rapidly, for it was not identified in the canyon of the East Mancos. Yet nearly in the line of its projected course westward is the Menefee fault, which was at first supposed to be its direct continuation. The Menefee fault is clearly exhibited in two places where crossed by the railroad on the south bank of the East Mancos.

IGNEOUS INTRUSIONS.

LACCOLITHS AND SHEETS.

The number of intrusive porphyry bodies in the La Plata Mountains which may be designated sheets or laccoliths is rather large, as may be seen by the geologic map. A number of these masses are also exposed in the adjacent portion of the Durango quadrangle, especially in the valleys of Lightner and Junction creeks. Intrusions of this character are practically confined to the area of the domal uplift. They are most numerous in the La Plata and Lightner valleys.

Igneous sheets throughout geologic section.

The sheets exposed at the present time range through the geologic section from the lowest horizon seen in Lightner Creek — the top of the Carboniferous — to the horizon in the Mancos shales which is represented at the summit of Hesperus Peak. We may assume that magmas penetrated into higher strata, now entirely removed, and that they were also forced between the concealed Paleozoic strata in the same manner.

Porphyry bodies assume various forms.

In form the porphyry bodies vary from regular sheets, traceable with approximately the same thickness for a mile or more, to thick bodies more nearly approaching the ideal laccolith in shape. There is great variation also in the degree of regularity of intrusion. There are all degrees of transition from sheets which do not visibly depart from a certain horizon to directly cross-cutting dikes. So many centers of similar intrusions have now been described that it seems needless to discuss at length the conditions of such a center of eruption. It is evident that where many sedimentary formations of different character are intruded by numerous porphyry bodies there must be a great amount of variation in form and size.

The variation in thickness in the La Platas ranges from that of thin sheets, or dikes, which it is difficult to represent on a map of this scale, to the larger masses like those of Silver Mountain, the thick lateral arm forming The Hogback, and the adjacent sheet or laccolith of the Rampart

Hills. From experience in other localities, as well as from the developments here, it may be supposed that still larger bodies than any now observed once existed in the Cretaceous shales of higher horizon. As shown by the map and pointed out in the description of rocks, the diorite- and monzonite-porphyries greatly predominate and were also the first ones intruded. They were followed by a number of syenite-porphyry injections, and still later by a few lamprophyric porphyries.

CENTERS OF PORPHYRY ERUPTION.

The deep dissection of the La Plata dome has exposed a most complicated system of cross-cutting porphyry bodies in the southeastern part of the mountains. Apparently these centers represent the channels through which a considerable part of the magma injected in sheet form must have ascended. Another mass apparently filling an eruptive channel is that shown at the head of Bedrock Creek.

Intricate system of dikes connected with massive intrusions.

It will be seen, on reference to the geologic map, that the large masses of Baldy Peak and Silver Mountain are represented as connected with a very intricate system of dikes, including many in Deadwood Gulch, Burnt Timber Gulch, the ridge between them, and the ganglionic center situated to the north of Silver Peak at the head of Lightner Creek. This expression of relations is throughout more or less generalized. The entire area concerned is vastly more complex than represented, but defies satisfactory analysis on account of the large amount of grass or timber-covered ground and the slide masses, which are locally very prominent. The accurate representation of the relations here would require good rock exposures and a detailed map of large scale; hence the map of this folio must be accepted as expressing an interpretation of a large number of observed facts rather than a delineation of masses traced out. Deferring details to a later section, it may be stated here that the map is intended to express the idea that beneath the western slope of Deadwood Gulch there must be a large stock-like conduit of porphyry, above which sedimentary formations have been crushed and fractured in the most complicated manner. This theory has been developed from the conditions observed on the present surface west of Deadwood Gulch.

Absence of McElmo formation on west slope of Baldy Peak.

Porphyry masses of Deadwood Gulch and Baldy Peak.—On the geologic map the La Plata and McElmo formations are represented as much broken up, from the bed of Deadwood Gulch to the crest of the ridge on the west. The McElmo is entirely omitted on a part of the west slope of Baldy Peak. The Dakota sandstone above is traceable almost continuously, and the Dolores formation below is recognizable throughout, though not the horizons within it. The western slope of Deadwood Gulch is largely grassed over in the portion concerned, but the La Plata sandstone was found in small exposures, apparently surrounded by porphyry, and the formation certainly can not be present in its whole development. The McElmo formation likewise can not be present in its normal thickness at this locality. Probably not all of the connections of the porphyry indicated by the map are correct, but the complex branching and intersecting character shown is certainly present, and is probably more complicated than represented.

A careful search was made for faults which might explain the absence or the diminished development of the La Plata and McElmo. The faults of Ohlwiler Ridge particularly suggested that the complications might be due to other faults, but no evidence of purely mechanical fracturing could be discovered where necessary to explain the situation.

Shattering of rocks above large intrusions.

The presence of large and irregular porphyry masses at any point in the sedimentary complex involves the shattering and dislocation of the rocks immediately above them. Especially, when the area between Baldy Peak on the south and Deadwood Mountain and Burnt Timber Gulch on the north is considered, it is readily seen that a large amount of dislocation must have occurred in the strata of horizons slightly above those exposed at the present time. It has therefore been assumed, as a basis for interpreting the eruptive geology of this locality, that many of these cross-cutting arms and dikes must have united at no very great depth and that we have here displayed the normal complications in the sedimentary formations, which must exist above a huge cross-cutting mass of intrusive rock. It is supposed that the ascending magmas have torn loose and carried upward the missing portions of the La Plata and McElmo formations, and doubtless portions of the Dolores also. The porphyry mass of Baldy Peak clearly cuts obliquely upward from the Dolores to the base of the Dakota. The connection with dikes west of Deadwood Gulch is shown in several arms, and the great development of unusually large plagioclase phenocrysts in these rocks shows the immediate source of the Baldy Peak mass. On the theory outlined above, erosion has removed the McElmo débris that was naturally above the porphyry mass now seen. It must be confessed that inclusions of sedimentary rocks in the porphyry bodies now exposed are rare; small fragments of sandstone or shale were observed in some places, however. Yet it is only necessary to assume that considerable quantities of magma were forced into higher horizons, carrying with them the greater part of the débris, to explain the rarity of fragments. The sandstone on the summit of Baldy Peak may well be such a fragment, rather than the base of formations above the porphyry mass.

Removal of shattered rock above Baldy Peak eruptive.

Buried porphyry body west of Deadwood Gulch.

There is a structural element favoring the hypothesis that a buried porphyry body of large size exists beneath the ridge west of Deadwood Gulch. This consists of a nearly horizontal attitude or a slight northerly dip of the sediments in Deadwood Mountain from the summit down the south and southeast slopes, and in an easterly dip to the strata of Paine Ridge on the east.

The large porphyry arms near the head of Deadwood Gulch, connecting in one direction with Silver Mountain and in another with the porphyry of Burnt Timber Gulch, are thoroughly well determined. They constantly exhibit a tendency to lateral intrusion on stratification planes, and many contacts seem on first sight to indicate the usual sheet form for the bodies concerned. The soft, unmetamorphosed Dolores strata of Paine Ridge belong to the upper part of the formation, as shown by numerous exposures of "Saurian conglomerate." They are traversed by many small tongues or fingers of porphyry, only a portion of which are shown by the map. That this area of intense fracturing containing so many practically contemporaneous igneous masses does not exhibit considerable metamorphism of the sedimentary beds is a fact which will be especially commented upon in discussions under the head of "General geologic problems."

Irregular mass in Burnt Timber Gulch.—The gulch on the southwest slope of Deadwood Mountain well deserves the name given it. Once covered by a heavy forest of fir and spruce, its steep slopes are now a mass of tangled timber, with a new growth of aspens springing up in many places. Under these conditions an accurate outlining of the extremely irregular porphyry mass there present is well nigh impossible, but the representation on the map is certainly not far from correct. This porphyry cuts across the strata in general, but at several points has arms which wedge open the adjacent beds on stratification planes. No actual connection of a well-developed sheet was found. The contact along the south bank of the gulch, near the bed of the creek, seems parallel to the stratification, but at the point represented a sharp contact in vertical position crosses the gulch and runs up the north side. The complexities in form of the mass are actually much greater than those shown.

There is locally much bleaching and metamorphism of strata, especially on the north side of Burnt Timber Gulch. But this condition is more appropriately connected with the syenite stock eruption not far away to the north than with the porphyry intrusion, for the strata near the latter in various places are almost unaltered.

The Silver Mountain mass.—The large porphyry mass of Silver Mountain appears from some points of view to be a huge laccolith, and the observed contacts seem in places to confirm this idea; but at other points marked cross-cutting contacts are exposed. Direct connection with the complex of Deadwood Gulch is plain, but the connection with the eruptive center at the head of Lightner Creek is less distinct. As observed from the trail on the eastern side of Lightner Gulch, the base of the mass appears in approximate conformity with the sediments for a long distance, but there are many visible irregularities. From the contact on the eastern slope of the mountain at about the level of 9500 feet to the summit at nearly 12,500 feet all is porphyry of light-gray tone. From the ravine on the eastern side, where the syenite-porphyry dike cuts both porphyry and underlying sediments, the contact of the Silver Peak mass seems more like the base of a laccolith than of a cross-cutting body, yet much of this line is concealed by great talus slopes. At the northeastern extremity is the apparent connection with the eruptive center in Waterfall Gulch, a branch of Lightner Gulch.

Connecting arms between large intrusions.

On the south the contact is by no means regular and the connecting arm toward Deadwood Gulch clearly cuts obliquely across the sediments. On the northeast side of Baker Peak the contact of the large body is markedly cross cutting, while along the western face of the same summit the porphyry is very nearly conformable to the stratification for half a mile. This latter locality seems to have given some of the early explorers of the La Plata Mountains the idea of a regular contact between the porphyry and sediments, which, by an effort of the imagination, they extended throughout the group. The "Baker contact" was long regarded as the best exposure of the contact running through the group. No doubt the Hayden map originally gave rise to this idea.

As a matter of fact, the "Baker contact" can be easily traced to the point where, as shown by the map, the wall of the porphyry mass suddenly changes to a nearly vertical position and runs abruptly down the slope to the west, crosses the gulch, and runs up high on the other side. So much of the boundary of the Silver Peak mass is concealed that the outline given it can plausibly be considered as due rather to vertical than to approximately horizontal and conformable contacts. Probably this body is a local thickening of an intrusion which, being developed in greatly shattered rocks, has of course many irregular contacts, though related more closely to the laccolith than to the stock form. It thus closely resembles the Baldy Peak mass.

There is more than one type of texture in the Silver Mountain mass, with but little variation in mineral composition. It was not found practicable to follow the observed boundaries between varying textures on account of débris and cliff exposures, but it does not seem probable that distinctly different periods of eruption can be made out. The mass is geologically a unit.

Eruptive center at head of Lightner Creek.—The porphyry mass crossed by Waterfall Gulch, a small branch of Lightner Gulch, is a complex of intersecting fissures between which are wedges or blocks of angular cross section, as now exposed. These are often too small for mapping and on the accompanying topographic map the expression of such relations is necessarily almost diagrammatic. While Waterfall Gulch exposes a good section through the heart of this porphyry ganglion, the dikes are often obscured at points of intersection. Several small dikes and irregular outcrops observed to the west and north have been omitted from the map because it was thought best not to complicate the representation too much. A connection with the Silver Mountain mass is apparently effected along at least one dike, which was not however, actually traced for the entire distance, owing to areas of slide or vegetation.

Large porphyry body in Bedrock Gulch.—Toward the head of Bedrock Gulch there occurs a large porphyry body, which begins at an elevation of about 9900 feet and extends across the steep divide at the head of the gulch to the north of Gibbs Peak into the head of the East Mancos Valley. A branch also crosses into the head of Madden Gulch. Although the character of the mass as a cross-cutting body seems determined by the fact that it extends from the bed of Bedrock Creek to the base of the La Plata sandstone on Gibbs Peak, yet the southern and western extensions are more like a sheet intruded at or near the base of the La Plata. Several conditions subject the representation of this mass on the map to possible future correction. One of these conditions is the extensive decomposition of the porphyry itself, all the dark silicates having been removed and the feldspars kaolinized. Further, the mass was once thoroughly impregnated with pyrite, and this has in much of the mass been dissolved, leaving the usual reddish or yellowish iron stain. Moreover, the mass occurs in an area where all rocks are intensely fractured into minute irregular fragments, and through the processes of weathering exposures rapidly crumble and form slide masses, concealing most of the contacts. As the surrounding sediments and the syenite which borders the porphyry on one side are similarly decomposed and stained, the tracing out of the porphyry contacts is extremely difficult. Indeed, the line between the porphyry and the syenite was not accurately located at any point. The northern part of this mass still contains so much pyrite that Mr. Purington has represented it on the Economic Geology sheet as practically a pyritiferous ore body. It seems possible that the conduit of Bedrock Gulch was the one through which the magma of the important porphyry sheets and arms to the west ascended.

Conduit in Bedrock Gulch a source of important intrusives.

Nature of intrusions above the Dakota.

Outlying porphyry masses.—It will be noted by reference to the map that most of the sheets injected into the strata below the Dakota sandstone have a general resemblance in their lateral development and extension; but above the horizon of the Dakota in the soft Mancos shales there are fewer and larger masses. The long ridge called The Hogback is caused by a thick arm of porphyry which is distinctly limited, as represented by the map, although its contacts are seldom seen, owing to talus slopes. From the southern base of the mass to the crest it is in some places more than 1000 feet thick. The character of this arm as a lateral injection rather than a cross-cutting body is shown by two remnants of shale which were found upon the crest of the ridge. As these lie upon the northern side they have a dip to the north. At other places along the crest of the ridge indications of the former shale covering were also observed, either in the form of shale fragments included in the porphyry or in the peculiar corrugated surfaces of the porphyry which it characteristically assumes when in contact with shale. Although the base of the mass is not sharply exposed as a rule, it is clear at the western end that its base corresponds very closely to the general stratification of the shales. The projection to the northwest across the branch of the Middle Mancos is partially cross cutting. This arm evidently ended very abruptly and is represented on the west side of the Middle Mancos by a small outcrop, the base of which is at the same general level as the base of the porphyry at the end of the main Hogback.

Flat laccolith of the Rampart Hills.

The porphyry mass which extends from the Rampart Hills northward across the West Mancos Canyon is practically a rather flat laccolith. As shown by the map, it does not occupy the same stratigraphic plane throughout, but descends northward to the upper surface of the Dakota and in the region of Deep Canyon cuts a little below the top of the Dakota and is injected upon one of the shaly division planes in the Dakota itself. It is possible that this mass is connected with The Hogback.

The intrusions of porphyry in the Mancos shales, from the Sharkstooth northwest along the crest of the ridge bordering Bear Creek, are the only other important outliers within the La Plata quadrangle. These masses are doubtless irregularly connected, but the outline exhibited was in a measure conjectural, especially on the southwestern side. Here these porphyry sheets have, by weathering, broken into slowly moving masses of débris which are creeping down the southwestern slopes and in some places almost reach to the North Fork of the West Mancos. This movement appears to go on through the washing out of the soft shales below, and the slide is thus gradually let down until it appears to occupy a horizon considerably below that of its original injection. That the débris masses are actually moving down the slope is seen in some places, where they have penetrated into the forest and partially killed off the growth of trees, some of the stumps being seen projecting through the slide mass. The outlying bodies to the east of the La Plata Mountains are mainly in the Dolores formation and are comparable with the bodies of the La Plata Valley.

Creeping of débris masses on slopes.

STOCK ERUPTIONS.

The map shows stocks of three different kinds of granular rock, which penetrate all formations in their path. It is shown in many places that they are distinctly later than the porphyries of the laccolithic type. The rocks filling these large conduits are of three kinds, which have been described in the preceding section. No doubt the three rocks belong to somewhat different epochs of eruption, but as they do not come in contact their relative age is unknown.

From the phenomena here and at other laccolithic centers, as the Rico Mountains, it is inferred that the stock eruptions are of a type quite different from those of the laccolithic intrusions. This subject is discussed somewhat more in detail in the section on "General geology." Metamorphism of the calcareous strata about the stocks is common.

Monzonite stocks.—The stock within which are situated several of the highest and most rugged peaks of the mountains, including Mount Moss and Babcock and Spiller peaks, is composed chiefly of monzonite. The rugged topography within the eroded stock is but imperfectly represented in figs. 10 and 11. The extremely jagged crest of Mount Moss shown in fig. 11 and the divide connecting it with Babcock Peak are entirely due to the monzonite. As stated in the description of this view, there is a lateral wedge-like arm from this stock which tilts the strata and intercalated porphyry sheets, as may be seen from a study of the illustration. The phenomena at the head of the West Mancos gave Holmes the idea, which he has expressed in the Hayden reports, that the principal eruptive conduit of the La Plata Mountains was situated at this point. Without distinguishing the difference between the granular stock rock and the porphyries of the intruded sheets in Hesperus Peak, Holmes naturally assumed that all the intrusions were offshoots from the cross-cutting body. As a matter of fact, there are but two sheets injected laterally into the strata for any considerable distance which seem to be directly connected with the stock in origin. These are shown on the map as cutting through Banded Mountain, and one extends for several miles northward along the west bank of Bear Creek. Even this connection is open to some doubt, however, because outcrops are not perfectly continuous in the region of Banded Mountain, and it is possible that these sheets are also cut by the stock. In character, however, the rock of these sheets is more nearly like the monzonite than is the rock of adjacent sheets.

There is much metamorphism adjacent to this monzonite stock. All through the strata of the Dolores near it there is a considerable development of silicates of iron, lime, and magnesia, such as pyroxenes, garnet, and probably vesuvianite, and small fissure planes through both sedimentary and igneous rocks are frequently coated by scales of brilliant specular iron. Some of the impure limestones of the Dolores have been transformed into granular masses of coarsely crystalline calcite, garnet, and pyroxene.

Metamorphism adjacent to monzonite stock.

Diorite stocks.—The principal diorite stock is that extending from Diorite Peak southward to the valley of Basin Creek. It is irregular in shape, as shown by the map, and distinctly cuts across a number of typical porphyry sheets. As explained above in describing the rock, it is closely allied to the monzonite, and indeed grades in places within the mass into a facies which must be called monzonite. The metamorphism about this stock is of the same character as that adjacent to the monzonite stock to the west. Several smaller centers of diorite eruption occur in the mountains. Of these a small tongue upon the crest of the ridge northeast of Diorite Peak is undoubtedly but an arm of the stock just described.

Diorite younger than porphyry sheets.

The irregular cross cutting body of Lewis Peak is of a rock very similar to that of Diorite Peak, and the metamorphism of the strata about it is of the character already described. This smaller stock is connected with a series of diorite dikes which extend to the northeast, crossing the boundary of the quadrangle and appearing very prominently in a ridge which has been termed "Dike Ridge." Another small diorite stock occurs near the end of the ridge between Madden and Bedrock gulches. It exhibits no features requiring special mention.

Syenite stocks.—Two elongated stocks of syenite are shown on the map. The one on the eastern side of the La Plata, crossing the ridges between Tirbircio Gulch and the western spur of Deadwood Mountain, is formed of a very distinct type of syenite, rich in alkali feldspar, as described above. It is a much more highly alkali rock than any of the intrusive sheets. The mass crossing the La Plata River and extending far up the ridge north of Bedrock Gulch is of the same rock type as the one just referred to; but the mass is very much more obscured by decomposition, and in its upper portion by the shattering and staining of iron oxide, which renders its distinction from the porphyry mass of Beckrock Gulch difficult. This mass cuts across several of the largest porphyry sheets in the mountains. It is assumed from analogy in other localities that the syenite eruptions are later in date than either the monzonite or diorite intrusions.

DOLORES PLATEAU.

In the first section of this text the physiographic relations of the La Plata Mountains to the Dolores Plateau were fully described. It is clear from the geologic map that if the porphyry bodies of the Rampart Hills and the Hogback were not present in the Mancos shales, this latter soft formation would have been almost completely eroded from the western slopes of the La Plata Mountains. From the zone of faulting to its junction with the East Fork, the West Mancos flows in a canyon which is typical of the Plateau country to the westward. The rim of the canyon is a scarp caused by the Dakota sandstone. Beneath the Dakota the alternating series of sandstones and shales belonging to the McElmo formation produce a succession of benches and small scarps corresponding to those which may be found in any valley of considerable depth carved below the Dakota horizon. The La Plata sandstone is apparently exposed at the mouth of Deep Canyon, but it is possible that the white stratum supposed to represent the La Plata is in fact one of the lowest sandstones of the McElmo. The smaller canyons of Turkey and Chicken creeks have cut through the Dakota, but do not reveal any considerable thickness of the McElmo. Where the Mancos shale has been entirely removed from the surface of the plateau, it is almost invariably covered by a scattered growth of white pine, and angular fragments of the Dakota sandstone are scattered more or less thickly over the entire surface. Remnants of the Mancos shale occur at many points on the divides between the principal water courses. They cause knolls like those shown by this map upon the narrow ridge between the West Mancos and Chicken Creek.

Dolores Plateau determined by the Dakota sandstone.

THE SOUTHERN THIRD OF THE AREA.

From the point where the steep dips of the sedimentary formations change to gentler dips at the base of the La Plata Mountains proper, the structure is that of a large area extending southward into New Mexico. As has been pointed out, this area is in fact the eastward extension of the Mesa Verde, as it changes in character from the nearly level surface of the mesa proper to the more highly inclined mesas of the Durango quadrangle, seen in fig. 2. The principal geological interest of this portion of the quadrangle lies in the presence of the coal-bearing formation, the Mesaverde. The development of the coal horizons has thus far not been extensive within the La Plata quadrangle, except in the vicinity of Hesperus, but banks have been worked at many localities for the use of ranchmen in the immediate vicinity.

As was mentioned in the physiographic sketch, there is evidence that the East Mancos River formerly discharged through what is now known as East Canyon. This is conclusively shown by the gravel terrace on the divide at the very head of the latter canyon, by the presence of remains of this terrace farther down the stream, and by the existence of porphyry pebbles in or near the stream bed. These could only have come from the La Plata Mountains. Another interesting feature of the present drainage is the relation of the La Plata Valley to the canyons of minor streams on either side. Hay Gulch, whose headwaters are within the surface covered by the Mesaverde formation, has eroded its canyon to a much deeper level than that upon which the La Plata River now flows. This can be explained only as due to the fact that Hay Gulch is of very recent origin, while the La Plata, a much older stream, had at this distance from its source become choked with débris from the mountains at a period before the active erosion in Hay Gulch began. The grade of the river was thus long ago established, while that of Hay Gulch in its upper reaches is still changing.

Some further discussion of these episodes in the erosional history of the region will be given by Mr. Spencer in the following section.

GENERAL GEOLOGIC PROBLEMS.

The oldest formation displayed in the La Plata quadrangle being the Dolores (Triassic), there is no evidence from the region itself as to pre-Mesozoic history; and even for the events of Mesozoic time no special clues, not already indicated in the descriptions of the formations, have been found in the area. The description of the Durango quadrangle will necessitate a review of the geological history of the entire region from the Archean to the post-Cretaceous, and for this reason the history of the La Plata quadrangle during Mesozoic time will not be further discussed in this place. Special consideration of the phenomena here exhibited will begin with the igneous intrusions and the uplift of the La Plata dome.

ORIGIN OF THE LA PLATA DOME.

Relation of dome to San Juan structure.—The southerly dip of the strata from the base of the mountains proper and the gentle westerly dip of the Dakota sandstones and underlying strata of the Dolores Plateau are in the main independent of the La Plata uplift. This is shown by the continuation of these structures respectively east and north from the La Plata quadrangle. It therefore appears that the La Plata dome was uplifted at the point where the southerly dips away from the large San Juan center swing rather quickly to a westerly dip. At this angle, so to speak, the local elevation of the La Platas took place, and it is difficult to estimate the influence of the local uplift in modifying the broader structure at a distance of more than 8 to 10 miles from the center of the mountains.

La Plata uplift at an angle in the San Juan structure.

The San Juan structure of this vicinity affects all sedimentary formations from the base of the Paleozoic to the post-Laramie Animas beds. But it is abundantly proved in the western part of the San Juan Mountains that all Cretaceous formations were uplifted and extensively eroded before the beginning of the San Juan volcanic eruptions, the probable source of the materials forming the Animas beds. From these facts and other evidence the conclusion has been drawn in the Rico report that the broad "doming of the San Juan region has been the result of successive deformations in the same direction, repeated at each period of continental uplift affecting this and adjacent regions." Hence it is impossible to ascertain what phase of development of the San Juan structure may have existed on the site of the La Plata Mountains at the time of the domal uplift. It may be that the local movement was but a part of the general San Juan disturbance of a particular period, the local intensity being due to hidden causes.

Age of the uplift.—The age of the La Plata dome can not be accurately shown by any evidence to be found in the region at present. From the data accumulated in the Telluride quadrangle and adjoining localities, where intrusive masses similar to and believed to be contemporaneous with those of the La Platas have either penetrated or uplifted the volcanics of the San Juan, it is certain that at least a portion of this great volcanic series had been erupted at the period of porphyry intrusions. This question has been discussed at some length in the Telluride folio (No. 57) and in the report upon the Rico Mountains (Twenty-first Annual Report, Part II). The age of the La Plata uplift is unquestionably Tertiary, and presumably early Tertiary. From corresponding data it has been shown that the laccoliths of the West Elk Mountains are of Tertiary age, since they uplifted post-Laramie beds which are probably to be correlated with the Animas formation (Anthracite–Crested Butte folio, No. 9).

Uplift probably of early Tertiary age.

Connection of porphyry intrusion and uplift.—The cause of the vertical upthrust to which local dome-like elevations, like those of the La Plata and Rico Mountains, are due must remain in large measure a matter of hypothesis. As is well known, the group of the Henry Mountains has become celebrated through the work of G. K. Gilbert, as the original illustration of the laccolithic hypothesis. So far as descriptions of the Henry Mountains go, they are comparable with the La Plata and Rico mountains only in the presence of great masses of porphyry of the same type. As already pointed out by Gilbert and others, the mountain groups of the Plateau country are undoubtedly contemporaneous, or nearly so, in their origin, and it was at first the most natural deduction to assume from the abundance of the porphyry masses of the same type in all of them that their origin might be throughout similar to that of the Henry Mountains. But there is this important difference: in the Henry Mountains the structure of the sedimentary rocks appears to be directly traceable to laccoliths of porphyry, and Gilbert has not described any structures in the heart of the mountains which are not evidently due to the intrusions themselves; in the La Plata and Rico mountains, on the contrary, there is evidence of uplift below visible porphyries, in the latter affecting horizons below any laccolithic eruptions which can be plausibly hypothecated. The nature of the upward movement in the Rico Mountains seems also to indicate a force distinct from that of the upward movement of magmas, since it was manifested at a period later than any of the igneous intrusions represented by visible rocks. It therefore seems necessary to conclude that, if the local uplifts of these centers are due entirely to the upward pressure of molten magma, the force was applied to rocks at great depth and not at the horizons of intrusion for the comparatively small laccoliths and sheets of which there is direct evidence.

Henry Mountains an illustration of uplift by laccolith.

Uplifts of La Plata and Rico mountains not wholly caused by visible laccoliths.

Displacement by visible intrusives.—It is clear that the porphyry masses shown by the map have displaced the sedimentary formations above them in an amount equal to their total mass. This displacement is clearly confined to horizons above the base of the Dolores formation. It is now impossible to estimate closely the amount of that displacement because so much of the porphyry mass has been entirely removed by erosion. If the porphyry mass thus removed was considerably greater than that indicated by present exposures, the displacement by porphyry is perhaps comparable to the total deformation above the base of the Dolores. From the doming of the lowest stratum exposed, which belongs nearly at the base of the Dolores, it is necessary to assume either the presence of intrusive porphyry bodies of great size not revealed by the dissection of the mountains at this time, or a vertical upthrust of some other origin.

Buried laccoliths.—The assumption that other porphyry masses similar to those exposed in the La Plata Valley occur beneath the lowest horizon now exposed is certainly a very plausible one. An examination of the section B–B of the Structure Section sheet shows that the somewhat irregular doming of the structure from the La Plata Valley toward Snowstorm Peak might be very easily caused by a laccolith situated at or near the base of the Dolores formation. This local disturbance, which produced a very steep dip on the eastern side of the dome, is the most pronounced irregularity in the structure of the mountains; but there are several other localities where there are abnormal dips which may in a similar manner be due to local porphyry bodies not far below the present surface.

The domal uplift of the base of the Dolores requires the assumption of a great quantity of intrusive matter, if the whole of the domal uplift is to be explained in this manner, and at this point a comparison between the La Plata and the Rico domes is of value.

Rico dome not of laccolithic origin.

Comparison with the Rico dome.—The Rico dome is approximately of the same size as the La Plata; perhaps somewhat larger. Its dissection by the Dolores River reveals its internal structure, however, to a much lower horizon. While the series of sediments affected by that uplift was undoubtedly the same as that at the La Plata center, erosion has revealed the very base of the Paleozoic section, and there are also certain small exposures of Algonkian quartzite and schist. The Rico Mountains are like the La Platas in exhibiting an extensive series of intrusive diorite- and monzonite-porphyries and in the existence of later stocks of monzonite. The distribution of the intrusive porphyries there is seen to extend throughout the sedimentary section, although they are most numerous in the Dolores formation; but the presence of the underlying Algonkian quartzites, whose attitude is certainly unconformable to that of the Paleozoic sediments, shows that some deeper-seated force than laccolithic intrusion in the Paleozoic or Mesozoic sediments is necessary to explain the uplift. There is a notable amount of faulting in the center of the Rico dome, resulting in the upthrust of certain blocks which are immediately responsible for the presence of the Algonkian quartzites. But this faulting does not do away with the necessity for assuming an uplift of domal character independently of the porphyries. The faulted blocks demonstrate the absence of porphyry masses capable of producing the full domal structure at the center of uplift, unless they are beneath the base of the Paleozoic in rocks not favorable for the laccolithic type of eruption. While, therefore, the La Plata dome might be hypothetically explained as largely due to laccolithic intrusion at horizons not exposed by erosion, the facts of the Rico Mountains have led to the conviction expressed in the Rico report—that in that case "the structural features are not chiefly due to igneous intrusion, and the intrusions may even be regarded as due to the earth stresses which have produced the principal structure. This conclusion rests upon the insufficiency of the exposed igneous masses to produce the structure seen, the improbability of the existence of hidden masses of importance, and the abundant evidence of fault blocks thrust up in the heart of the dome since the porphyry intrusions."

Conclusion as to the origin of Rico dome.

IGNEOUS PHENOMENA.

Sheets and laccoliths older than the stocks.

Comparison of stock and laccolithic intrusions.—The association of stock and laccolithic intrusions at two decidedly local centers like the Rico and La Plata mountains gives an opportunity for instituting certain comparisons between the phenomena of these two types of intrusion. It is to be noted that they contrast in age, form, rock structure, and associated metamorphism. It is clear that the intrusive sheets and laccoliths are distinctly earlier in time of eruption than the cross-cutting stocks that have been considered. No instance was observed in adjacent regions of porphyry sheets later than stocks. While the magma of the porphyry masses undoubtedly must have risen through conduits cutting across the strata of lower horizons, it constantly showed a tendency to lateral extension by forcing open the strata upon favorable planes of stratification. The magma of the stocks of granular rocks, on the other hand, often cut directly across rather steeply inclined sedimentary beds without any noticeable tendency to force its way by lateral intrusion.

Sheets and laccoliths are porphyritic, and stocks are granular.

It can hardly be a matter of accident that the magmas which tend to force themselves laterally between the strata as sheets and laccoliths have consolidated with the porphyritic structure, even in their conduits as far as seen, nor that the contents of the stock are almost always a distinctly granular rock. As was particularly pointed out in the Telluride folio, the development of the granular structure is connected with the stock form or with the period of eruption. It is developed as well at the highest levels now preserved in the San Juan—over 14,000 feet in Mount Sneffels and Mount Wilson—as at the lowest elevations. Similarly the porphyritic structure is characteristic of the earlier magmas with a tendency to lateral intrusion, at whatever horizon it may have occurred. In the report on the Rico Mountains, to which the reader is referred for a fuller discussion of this question, it was suggested that the essential difference between two types of eruption appeared to be in the intensity of the force by which the magmas have been brought to their position; or perhaps, rather, the suddenness of the application of the force. The porphyries appear to have been injected under the influence of a great force steadily applied—applied so slowly that planes of weakness between the adjacent strata became fissures into which the magma was injected. In the case of the stock eruptions the force appears to have been applied so suddenly that vertical fissures penetrating the sedimentary rocks for long distances were formed. Since there is but slight displacement of strata it is necessary to assume that the rapidly ascending magmas cleared their channels by carrying upward the rock of the space now occupied by the stocks, for there is absolutely no indication of the assimilation of the rocks passed through. It is not known whether the channels extended to the surface at the time of eruption or not, but in some instances in the San Juan Mountains proper such would appear to have been the case. Some of the stocks of the Telluride and adjacent quadrangles penetrate several thousand feet of surface volcanics, and it seems almost impossible that these intrusions can have taken place to levels so near the surface, as in these cases, without the fractures extending to the surface, permitting the magmas to ascend and issue as lava streams.

Form of occurrence determined by intensity of intrusive force.

Magma of stocks probably reached the surface.

A notable distinction between stocks and laccolithic intrusions lies in the almost uniform presence of extensive zones of contact metamorphism about the stocks and their almost total absence from the vicinity of porphyry laccoliths, even when the latter are of great size. It therefore appears that the magmas ascending in stocks were accompanied by certain mineralizing agents not associated with the magmas of the porphyry bodies. The minerals of the contact zones are such as have been formed synthetically by the aid of the so-called mineralizing agents, fluorine, chlorine, and superheated steam. It is therefore a natural suggestion that the presence of steam and other gaseous substances with the magmas ascending in stocks may indicate that the stock eruptions were the result of an explosive eruption, while the porphyry magmas containing at least a relatively small amount of water vapor had much less of this element of force.

Contact metamorphism associated with stocks and not with laccoliths.

Zonal variation in composition of Indian Trail Ridge laccolith.

Magmatic differentiation.—The evidences of magmatic differentiation found in the igneous rocks of the La Plata Mountains are of two kinds. The most directly significant fact is the variation of composition exhibited by the rather basic intrusive sheet or laccolith of Indian Trail Ridge. Although the former lateral extent of this body is unknown, it appears from the remaining portion of the mass to have been fairly regular in form. It has been described in the section on the igneous rocks as exhibiting a very marked zonal variation in composition and structure. This zonal variation is repeated toward the center from the upper and lower contacts respectively. While the variation in composition is not very great, it is still marked. In character it corresponds to many other instances of zonal variation interpreted as differentiation in place, in that the center of the mass is comparatively rich in silica and the alkalies and the contact zones are much more basic. The differentiation of this mass has been of the kind interpreted by G. F. Becker as due to convection currents (Am. Jour. Sci., 4th series, Vol. IV, 1897, p. 257).

Evidence of magmatic differentiation.

In another direction there is evidence in favor of magmatic differentiation at the source of the La Plata magmas, in the presence of a considerable number of basic dikes and thin sheets which, wherever they come in contact with the normal porphyries, are found to be of later age. These rocks are directly comparable with the basic types which are now known in many centers where diorite- and monzonite-porphyries have been erupted in large quantities. The constant association of such later magmas in comparatively small volume at centers of eruption can not be regarded as other than significant.

Two groups of differentiation products.

Upon the modern hypothesis of differentiation it is to be expected that the later magmas at any eruptive center will be either more basic or more acid than the earlier products. Unfortunately the sequence of eruption of the La Plata magmas can not be ascertained in all details. Thus, while the stocks are all later than the diorite- or monzonite-porphyries, no fact was observed tending to show the relative ages of the augite-syenite and diorite stocks. Viewing the basic dikes and sheets as melanocratic differentiation products,* the complementary leucocratic rocks may be represented by the augite-syenite of the two stocks or by the dikes described as syenite-porphyry. Since there can not well be any connection between degree of differentiation and the eruptive acts, it is not to be wondered at if the two complementary magmas of theory are not always in evidence in corresponding amounts. As a matter of fact, the melanocratic forms have been much more commonly observed than the leucocratic types in many localities. In the La Platas a few highly feldspathic dikes were noted in the vicinity of Snowstorm Peak, but the volume of these dikes is almost insignificant. But if the augite-syenite be taken as representing the leucocratic differentiation product of the La Plata magma, the melanocratic rocks become of the lesser volume.

It is noteworthy that the intrusive mass of Indian Trail Ridge corresponds closely in its outer zones to the more pronounced melanocratic rocks. As that occurrence clearly shows that these magmas are capable of further differentiation, it furnishes in itself an element of evidence in favor of a similar origin for the melanocratic rocks of the small dikes and sheets.

EROSIONAL HISTORY OF THE LA PLATA QUADRANGLE.†

Tertiary erosion of the La Plata dome.—The fact has been brought out in the preceding discussion that the structure of the La Plata Mountains probably had its origin at a period later than that during which the San Juan tuffs were formed; that is to say, after the lapse of a portion of Tertiary time. Just what the date of the earth movement which resulted in the production of the La Plata dome may have been, or how long its uplift and intrusion by igneous rocks, which form so important a part of its present make-up, may have been in progress, can not be determined from any data now at hand. As has been pointed out in the case of the Rico dome, it may be that erosion was active in the La Plata region before the accumulation of volcanic materials ceased. Whether this was so or not, the effect of the La Plata uplift was the formation of a dome affecting whatever Tertiary rocks previously covered the La Plata and adjacent quadrangles.

Removal of Tertiary and Cretaceous formations.

With the uplift of the La Plata dome radial streams were developed which were consequent upon the dip slopes produced. These streams rapidly cut their way through the Tertiary covering into the Cretaceous formations, and finally completely removed the former from the dome and from a large area about it, and eroded practically all of the Cretaceous from the central region. During this epoch of erosion the lower Mesozoic formations and the resistant intrusive rocks which are now exposed were discovered; the streams ate their courses by headwater erosion into the heart of the dome (in the case of La Plata River almost through the most resistant portion of the mountains); the sandstone scarps of the upper Cretaceous reached practically their present position. and the streams of the outlying country attained very nearly their present adjustments. No records remain to us of the stages and incidents of this epoch of erosion such as are of frequent occurrence in regions where the task of denudation has been less arduous than in this portion of the Rocky Mountain province. Since the beginning of the existing physiographic record the amount of erosion accomplished has been unimportant, and is almost negligible in comparison with that which antedates the record. It may be tentatively suggested that all this early erosion was accomplished in the latter part of Tertiary time—that is to say, that it corresponds in general with the Pliocene—while the later stages discussed in the following paragraphs belong to the Pleistocene.

Remnants of an early Pleistocene land surface.

Pleistocene erosion.—Evidence has been preserved of a former higher position of the valley floors in the region surrounding the La Platas. All the way from the western edge of the Mesa Verde to well within the La Plata quadrangle a strongly marked shoulder is visible in the soft Mancos shales a short distance below the sandstone scarp. This shoulder is part of an old land surface which is further represented by the gravel-covered mesa between the East Mancos and Cherry Creek, by the knoll at 8100 feet just east of Dix, by the gravel-topped ridge just east of Cima, and by the divide below 8500 feet on the opposite side of the La Plata. Remnants of it are also found south of Hesperus in the highest gravel-covered terraces on both sides of the river. Still farther eastward it has been identified as far as the Florida River in the Durango quadrangle. From these remnants it is possible to reconstruct in imagination a wide, shallow valley running from the vicinity of the Ute Mountains, some 40 miles west of the La Plata River, along a line to the north of the Mesa Verde scarp, crossing the La Plata quadrangle, and extending at least 30 miles toward the east. This valley followed the belt of Mancos shale and was produced by side tributaries of the main drainage features, which were, in general, as at present, transverse to the zone of soft shales. This old valley floor represents an epoch in the history of erosion which left its general record in southwestern Colorado and the adjacent portion of Utah. Terraces and gravels of corresponding position in reference to the present drainage have been observed along the Dolores River in the vicinity of the great bend, along the lower portion of the San Miguel River, and along the Uncompahgre and Grand rivers in Colorado and the Green River in Utah.

Diversion of the East Mancos River.

Stream adjustments.—A peculiar condition of stream adjustment, which is to be explained by the conditions existing during the high-terrace epoch, is seen in the relations of the La Plata River and the abandoned course of the East Mancos to the drainage on either side. During the high-terrace stage of erosion the East Mancos must have flowed through East Canyon, which is directly in line with the gorge of the former stream where it issues from the mountains. Evidence of this old drainage is found in the gravel covering of the sloping mesa which lies at the head of the abandoned waterway, and its continuance into the canyon as a well-marked shoulder or terrace which has been cut into since the valley was abandoned by the East Mancos. The gravels are largely of igneous bowlders and were brought from the mountains by way of the river which has since found a new course farther to the west.

The conditions under which this diversion was

* Die Eruptivgesteine des Kristianiagebietes; III, Das Ganggefolge des Laurdalits, by W. C. Brögger, Kristiania, 1898, p. 263.

The proposition of Brögger to designate those diaschistic rocks rich in dark-colored constituents *melanocratic* and the complementary ones of lighter color *leucocratic* seems much more practical than any other proposed expression of the theoretical genetic relationships under discussion.

† By A. C. Spencer.

Conditions which produced the high terraces.

accomplished, and under which the La Plata River has been left in a channel several hundred feet higher than adjacent valleys, seem to have been as follows: During the high-terrace epoch precipitation was probably much greater than at present, so that the small streams which flowed over the southern slopes of the La Plata Mountains between the East Mancos and the La Plata, and on the surface of the Mesa Verde were actively eroding, and, not reaching back into the mountains, were not heavily loaded with materials derived at a distance, so that their energies could be devoted to corrading their channels. On the other hand, the long streams which had succeeded in cutting back into the heart of the mountains by head-water erosion were probably heavily loaded with the materials derived from their upper courses, and upon emerging from the mountainous region not only had little power to corrade their beds, but filled their channels. In the gravels of the high terraces we have evidence that this condition actually prevailed. It is under these conditions that one of the eastern tributaries of the Middle Mancos River, working in the soft shales of the Mancos formation, was able to divert the East Mancos, and Cherry Creek was able to cut and widen its valley and extend its eastern fork to within a mile of the La Plata River, where the divide has a height of less than 200 feet above the river. Also the headwaters of Alkali and Hay gulches, which are tributary to the La Plata River, have cut their channels to so great a depth in the massive sandstones of the Mesaverde formation that their beds are several hundred feet below the adjacent portion of the La Plata Valley, and their drainage actually reaches to the gravels which mark the former position of the river upon the high-terrace flood plain. In like manner, the drainage to the east of the La Plata River has eaten well back into the terrace.

The elevated character of the La Plata Valley.

In view of the hypothesis that precipitation was at a maximum during the high-terrace epoch, it is important to note that the climate is now more arid than formerly, as is shown by the fact that the small streams, once so active, are not now deepening their channels, because they carry no flowing water, while the La Plata is working upon bed rock, since the material supplied from above does not consume all of its energy.

The heavy precipitation which is indicated for the high-terrace epoch doubtless continued after the diversion of the East Mancos, and much of the erosion of the encroaching streams has been accomplished since that event, as may be seen from the extension of Cherry Creek into the La Plata terrace gravels at a level several hundred feet below that of the high terrace, and therefore at a later date than the high-terrace epoch.

Interpretation of lower terraces.—Below the high terrace already described there are two others marking stages by which the rivers have reached their present beds, and terraces similar to these are present along Cherry Creek, as well as adjacent to the Mancos drainage and the La Plata River. It is thought that they represent variations in climatic conditions rather than changes in level, though the latter hypothesis is possibly applicable. No criteria for determining the truth of one or the other of these suggestions have been recognized.

It may be reasonably supposed that the present dry period began after the completion of the third terrace, and that previous to this Cherry Creek had excavated the wide amphitheater of Thompson Park, and the Mancos drainage had produced its extended basin, separated from the Montezuma Valley to the west by a low shale ridge corresponding with the second terrace. These last features are illustrated in fig. 3. Fig. 7, looking down La Plata Valley, shows the three terraces. The present valley of the river may be distinguished on the left, with the third terrace in the central portion of the picture; above it and sloping toward the south is the second terrace, while the uppermost or first terrace is represented by the rounded knob upon the right below the sky line formed by the sandstone of the Mesaverde formation. The first terrace is also seen in the distance in the sloping timber-covered plain which seems to block the valley.

None of these stages of erosion have been recognized in the northern part of the quadrangle, except the possible indication of the high terrace in some bowlder beds upon the shale knolls between the West Mancos and Chicken Creek. If this identification be correct it may be argued that at the time of their deposition the Mancos shale must have covered the area of Dakota sandstone now found in the northwest corner of the quadrangle, joining with the shales still preserved along the northern border. In Bear Creek no terraces were noted.

Glacial moraines.

Glaciation of the La Plata Mountains.—The former existence of glaciers in the La Plata Mountains is attested by the almost universal presence at the heads of the more important streams of the characteristic amphitheaters which are known as cirques. These cirques, or high basins, frequently contain small lakes in rock basins excavated by the moving ice, and their rock floors are frequently scratched and scored in the manner common to surfaces which have been scoured by ice action. Fine examples of cirques are present at the head of the East Mancos, both forks of the West Mancos, Bear Creek, and particularly in several gulches at the head of the La Plata. In addition to these signs there are in several places accumulations of débris so located and of such character that they are judged to have been deposited as moraines at the side or front of an ice stream. Several of these moraines are found within the Durango quadrangle, adjacent to the northeastern part of the La Plata area. Another morainal deposit is seen in a line of low gravel hills transverse to the main La Plata Valley, at the old settlement of Parrott City, south of the place marked "Parrott" on the map. This moraine marks the probable maximum advance of the glacier of the La Plata River, the existence and importance of which are otherwise indicated by the broad U-shaped valley, quite distinct from the V-shaped valleys eroded entirely by running water. None of the other glaciers were as important as that which filled the La Plata Valley. Its lower limit was marked by the present 8600-foot contour, and it is doubtful whether any of the other ice streams descended to a position as low as 9000 feet. They all seem to have been short glaciers which never reached as far as the foothills. Above the snow fields, which were the collecting grounds of the ice streams, the mountain crags were always bare of ice, as shown by their present rugged appearance, and there could never have been any true ice cap covering the central mountainous area.

Post-glacial erosion.—The wasting of the La Plata glacier is supposed to have marked the introduction of arid conditions in the region surrounding the La Plata Mountains. With the reduction in rainfall and the retreat of the ice there was a corresponding diminution in erosion and in the load of the streams; consequently, they began locally to corrade their channels. This is the present condition of the La Plata River outside of the mountains, and in its upper part also some cutting has been done in the solid rock below the scoured floor of the glaciated valley.

ECONOMIC GEOLOGY.*

GOLD AND SILVER.

The first mines developed.

General statement.—The metalliferous deposits of the La Plata quadrangle are naturally confined to the mountainous portion. It was not until the year 1878 that prospecting for gold and silver was begun in this vicinity. In that year the mine called the Comstock was opened, and work was begun on the Cumberland or Snowstorm vein, near the head of the La Plata Valley. A stamp mill was erected at an early date to treat the ore of this mine, but its operation was not successful. By the close of the year 1881 many locations had been made, and the nature of the richest ores, tellurides of gold and silver, was well known. Among the mines first developed, besides those above mentioned, were the Century, in Bear Creek, the Tippecanoe, the Belle Hamilton, and the Ashland. The mining region was sometimes known as the California district.

Mines in operation in 1896.

For several years after the year 1883 there appears to have been little activity in the district. Three small stamp mills have lately been erected in the basin of the La Plata River, and one at the head of the West Mancos. A small mill for the treatment of telluride ores by the cyanide process was erected on Junction Creek, and in the La Plata Valley Messrs. Pret, Trachsler and Co. for a time treated telluride gold ores by a bromination process. The mines of the district which were working during the month of August, 1896, were the Durango Girl and Jenny Lind in Wall Gulch, the Small Hopes in Williams Gulch, the Little Kate in Basin Gulch, the Shoofly in Tirbircio Gulch, and the Mountain Lily in the gulch of the same name. The district had produced at that time in all about $300,000, of which it is estimated that one-half was in gold and one-half in silver.

Water power is abundant in the La Plata Valley, and the region is easily accessible. As in all mining regions of rugged topographic forms, the transfer of ore from mines situated high in the mountains to the valleys, where wagon and rail transportation is available, or where the ore may be profitably milled, is attended with difficulty. Wire-rope and bucket tramways worked by gravity appear to afford the most economical means for such transportation. No obstacle of a topographic nature exists to prevent the building of a railroad to the base of the mountains. The track of the Rio Grande Southern Railroad, which crosses the southern portion of the quadrangle, runs within 4 miles of the town of La Plata, in the center of the mining district. The greater part of the ore has until recently been shipped crude to Durango for smelting.

THE VEINS.

Three well-defined sets of fissures.

Fissuring.—From the nature of the deformation to which the rocks of this region have been subjected it is reasonable to suppose that they have been more or less broken up in the process. Heavy sandstone beds, tilted and separated by injected sheets, dikes, and stocks of igneous rock, would be unable to sustain, unbroken, the immense pressure which they must have experienced. The unequal distribution of fissures and joints in the La Plata Mountains, the varied amount of their development, and the lack of regularity in their occurrence, make it probable that the regional deformation of the rocks is in part directly the cause of the breaking up. This irregular fissuring has, however, been supplemented by another sort, of much more definite character. There are, to classify them in a general way, three well-defined sets of fissures whose development is fairly well marked in all parts of the area under consideration. One set strikes approximately east and west, and, from the evidence collected, it appears to have been formed by pressure acting on the area as a whole from an outside source previous to the intrusion of some of the latest laccoliths. The two other prominent systems run approximately northwest and northeast, and appear to have been the latest formed. All evidence as to their cause points to a force acting from the north from without the limits of the field. Slickensided and grooved faces on the walls of veins, and the orientation of prism angles in cases of double jointing have been the principal criteria employed in considering the probable direction of the rupturing force.

Crushed zones along northeast fissures.

It is worthy of note that, connected with the fissuring along a northeast direction, there are a large number of zones of crushed rock, of all widths from 1 foot to several hundred feet. These crushed zones, which, as will be described below, are now cemented by ore, occur in both sandstones and igneous rocks, although their most pronounced development appears to be in the porphyries. The crushed zones seem to be more abundant along the western side of the La Plata Valley, but their development is by no means limited to that side. It seems entirely reasonable to refer the crushing of the rock along the northeast lines to the force acting from the north previously referred to. The resistance to a force which tends to shove one portion of a rock formation over another by overthrust faulting would result in crushed zones such as are now seen. Moreover, detailed evidence collected in several portions of the field appears to lend weight to this suggestion.

Relation of veins to fissures.—The fissures have been filled in part by dikes of dioritic type and in part by mineral, so that now they are represented by veins. The word "fissure" must be distinguished from the word "vein," for which it is often wrongly used. "Fissure" means merely "crack," with or without an appreciable amount of open space. "Vein," in a strict sense, means a fissure which has been filled with gangue or ore minerals. Where a series of such spaces has been developed between the parallel strips of rock in a fissured zone and these spaces have become thus filled the resulting phenomenon is properly referred to as a zone or belt of veins. There are all gradations between the single vein and the zone, as for instance where the separate stringers unite in places, and include lens-shaped fragments of country rock. The deposit then becomes a linked vein. The distinctions being thus recognized, the term "vein" will be used in its more general sense as applying to the space between two well-defined walls which has been wholly or in part filled with ore or gangue minerals, there being usually within this vein more or less of the country rock in the form of included fragments.

Two classes of veins.

Characteristics of the veins.—The veins may be divided, according to their mode of occurrence, into two classes. Those belonging to the first class have the physical appearance of a solid filling between two walls and average 3 feet in width, although in the case of the Columbus vein such a filling has a width of 10 feet. In the Cumberland mine a vein consisting mostly of white quartz, which has been worked to a considerable extent, averages 5 feet in width. To the second class belong the veins which have the character of a filled fissure zone, as explained above. These are the more prevalent, and they average 2 feet in width, although they exhibit great variation. These veins, almost without exception, include fragments of the wall rocks, whether these be igneous or sedimentary. The two classes are distinguished only by the difference in size and amount of the fragments, so there is really a gradation between them and no sharp line can be drawn. The included fragments in every case that has been observed are sharply angular, with no rounding off of the corners. The fragments vary in size from those which are visible only under the microscope to those having a length of many feet. The influence which the country rock has had on the fissuring, in a purely mechanical way, is, in some instances, especially well marked. When the walls of a vein are in one place sandstone and in another porphyry, as in cases where veins cut sandstones with intercalated sheets of porphyry, it is generally noted that the vein is strongest and less split up in the igneous rock. This feature is well shown in the Bessie G mine, on Junction Creek; in the Lalla Rookh, on Burnt Timber Creek; and at the Comstock mine, in the La Plata Valley. In the diorite, in general, the lodes have the linked-vein character; and although the "pay streak" portion is usually firm, there lies on each side of this, next to the foot and hanging walls, a decomposed selvage of ground-up clayey material, the gouge. This should be considered a rather advantageous circumstance, as the diorite is intensely hard in its fresh state. The Small Hopes, in Williams Gulch, and the Mountain Lily and Tip Top mines, on the west side of La Plata Valley, are of the linked-vein type, in diorite. The alternation of widely and narrowly spaced zones of fissuring and the direct relation which the veins bear to these zones, which have been noted in the Telluride region, are not so apparent in the La Plata district. It is possible that some such relation might be worked out here by detailed study, as there certainly are many isolated fissures which show no sign of mineralization, but whose strike

*This account of the economic geology of the La Plata quadrangle is based upon field work done by Mr. Purington in 1896. It was prepared by him in the following winter, and soon after its completion he left the corps of the Survey. Recent developments in the La Plata mines have not warranted a reexamination. The value of the product of gold, silver, lead, and copper for La Plata County in 1900 is given at $20,100.37 by Harry A. Lee, the State inspector of metalliferous mines.—WHITMAN CROSS.

is the same as that of neighboring veins. It has also been observed that when the veins have a solid filling they are usually accompanied by small parallel stringers in the walls, a few on each side. Cases of faulting of the veins occur, but the throw is never of great magnitude. Usually a crosscut of a few feet in one or the other direction is sufficient to enable the miner to "pick up the lode." It has not been possible to establish a correlation between the various dislocations observed, since there seems to exist no coincidence in the directions of throw.

Relation of veins to zones of fissuring.

The direction pursued by the strongest veins is along the northeast-southwest and the east-west fissure systems, but some veins, especially those in Lewis and Wall gulches, strike a few degrees to the north of west. Although little appears to have been done in tracing veins across country, there can not be much doubt that some of them, especially those whose strike lies between the north and east, are continuous for long distances, their outcrops being plainly marked by sharp gaps in the divides and by the red, white, and yellow streaks caused by the hydrothermal alteration of the rock that accompanied the deposition of the ore.

Crushed zones.—As these remarkable occurrences have not generally been found to be of economic value they have received comparatively little attention. A short description of them should, however, be given. In Basin Gulch they have the most pronounced development, and in Boren and Bedrock gulches they are of considerable magnitude in connection with the zones of impregnation which will be later described. In Basin Gulch occur zones 200 feet wide, in which angular fragments of porphyry and sedimentary rock are cemented together by quartz and by sulphides and oxides of the metals. It is probable that these ore breccias have been formed in a manner similar to that of the veins, and it is appropriate that their description should be given here. On the other hand, for reasons which will be explained later, the description of the ore beds and of the impregnations will be given as subordinate to the account of the ores themselves.

THE ORES.

Minerals of the ore deposits.—The metalliferous minerals of the La Plata district, which have been found to contain and to be associated with greater or less amounts of the precious metals, are tellurides of gold and silver (sylvanite, petzite, and probably, calaverite and other telluride compounds which have not been determined), native amalgam, freibergite (argentiferous tetrahedrite), tennantite, stephanite (and other sulph-antimonides and sulph-arsenides of silver), pyrite, marcasite, chalcopyrite, galena, zinc blende, realgar, hematite, and magnetite. The gangue minerals are quartz, hydrous silica, calcite, rhodochrosite, dolomite, barite, fluorite, chlorite, asbestos, garnet, sericite, kaolinite, and zeolites whose specific character has not been determined. Some of the minerals occur in very small quantity and have been determined only with the aid of the microscope.

Classification of the ores.—The ores are in general of two kinds—telluride ores, and gold either free or associated with pyrite.

The most important ores at present developed are tellurides of gold and silver with accompanying iron pyrite in exceedingly minute crystals. The metallic constituents occur in a gangue of dark fine-grained quartz. Microscopic examination of these ores shows the presence of varying amounts of calcite, sericite (white mica), and hydrous silica. It is very probable in several cases that the veins themselves are dikes of porphyry which, through the aid of crushing subsequent to their intrusion have undergone impregnation and partial replacement by the ore-bearing solution. This is undoubtedly the case in the Columbus, Durango Girl, Jenny Lind, and Shoofly lodes. The phenocrysts of feldspar have been largely changed to sericite, while in the majority of cases the groundmass has been silicified. The ferromagnesian silicates have disappeared and their places are occupied by minute bunches of iron-pyrite crystals with chlorite, and occasionally secondary epidote. Kaolinite also occurs in these veins, perhaps as a decomposition product from the feldspars, which were probably of acid character. A partial analysis of the ore of the Columbus vein, by H. N. Stokes, gave 82.7 per cent of silica, .12 per cent of lime and 1.48 per cent of potash. Quartz veins of small size are found in the large veins or dikes and have an irregular arrangement like that in the crushed zones. Indeed, it seems probable that certain of the dikes of the region have suffered crushing, whereby sufficient open space was developed along them for the percolation of the solutions bearing the ore. The tellurides and sulphides are found in association with the white quartz crystals of the little veinlets and as small flakes and crystals in the dark-blue quartz of the main mass.

Telluride ores.

Besides iron pyrite, galena and zinc blende are found in the veins carrying the tellurides, but in small quantity. The iron pyrite, which sometimes occurs in these veins in considerable quantity, is, according to all reports, nearly barren of values. The tellurides, sylvanite, petzite, and a bronze-colored mineral which is probably calaverite, occur in the Jenny Lind mine in association with tabular crystals of barite. At the Durango Girl mine the telluride sylvanite is said to occur in masses of kaolinite. These larger masses were not seen by the writer; all the tellurides from the district that were seen were in small flakes and films in the quartz.

The manner of occurrence of the telluride ores elsewhere in Colorado appears to offer some analogies to that of the La Plata district, but it is not likely that complete replacement of the dikes, or of the country rock which forms their walls, has occurred here. The lodes are accompanied by impregnations of iron pyrite in the wall rocks, which are said to contain small quantities of the precious metals. Whether the walls contain traces of the tellurides is uncertain.

The Small Hopes and Mountain Lily veins are examples of the telluride lodes which have the character of linked veins, and such specimens of the metallic constituents as have been seen are included in stringers about one inch in width, of glassy quartz, showing comb structure. In the lodes of this character the pay streak averages about 18 inches in width.

The yield of the telluride veins, when the ore is sorted, averages $40 in gold and 40 ounces in silver to the ton. In several of the veins which have been worked, however, gold forms almost the entire product. Occasional small pockets, and even car-load lots, run very high, sometimes several thousand dollars to the ton. The distribution of the telluride ores is irregular in the district, but may be said to be greatest along the eastern side of the valley.

Ores of the second class, which consist of iron pyrite carrying gold values, have been worked to some extent and occur mostly in linked veins and narrow stringers in the rock. The Saxon mine, in Burnt Timber Gulch, appears to have been worked on such an auriferous pyrite deposit. Marcasite occurs also at this mine in considerable quantity and is said to be auriferous. In the Cumberland mine a wide vein containing white quartz, largely crystalline, barite, calcite, and clayey material which may be kaolinite, and carrying silver sulphides and tellurides, was explored to the aggregate amount of about 5000 feet of workings. The vein is also known as the Snowstorm, and has an average width of 5 feet. Its operation has never been successful, and it appears to contain very small amounts of metallic constituents.

Auriferous pyrite deposits.

Veins consisting of white quartz with vug character and containing gold in the free state, without the accompaniment of any great amount of metallic sulphides, have been worked in various parts of the area. Of such character is the Century mine in Bear Creek. The deposit at the Little Kate mine in Basin Gulch appears to be in one of the crushed zones of the district in which the fragments of country rock, here a diorite-porphyry, have been cemented by vein quartz containing metallic sulphides, largely iron pyrite. According to information received at the mine in 1896, the gold is associated with the pyrite, and at that time only about 50 per cent of it was caught on the plates when the ore was milled. The ore was then worked at the mine by means of a 20-stamp mill.

Free gold in quartz.

The larger part of the gold ores of the district which are not in the form of tellurides are low grade, from $3 to $8 to the ton.

Impregnations.—As the word impregnation is now used, its application is restricted to those occurrences where separate crystals, usually of metallic sulphides, fill spaces, however small, which have previously existed in the zones of rock forming the walls of and laterally bounding metalliferous veins. These veins may be of any size, and the impregnated bodies of rock which accompany them may be of any extent. The rock in the crushed zone and tracts above spoken of in Basin, Bedrock, and Boren gulches has been heavily impregnated with fine crystals of iron pyrite which is in some cases accompanied by small amounts of galena and zinc blende. Stringers of quartz carrying sulphides now form the cementing material of the fragments of the country rock. The stringers are small and have a reticulated or net-like structure. The impregnation has affected all the rocks included within the crushed zones. Microscopic examination has revealed the fact that almost inseparably connected with the process of impregnation in the igneous rocks is partial replacement of the original minerals by iron pyrite, sericite (white mica), calcite, silica, and chlorite. The processes of replacement are of various kinds, sometimes the carbonatization and sericitization are the most developed, in other cases silicification is most manifest. In this region the sedimentary rocks have been most subject to carbonatization, the igneous rocks to silicification with accompanying development of sericite. The mineralization of the dikes which now form the telluride lodes is, most probably, to be regarded as an intensified form of this impregnation accompanied by partial siliceous replacement. On the other hand, in the walls of these lodes, when the walls are sandstone, a carbonatization of the rock has accompanied its impregnation. A typical illustration of these processes may be seen at the Jenny Lind mine.

Replacement of the country rock accompanying impregnation.

The crushed-zone impregnations are of wide extent, occasionally several hundred feet in width and more than a thousand in length. They have been reported to carry values in gold, but all tests made on the material in the course of this work failed to show quantities of the precious metals sufficient to render the deposits economically valuable.

Ore beds.—Some of the most remarkable illustrations of the processes of impregnation to be seen in the district are the ore beds. The sandstone layers of the sedimentary beds have in places been thoroughly impregnated with iron pyrite, galena, and zinc blende, accompanied by smaller amounts of hematite and magnetite. Calcite, garnet, epidote, and asbestos are associated with the metallic minerals. In some of the beds magnetite is the most prominent constituent. The largest development of the impregnated beds is at the head of Bedrock Gulch, where a series of sandstone layers nearly 1000 feet in thickness is penetrated by a network of quartz stringers carrying pyrite, and is impregnated throughout by metalliferous sulphides. Connected with the mineralization of this mass there has been some development of a deep-purple fluorite which has apparently given a purplish color to the quartz grains of the sandstone.

Where the impregnation has affected the intercalated sheets of porphyry the result has been the production of a siliceous honeycomb which apparently represents the original groundmass. The cavities, which usually are empty but occasionally are filled with bunches of iron pyrite, evidently represent the former phenocrysts of quartz and ferromagnesian silicates. There are cases in which the impregnated beds have proved profitably auriferous, as on the northwest side of the East Mancos Valley and in the Gold Bug and Mammoth claims in the La Plata Valley. In these cases beds of sandstone are heavily impregnated with iron pyrite, with small amounts of hematite, and white quartz. The ore beds average 3 feet in width and carry from $4 to $12 to the ton in gold. They are generally referred to as "contacts," but it can not be said that this term, as applied to them, has the least significance.

Whether complete replacement of any part of the rock in the impregnated tracts has occurred can be determined only by further investigation. All the red sandstones of the district contain carbonates in greater or less amount, and it is probable that some molecular replacement of these carbonates by sulphides has occurred. No evidence of replacement of the sandstone grains has yet been obtained, however, even with the aid of the microscope. Even in the heaviest beds of magnetite and pyrite the microscope shows the presence of numerous original clastic siliceous grains.

As an accompaniment of the widespread impregnation a vast amount of decomposition, due to hydrothermal action, has affected the rocks. Besides rendering the mass friable and easily subject to disintegration, the most brilliant coloring has resulted. Many shades of red, brown, and yellow, besides dazzling white, are displayed on the sides of the mountains, and the decomposed areas are thus visible for many miles.

Although it does not seem likely that the impregnated masses of the La Platas will prove of economic importance except in the localities mentioned, yet it should be borne in mind that deposits not different from these in physical form or in genesis are worked at the present day as low-grade gold ores. They should not, therefore, be omitted in the consideration of the possible economic resources of the region.

Origin of the ore.—The limited amount of investigation which has been possible in this interesting region makes the writer reluctant to enter upon this subject. But it is felt that some theoretical discussion is desirable, and therefore the following hypothesis is advanced with much hesitation.

The ore of the La Plata district was probably derived from the basic constituents of igneous rocks. It is highly improbable that any such process as secretion of the ore from the rock now forming the walls of the veins has taken place. The phenomena observed along the walls of the veins exclude this hypothesis. Such a vast body of igneous rock as is manifested by the dikes, sheets, and laccoliths of dioritic composition, and of which the amount now visible represents but a small portion of the whole, seems amply sufficient to account for the metalliferous and gangue minerals of the veins. Evidence points to ascending solutions as the means by which the ore was deposited; but the intimate connection everywhere existing between masses of igneous rock and the veins, and the almost immediate loss of value experienced as soon as the veins leave the vicinity of igneous rocks, make it reasonable to suppose that the ore was derived from no great depth. That the deposition of ore was a close follower on the igneous intrusions seems also likely, since abundant heat would have been supplied if water had penetrated to the uncooled portion of the igneous rock mass. The water, having become gradually charged with alkaline sulphides and carbonic acid, would act as a solvent for silica, lime, and any of the metals with which it might come in contact. Ascending along fissures and zones of crushing, it would, through a change in the governing conditions, deposit its contents along the paths pursued. Where the space to be filled existed in open vertical or nearly vertical fissures, veins have been formed. Where it existed in the porous parts of igneous rocks and in the interstitial spaces of sandstone beds, impregnations and ore beds have resulted. It has been shown in several cases in the investigation of various ore-bearing districts that the basic constituents of igneous rocks contain more or less metallic elements. Very minute quantities so contained would, in the present case, suffice to account for the ore.

Ore derived from no great depth by ascending waters.

PLACER DEPOSITS.

Alluvial gold is very widely distributed in the La Plata district, and were it more concentrated, doubtless considerable quantities might be profitably extracted. The La Plata Valley has so far produced very little placer gold. In Bedrock and Boren gulches, as well as in the main valley, unsuccessful attempts at placer mining have been made. In the West Mancos Valley considerable work has been done, but, as the workings are now abandoned, it is to be inferred that they did not pay. In the valley of the East Mancos for a distance along the river of about 3 miles below Rush Basin, placer mining appears to have been the most successful. Here the gold is coarse, and nuggets of small size are not infrequently found. It is reported that considerable gold has been taken at a profit from the East Mancos. In general the gold is exceedingly fine, though not flaky. Its distribution is not confined to the area of the quadrangle, being found for many miles down the La Plata River, and down the Mancos to its junction with the San Juan. The gold is found also in gravels above the level of the present streams, such as the area north of Hesperus called "Gold Bar" and a small tract on the East Mancos River about 2 miles northeast of Menefee Mountain. The finely divided state of the gold and the difficulty of getting sufficient water to the deposits appear to be the principal impediments in connection with placer mining in this region.

Auriferous bog-iron deposit.

A rather unusual occurrence in Rush Basin, at the head of the East Mancos River, is a bed of auriferous bog iron ore which is still being deposited. It is now one-half mile in length, and its lower limit lies at 11,300 feet elevation. It reaches up the sides of the valley 200 yards on either side, and is in places 10 feet thick. It consists of laminated scales of limonite inclosing many vegetable remains, and specks of iron pyrite can be discerned in it. The writer has seen gold panned from the deposit, and it is said that every pan will give a color. Surface waters charged with carbonic acid bear iron in the form of sulphate and carbonate from the sulphide-bearing beds above, and deposit the iron as ferric oxide. An old shaft, which was sunk in the deposit, is constantly full of water and forms a mineral spring.

COAL.

The Mesaverde formation in the southern portion of the quadrangle contains workable coal. This coal has been mined to a considerable extent at Hesperus, and even more at Porter, 8 miles southeast of Hesperus, on the line of the Rio Grande Southern Railroad. The coal occurs interbedded with a white sandstone, the beds of which dip about 5° to the south. There are two beds of coal in its typical development; the upper bed, locally known as the Peacock bed, is 5½ feet thick, while the lower bed, separated from the upper by 70 feet of white sandstone, is 3 feet thick and is known as the Porter bed. The same seams have been worked as far eastward as the town of Florida, on the Denver and Rio Grande Railroad, but toward the west they become of less importance, so that at a distance of 10 miles from the La Plata River there is said to be no workable coal at this horizon. The coal is not of uniform thickness, but is developed in a succession of lenses or "basins."

The coal outcrops within the La Plata quadrangle for a distance of about 25 miles. The lower of the two beds is the only one worked at Hesperus, although both are worked at Porter. The quality of the coal improves toward the south. The following analysis of the lower bed at Porter was kindly furnished by J. A. Porter, of Denver:

Analysis of coal from lower bed at Porter.

Volatile combustible matter	36.61
Fixed carbon	57.21
Ash	4.95
Sulphur	0.65
Total	99.42

The coal at Hesperus is lower in fixed carbon but does not vary greatly from the above. At Porter the coal has fairly good coking qualities, while at Hesperus it is non-coking, but burns more freely. The weight of the Porter coal is about one ton to the cubic yard. The coal mined at this horizon furnishes the greater part of the supply for the San Juan mines.

General Geology, March, 1901.

Economic Geology, May, 1897.

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

TOPOGRAPHIC SHEET

COLORADO
LA PLATA QUADRANGLE

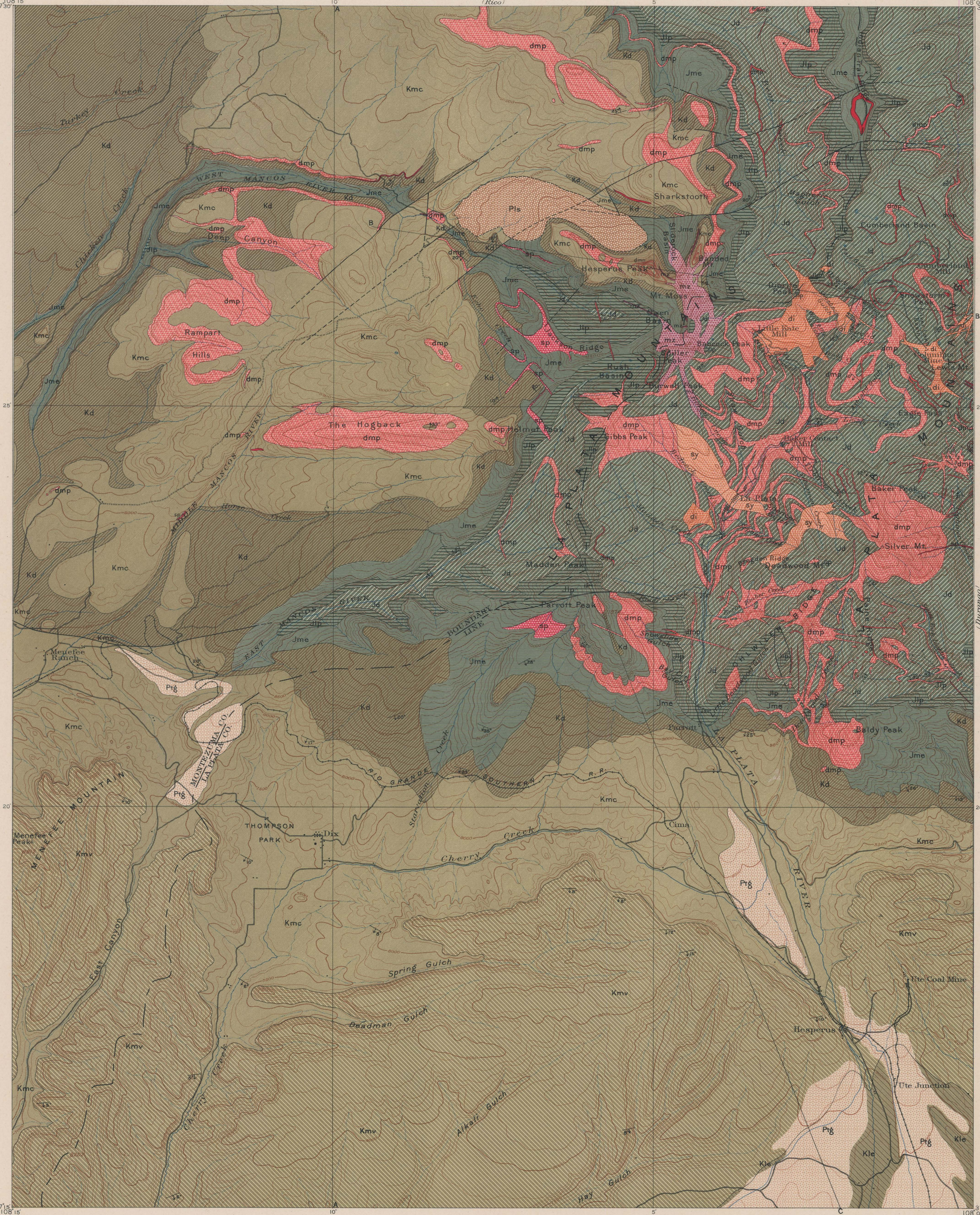
Henry Gannett, Chief Topographer.
E.M. Douglas, Topographer in charge.
Triangulation and Topography by Frank Tweedy.
Surveyed in 1895.

Edition of Jan. 1899.

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

HISTORICAL GEOLOGY SHEET

COLORADO
LA PLATA QUADRANGLE



Henry Gannett, Chief Topographer.
E.M. Douglas, Topographer in charge.
Triangulation and Topography by Frank Tweedy.
Surveyed in 1895.

Scale $\frac{1}{62500}$

Contour interval 100 feet.
Datum is mean sea level.

Edition of Oct. 1899.

Geology by Whitman Cross.
Assisted by A.C. Spencer and H.S. Gane.
Economic Geology by Chester W. Purington.
Surveyed in 1896–97.

LEGEND

SURFICIAL ROCKS
(Areas of Surficial rocks are shown by patterns of dots and circles.)

PLEISTOCENE

- Pls — Landslides *(a confused mingling of large and small blocks of various formations from the mountains above)*
- Ptg — Terrace gravels *(gravel and bowlder beds of alluvial origin)*

SEDIMENTARY ROCKS
(Areas of Sedimentary rocks are shown by patterns of parallel lines.)

CRETACEOUS

- Kle — Lewis shale *(dark shales, somewhat arenaceous; fossiliferous)*
- Kmv — Mesaverde formation *(alternating sandstones and shales. Contains workable coal seams, and is fossiliferous)*
- Kmc — Mancos shale *(dark shale with local calcareous and sandy layers; fossiliferous. Includes the Benton and Niobrara formations and part of the Pierre)*
- Kd — Dakota sandstone *(indurated quartzose sandstone with carbonaceous shale, locally containing coal)*

JURATRIAS

Subdivisions of the Gunnison formation

- Jme — Mc.Elmo formation *(alternating sandstones and shales)*
- Jlp — La Plata sandstone *(white massive sandstone with thin blue limestone and calcareous shale)*
- Jd — Dolores formation *(calcareous sandstone, grit, conglomerate, and some shale, with prevailing red color; fossiliferous)*

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

EOCENE?

- Basic dikes and sheets *(vogesite, augite-kersantite, and allied rare rocks)*
- di — Diorite *(in stocks and dikes. Contains augite, hornblende, and biotite)*
- mz — Monzonite *(in a stock and associated dikes and sheets. Contains augite as the chief dark silicate)*
- sy — Augite-syenite *(in two stocks)*
- sp — Syenite-porphyry *(in sheets and dikes)*
- dmp — Diorite-porphyry and monzonite-porphyry *(in stocks, sheets, and dikes)*

Faults

Landslide boundaries

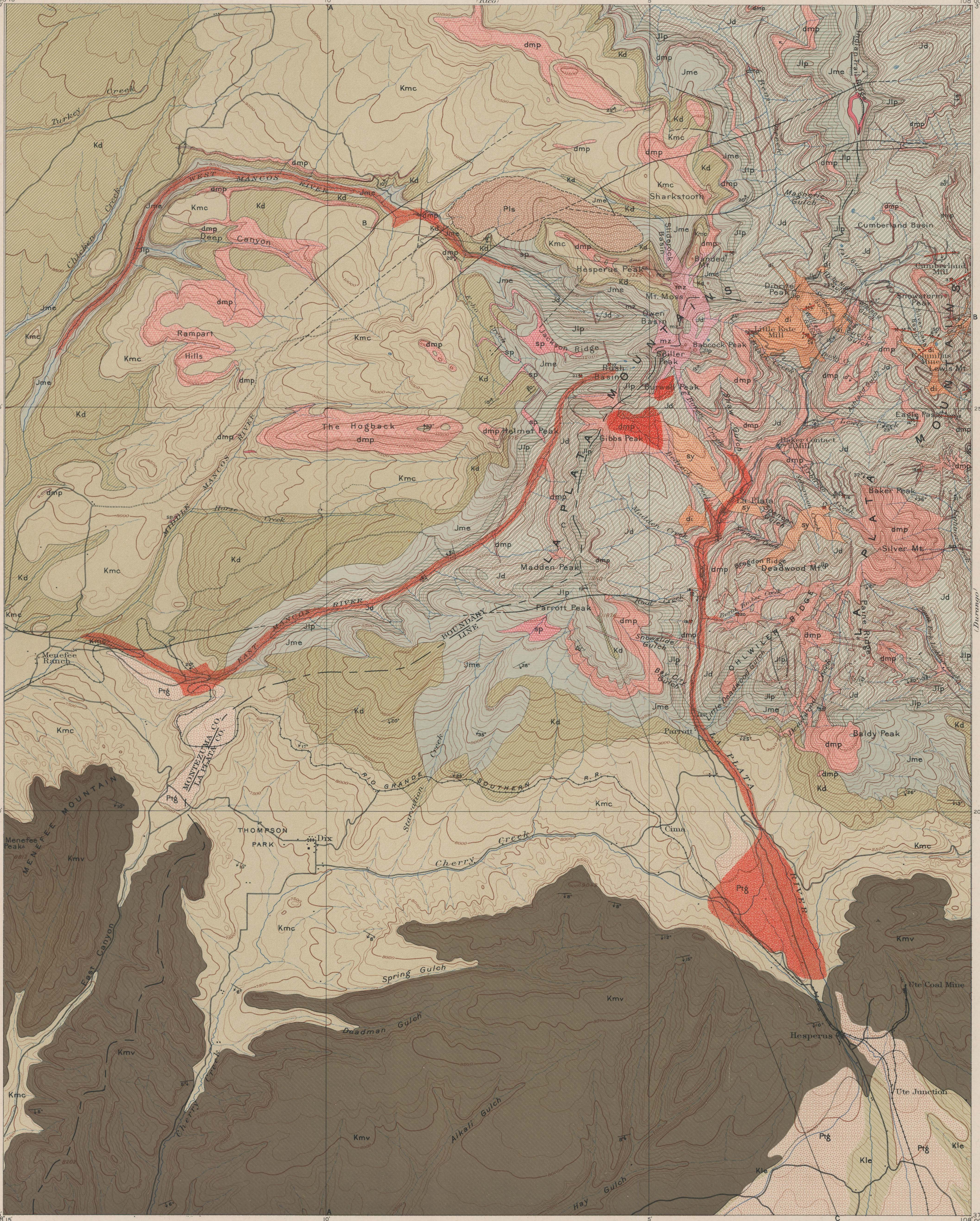
Sections

15° *Strike and dip of stratified rocks*

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

ECONOMIC GEOLOGY SHEET

COLORADO
LA PLATA QUADRANGLE



Henry Gannett, Chief Topographer.
E.M. Douglas, Topographer in charge.
Triangulation and Topography by Frank Tweedy.
Surveyed in 1895.

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.

Edition of Oct. 1899.

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Economic Geology by Chester W. Purington.
Surveyed in 1896–97.

LEGEND
(continued)

Known productive formations

Gold and silver bearing veins (showing strike and dip)

Gold bearing gravels

Areas of brecciated rock impregnated with pyrite slightly auriferous

Kmv — *Coal (Mesaverde formation, containing productive coal beds)*

NAMES OF MINES.

(Indicated on the map by numbers.)

1 Century.
2 Tippecanoe.
3 Cumberland.
4 Small Hopes.
5 Bessie G.
6 Moonlight.
7 Mountain Lily.
8 Tip Top.
9 Little Kate.
10 North Star.
11 Western Belle.
12 Jenny Lind.
13 Eagle Pass.
14 Eureka-Bulldozer.
15 Hibernia.
16 Baker Contact.
17 Shoofly.
18 Comstock.
19 Gold Bug.
20 Mammoth.
21 Georgia Girl.

LEGEND

SURFICIAL ROCKS
(Areas of Surficial rocks are shown by patterns of dots and circles.)

PLEISTOCENE

Pls — Landslides *(a confused mingling of large and small blocks of various formations from the mountains above)*

Ptg — Terrace gravels *(gravel and bowlder beds of alluvial origin)*

SEDIMENTARY ROCKS
(Areas of Sedimentary rocks are shown by patterns of parallel lines.)

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Kle — Lewis shale *(dark shales, somewhat arenaceous; fossiliferous)*

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EOCENE?

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di — Diorite *(in stocks and dikes. Contains augite, hornblende, and biotite)*

mz — Monzonite *(in a stock and associated dikes and sheets. Contains augite as the chief dark silicate)*

sy — Augite-syenite *(in two stocks)*

sp — Syenite-porphyry *(in sheets and dikes)*

dmp — Diorite-porphyry and monzonite-porphyry *(in stocks, sheets, and dikes)*

Faults

Landslide boundaries

Sections

Strike and dip of stratified rocks

Mines and prospects of silver and gold

Legend is continued on the left margin.

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

STRUCTURE-SECTION SHEET

COLORADO
LA PLATA QUADRANGLE

Henry Gannett, Chief Topographer.
E.M. Douglas, Topographer in charge.
Triangulation and Topography by Frank Tweedy.
Surveyed in 1895.

Scale 1/62500
Miles
Kilometers

Edition of Dec. 1899.

Geology by Whitman Cross.
Assisted by A.C. Spencer and H.S. Gane.
Economic Geology by Chester W. Purington.
Surveyed in 1896-97.

LEGEND

SURFICIAL ROCKS

SHEET SYMBOL / SECTION SYMBOL

PLEISTOCENE
- Pls — **Landslides** *(a confused mingling of large and small blocks of various formations from the mountains above)*
- Ptg — **Terrace gravels** *(gravel and bowlder beds of alluvial origin)*

SEDIMENTARY ROCKS

SHEET SYMBOL / SECTION SYMBOL

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- Kd — **Dakota sandstone** *(indurated quartzose sandstone with carbonaceous shale, locally containing coal)*

JURATRIAS (Subdivisions of the Gunnison formation)
- Jme — **Mc Elmo formation** *(alternating sandstones and shales)*
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- Jd — **Dolores formation** *(calcareous sandstone, grit, conglomerate and some shale, with prevailing red color, fossiliferous)*

CARBONIFEROUS
- C — **Carboniferous and older sediments**

IGNEOUS ROCKS

SHEET SYMBOL / SECTION SYMBOL

EOCENE ?
- **Basic dikes and sheets** *(vogesite, augite-kersantite, and allied rare rocks)*
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Faults

Landslide boundaries

Strike and dip of stratified rocks

Known productive formations

Gold and silver bearing veins (showing strike and dip)

Gold bearing gravels

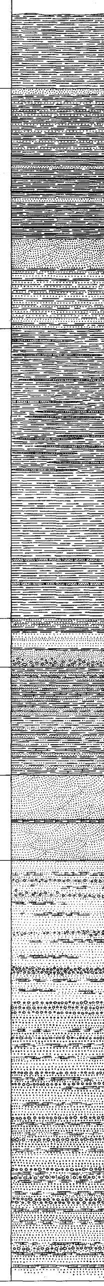
Areas of brecciated rock impregnated with pyrite slightly auriferous

Kmv — *Coal (Mesaverde formation, containing productive coal beds)*

COLUMNAR-SECTION SHEET

GENERALIZED SECTION OF THE SEDIMENTARY ROCKS OF THE LA PLATA QUADRANGLE.

SCALE: 1 INCH = 400 FEET.

Period.	Formation Name.	Symbol.	Columnar Section.	Thickness in Feet.	Character of Rocks.
CRETACEOUS	Lewis shale.	Kle		300+	A series of gray or drab clay shales, very similar to the Mancos shale in character. The shales include, in varying abundance, thin calcareous lenses or concretions of impure limestone containing some of the fossils known in the Mancos shale. Only 200 or 300 feet of the formation now remains in this quadrangle. In the adjoining Durango quadrangle a total thickness of 2000 feet is shown.
	Mesaverde formation.	Kmv		1000	An alternating series of gray or yellowish quartzose sandstones and sandy shales. In the lower portion is a massive, coarse, cross-bedded sandstone, which causes the most prominent scarp of the Mesa Verde. Above this a variable complex of sandstones and shales contains a number of productive coal seams. Invertebrate fossils, of which a list is given in the text, occur at numerous horizons. A few fossil plants have been found.
	Mancos shale.	Kmc		1200	Soft, dark-gray or almost black, carbonaceous clay shales, containing thin lenses or concretions of impure limestone. Embraces the Colorado group and a portion of the Pierre division of the Montana. Fossils occur more or less abundantly at several horizons. The species identified are enumerated in the text.
	Dakota sandstone.	Kd		100-300	Gray or rusty-brown quartzose sandstone, with a variable conglomerate containing small chert pebbles at or near the base. Carbonaceous shale partings occur at several horizons. Coal of poor quality is locally present in these shales. Indistinct fossil leaves occur sparingly.
JURATRIAS	McElmo formation.	Jme		400-500	A complex of alternating friable, fine-grained, yellowish or gray sandstones and variegated shales. The sandstones are seldom more than 20 feet in thickness. They often include flakes of greenish clay or shale. The shales are chiefly green in color, but may be pink, dark red, or chocolate-brown. Some shale layers are sandy and others highly calcareous. No fossils have been found in the McElmo strata of this quadrangle.
	La Plata sandstone.	Jlp		300-400	Consists principally of two very massive, friable, white sandstones, with a narrow band of dark limestone or calcareous shale between them. The sandstones are quartzose, of even grain, distinctly cross bedded, and form massive cliffs where exposed. A delicate net veining with white quartz is characteristic. No determinable fossils have been found.
	Dolores formation.	Jd		1700+	A series of reddish sandstones, grits, and conglomerates with persistent calcareous cement. The upper third of the formation is finer grained and predominantly brighter red in color than the lower part. Many of the strata are sandy marls and may locally become dense sandy limestones, mottled red and gray, with conchoidal fracture. Fine limestone conglomerates occur very variably in this upper third, and in them are found abundant teeth of a crocodile (*Belodon*) and of a megalosauroid dinosaur, with a rare gasteropod shell similar to *Viviparus*. The lower two-thirds of the formation consists of alternating arkose sandstone and conglomerate, the pebbles of the latter being of granite, gneiss, Algonkian quartzite, and schist, and, rarely, of a dark dense porphyry. The exposed thickness of the formation in this quadrangle is about 1700 feet, while the total thickness, seen in the adjacent Durango quadrangle, is about 2000 feet.

WHITMAN CROSS,
Geologist.

ILLUSTRATION SHEET

FIG. 1.—VIEW FROM BALD KNOB, LOOKING NORTH ALONG THE EAST FACE OF THE LA PLATA MOUNTAINS.

The steep slope on the left belongs to Lewis Mountain. The metamorphosed Dolores beds are steeply upturned and seamed by many dikes. Beyond these slopes appears the summit of Snowstorm Peak. The projecting shoulder of the middle ground exhibits nearly horizontal Dolores strata, with several intrusive sheets of porphyry. The distant peaks belong to the western part of the San Juan Mountains.

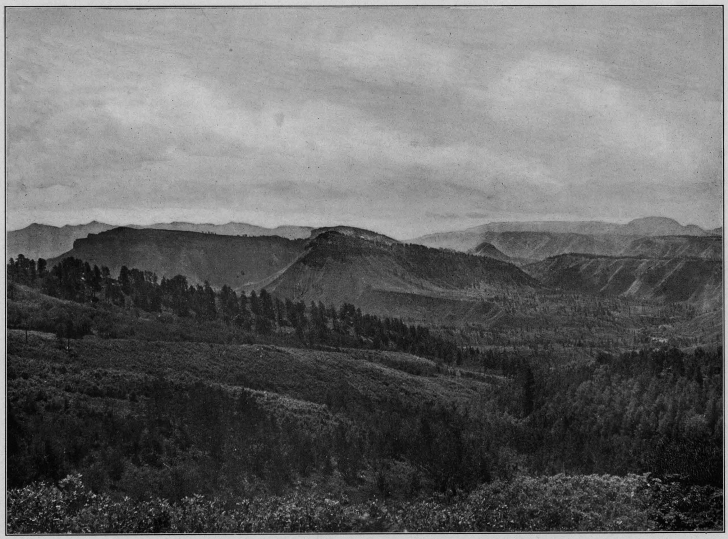


FIG. 2.—VIEW FROM BALDY PEAK, LOOKING SOUTHEAST TOWARD DURANGO.

The prominent valley is that of Lightner Creek. The prominent pointed ridges represent remnants of a sloping mesa caused by the Mesaverde sandstones. Below the scarps are the exposures of the homogeneous Mancos shales.

FIG. 3.—VIEW SOUTHWEST FROM THE RAMPART HILLS, SHOWING THE DOLORES PLATEAU, THE MESA VERDE, AND THE EL LATE MOUNTAINS

The nearly level floor of the plateau is underlain by the Dakota sandstone, upon which are rounded knolls and ridges of Mancos shale. On the left appears the Mancos Valley as it cuts into the Mesa Verde. The escarpment of the Mesa Verde is caused by the heavy sandstones of the formation of the same name. Ute Peak, the most prominent summit of the El Late Mountains, appears at the extreme right of the view.

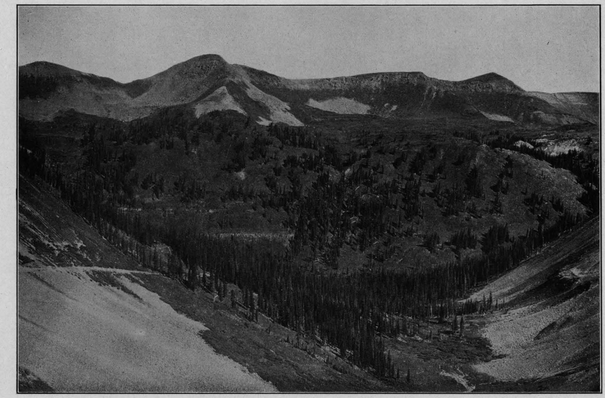


FIG. 4.—INDIAN TRAIL RIDGE, AS SEEN FROM THE EAST, LOOKING ACROSS THE LA PLATA VALLEY FROM SILVER LAKE BASIN.

The view shows the light-colored La Plata sandstone forming the top of the ridge, the basins excavated in the Dolores strata immediately below it, and the steep western slope of the main La Plata Valley.

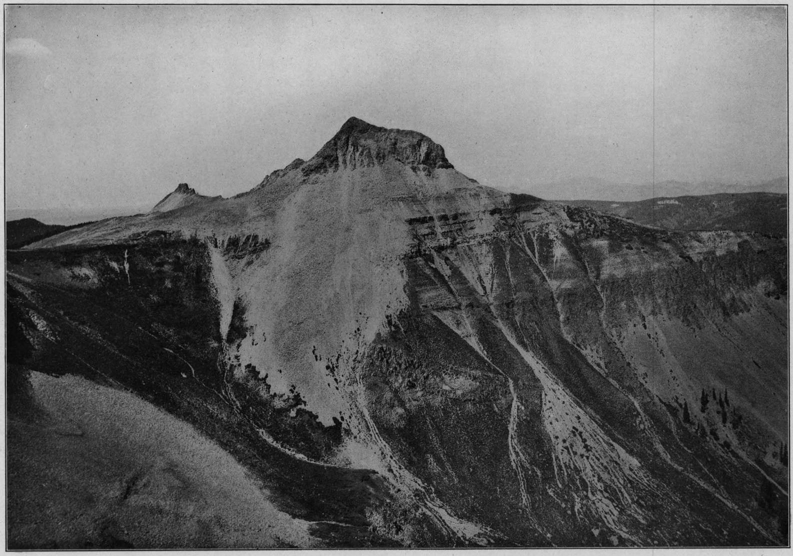


FIG. 5.—THE SHARKSTOOTH, FROM THE EAST LOOKING ACROSS BEAR CREEK.

The summit of this most northern point of the La Plata Mountains is due to an intrusive sheet in the Mancos shales. The débris from the disintegration of that sheet spreads out over the soft shales as a wide field of slide rock. A notable talus slope from the upper cliffs partially conceals the outcrops of the Mancos shales, the Dakota sandstone, and the Lower McElmo formation, within which is a thick intrusive sheet of porphyry.

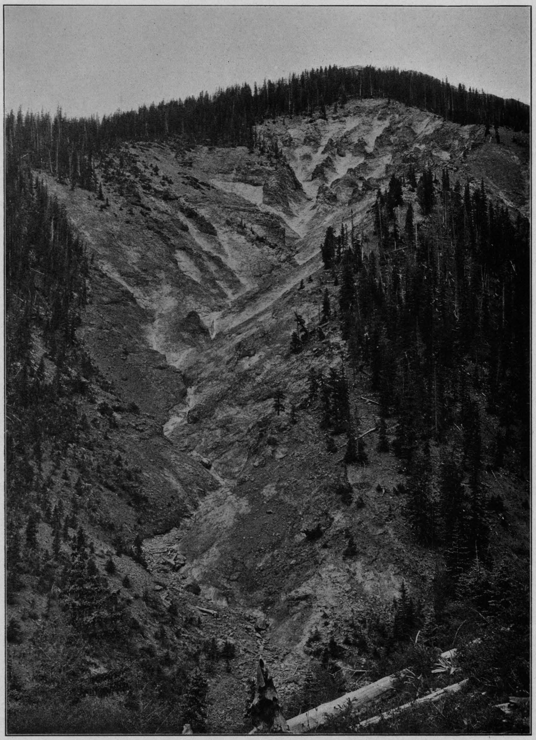


FIG. 6.—A RAVINE UPON THE NORTHEAST SLOPE OF GIBBS PEAK.

The rock within which this ravine is excavated is brecciated and iron-stained porphyry. Erosion is progressing very rapidly at the present time. The site of this ravine was once forest covered.

FIG. 7.—VIEW DOWN THE LA PLATA VALLEY FROM THE ENTRANCE TO THE MOUNTAINS.

The level ground in the center of the view belongs to the terrace called the Gold Bar. The present stream bed of the La Plata is on the left. The sky line represents the principal sandstone horizon of the Mesaverde formation. In the gap on the left is situated the station Hesperus. Beyond that may be seen another strong terrace line.

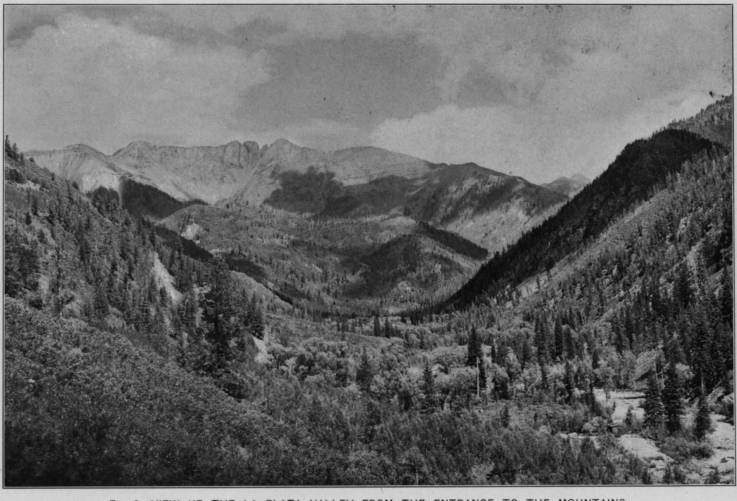


FIG. 8.—VIEW UP THE LA PLATA VALLEY FROM THE ENTRANCE TO THE MOUNTAINS.

The view shows the U-shaped valley of the La Plata. To the left of the center are Babcock and Spiller peaks, where a stock of monzonite causes the more rugged forms.

FIG. 9.—VIEW DOWN THE LA PLATA VALLEY FROM THE DIVIDE AT ITS HEAD.

This view shows how wide and deep this valley is at the very heart of the mountains. The steep slopes on the right are characteristic of both sides of the valley. The summits near the center are Parrott and Madden peaks, the former capped by porphyry, the latter by the light La Plata sandstone.

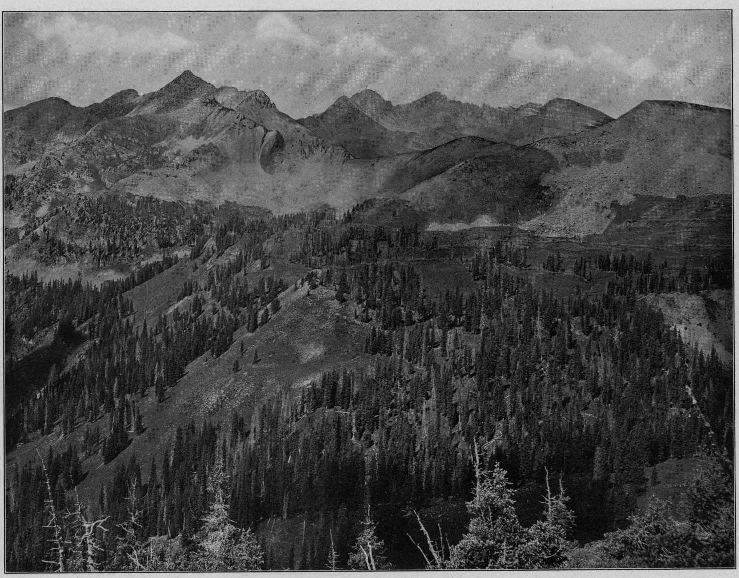


FIG. 10.—THE WESTERN SUMMITS OF THE LA PLATA MOUNTAINS FROM THE DIVIDE AT THE HEAD OF THE RIVER.

This view is panoramic with fig. 9. It shows the rugged character of the summits within the monzonite stocks. Near the center is Mount Moss. The sharp point on the left is Diorite Peak. Banded Mountain and Hesperus Peak are on the right.

FIG. 11.—THE HEAD OF THE WEST MANCOS RIVER FROM JACKSON RIDGE, SHOWING HESPERUS PEAK, MOUNT MOSS, AND SPILLER PEAK.

In Hesperus Peak, on the left, are many intrusive sheets of porphyry intercalated in the Mancos shales. The monzonite stock of Mount Moss, in the center of the view, sends off a wedge-like arm which upturns the shales and sheets of Hesperus Peak. On the right is Spiller Peak, the summit of which is also formed of monzonite, which has greatly indurated the strata of the McElmo formation forming the cliffs seen in the view. The loose rock of the foreground belongs to the syenite-porphyry sheet of Jackson ridge. The cliffs in the gorge of the West Mancos belong to the indurated La Plata sandstone.