DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, SECRETARY
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

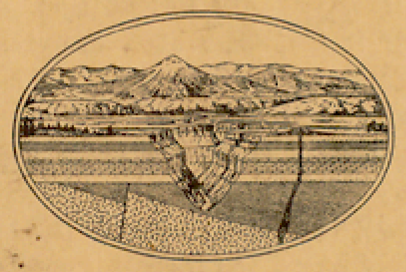
GEOLOGIC ATLAS
OF THE
UNITED STATES

SILVER CITY FOLIO

NEW MEXICO

BY

SIDNEY PAIGE



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GEOLOGIC ATLAS OF THE UNITED STATES.

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

THE TOPOGRAPHIC MAP.

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

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

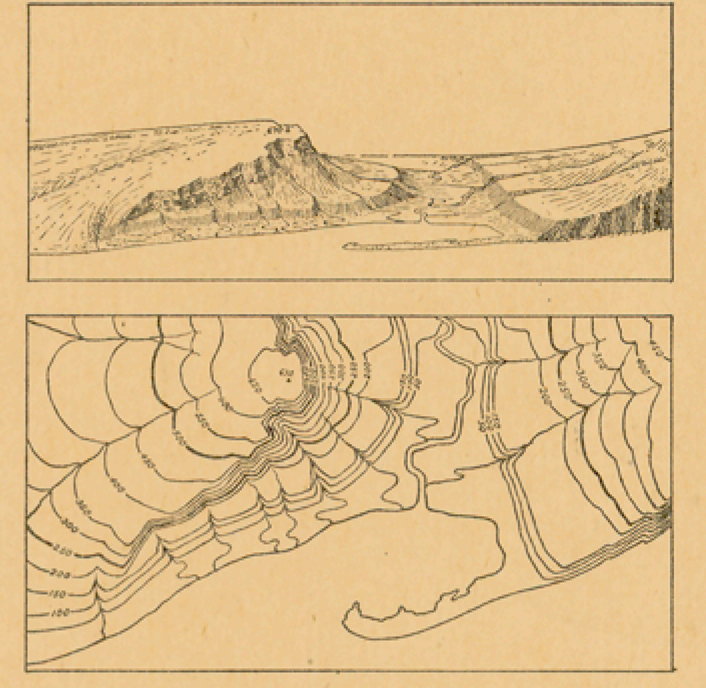

FIGURE 1.—Ideal view and corresponding contour map.

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

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

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

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

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

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

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

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

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

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

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

THE GEOLOGIC MAPS.

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

KINDS OF ROCKS.

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

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

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

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

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

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

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

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

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

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

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

FORMATIONS.

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

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

AGES OF ROCKS.

Geologic time.—The time during which rocks were made is divided into *periods*. Smaller time divisions are called *epochs*,

DESCRIPTION OF THE SILVER CITY QUADRANGLE.

By Sidney Paige.

INTRODUCTION.

GENERAL RELATIONS OF THE QUADRANGLE.

The Silver City quadrangle is bounded by meridians 108° and 108° 30′ and parallels 32° 30′ and 33° and includes one-fourth of a "square degree" of the earth's surface, an area, in that latitude, of 1,003 square miles. It is in southwestern New Mexico (see fig. 1) and almost wholly in Grant County, but along the east half of its south side it includes a narrow strip of Luna County. Silver City, from which the quadrangle is named, stands near the center of the area.

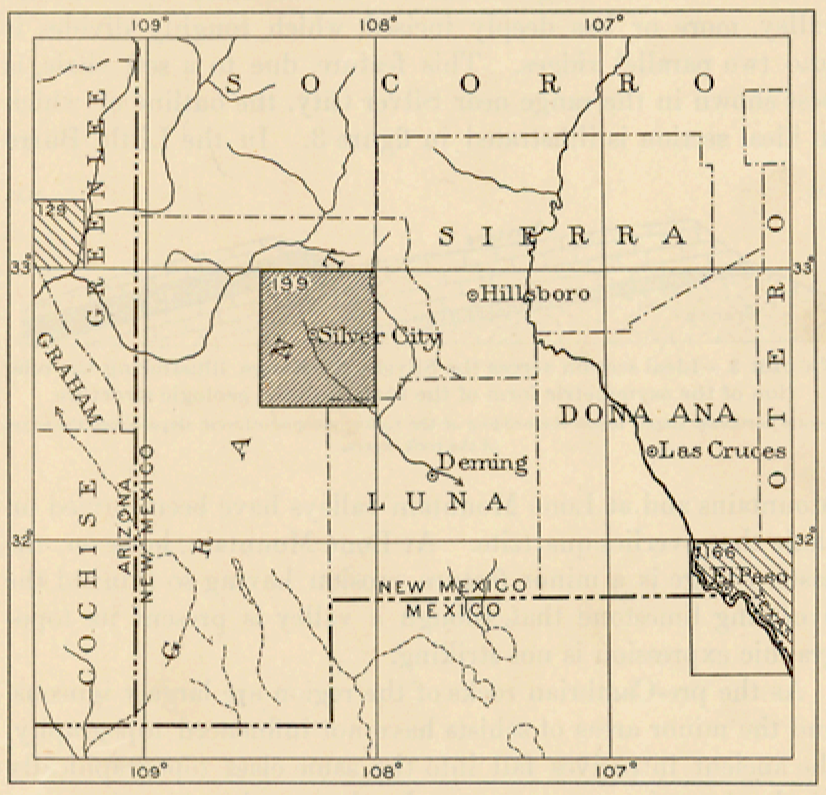

FIGURE 1.—Index map of southwestern New Mexico and adjacent region in Arizona.

The location of the Silver City quadrangle (No. 199) is shown by the darker ruling. Lighter ruling shows other quadrangles described in folios, namely, 129, Clifton; 166, El Paso.

In its general geographic and geologic relations the quadrangle forms a part of the Basin Range province and lies not far south of the southeastern border of the Colorado Plateau. It is crossed by the Continental Divide, which separates streams whose waters flow to the Gulf of Mexico from streams whose waters flow to the Pacific.

GENERAL GEOLOGY AND GEOGRAPHY OF THE REGION.

Western New Mexico and eastern Arizona include parts of two distinct and striking physiographic divisions. Much of the northern part of the region lies in the Plateau province; the southern part lies in the Basin Range province and has two dominant characteristics: first, the ranges within it have definite and parallel trends; second, those of the western half trend northwestward and those of the eastern half trend more nearly north. The Silver City quadrangle is in the area where these variably trending ranges coalesce, near the boundary between Arizona and New Mexico. (See fig. 2.)

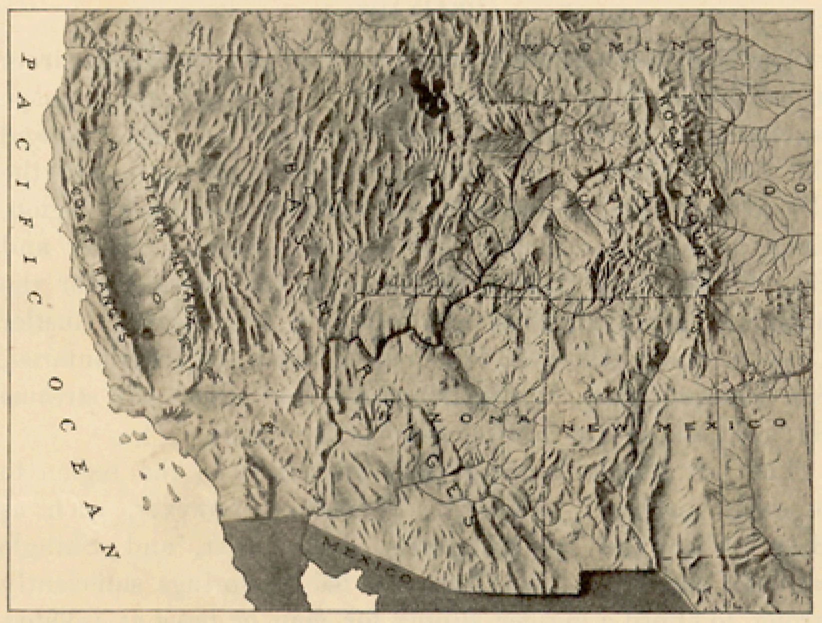

FIGURE 2.—Relief map of part of western United States.

The Silver City quadrangle is in the Basin Range province in southwestern New Mexico, at the intersection of the Basin Ranges, trending southeastward, and the Rocky Mountains, trending southward.

The northwestward-trending ranges comprise a number of fairly distinct, narrow, and comparatively short mountain masses, separated from each other by relatively narrow valleys filled with fluviatile or lacustrine deposits. Ransome[1] says:

> The individual ranges, such as the Dragoon, Chiricahua, Pinalino, Galiuro, Santa Catalina, Tortilla, Pinal, Superstition, Ancha, and Mazatzal mountains, rarely exceed 50 miles in length or 8,000 feet in altitude. * * * Their general trend * * * near the Mexican border * * * becomes more nearly north and south, and the mountain zone as a whole coalesces with a belt of north-south ranges which extends northward through New Mexico and borders the Plateau region on the east.

The northward-trending ranges, such as the Peloncillo, Pyramid, Hachita, Mimbres, San Mateo, Caballos, and San Andreas mountains, have much in common with the northwestward-trending ranges described above.

Though the Silver City area is not far from the plateau region on the north, its relation to the plateau is masked by vast fields of lava.

Lindgren, Graton, and Gordon[2] have presented an epitome of the geologic history of the New Mexico region which may fitly reappear here:

> The pre-Cambrian rocks of New Mexico tell a story, dimmed by antiquity, of periods of sedimentation on an unknown basement; of granitic intrusions tremendous in scale; of igneous and dynamic metamorphism. The "historical" records may be said to begin with the Cambrian period, when the Rocky Mountain core of northern New Mexico, and in fact the whole north-central part, was a land area subject to degradation, the sediments produced by which accumulated in the Cambrian strata of southern New Mexico. The northern land area was submerged at the end of the Mississippian (lower Carboniferous) and sedimentation went on, with some interruptions, until the close of Cretaceous time, when the Territory was covered by a mantle of sediments, perhaps 10,000 feet in thickness.
>
> At the beginning of the Tertiary period igneous intrusive activity began; laccoliths, stocks, sills, and dikes of monzonite and quartz monzonite, with corresponding porphyries, were forced into the sediments, evidently bulging them in places, but rarely breaking the tough crust and rarely reaching the surface.
>
> These intrusions were accompanied by a general continental uplift, raising the whole Territory 3,000 to 10,000 feet above sea level. Dislocations outlining the principal ranges accompanied this crustal movement. In the prolongation of the Rocky Mountains of Colorado the sediments were domed and then cut by vertical faults, along which subsidence took place. After erosion these conditions would produce the impression of a vertical upthrust of the pre-Cambrian rocks. This north-central part now forms the highest mountain region of the Territory, rising to elevations of 13,000 feet. South of Glorieta, where the Rocky Mountains proper dip below the Cretaceous sediments, the beds were subjected to stresses which produced monoclinal blocks with more or less pronounced fault scarps. The principal disturbances probably outlined the present valley of the Rio Grande and are marked by a series of sharply accentuated north-south ranges of apparently tilted blocks, such as the Sandia, Manzano, Oscura, San Andreas, and Organ ranges on the east side and the Nacimiento, Limitar, Magdalena, Cristobal, Caballos, and Cuchillo Negro ranges on the west. Some of the scarps face east, others west. Here also the apparent tilting may be the result of doming, faulting, and subsidence. At the same time was outlined the easternmost chain of the New Mexico ranges, which is separated from the Organ, San Andreas, and Oscura chain by the structural depressions of the Sacramento Valley. Like a graceful festoon this chain extends into New Mexico from trans-Pecos Texas and contains three units, the Guadalupe and Sacramento mountains and the Sierra Blanca, all of them with gentle easterly slopes and steep western scarps. At the north the Sierra Blanca merges into a Cretaceous plateau; on the east side of the chain lie the almost level Tertiary strata of the Llano Estacado, affected only by a slight continental uplift. This plain is separated from the ranges by erosional scarps.
>
> The northwestern part of New Mexico participated in the general uplift but suffered only slight deformation. This is the Plateau province proper, characterized by gently dipping Cretaceous strata that have been sculptured by erosion into terraces and scarps. It contains the broad uplift of the Zuni Plateau, in which erosion has exposed the older strata down to the pre-Cambrian. It is surmounted by some flows of Tertiary and Quaternary lavas. On the east it is limited by the ancient land mass of pre-Cambrian rocks, the Hopewell Mountains, and farther south by the westward-facing scarp of the first of the monoclines of central New Mexico, the Sierra Nacimiento.
>
> In central New Mexico the Plateau province extends far to the east; it is generally considered to cease at the Rio Grande, but in reality the high plateaus continue for some distance east of the local interruption by the Manzano and Oscura ranges until, near the eastern boundary of the Territory, they finally merge into the Great Plains.
>
> Northeastern New Mexico is commonly referred to as a part of the Great Plains, but it is in reality, as pointed out by Hill,[3] an eroded plateau of Cretaceous rocks, surmounted by basaltic flows.
>
> The Mimbres or Black Range, which lies west of the Rio Grande, is supposed to mark the southeastern limit of the Plateau province. In structure it appears to show some relationship with the Rocky Mountain ranges of northern New Mexico. Its appearance is that of an upthrust of pre-Cambrian rocks, flanked on both sides by Paleozoic rocks dipping away from the core.
>
> The extreme southwest corner of New Mexico embraces a part of a province foreign to the Territory as a whole—that of the Arizona desert ranges, numerous and small, trending northward and separated by desert basins. That these ranges are post-Cretaceous admits of little doubt. Probably they were outlined during the same early Tertiary deformation that produced the ranges of the Rio Grande valley. They differ from the latter by a far less marked monoclinal structure. They were probably outlined by faults, but few of the dislocations are conspicuous in their present topography.
>
> The orogenic movements which outlined the present topography tended to create lake basins. Thus a large Eocene lake existed in northwestern New Mexico and another of later Tertiary age in the upper valley of the Rio Grande.
>
> Ever since the uplifts and deformations erosion has been actively endeavoring to modify the scarps of the ranges and trench the plateaus. From the bulging domes of sediments over laccolithic intrusions it has carved the mountain groups of the Cerrillos, Ortiz, and San Pedro.
>
> About the middle of the Tertiary, after erosion had been at work for a long time, masses of lava began to pour out over the southern part of the Plateau province. They flooded the Black Range and the country westward to the Arizona line. At centers of eruption there rose above this plateau great piles of volcanic rocks, such as the Mogollon Range in the west, the San Mateo Mountains north of the Black Range, and the Valles Mountains northwest of Albuquerque. The andesitic and rhyolitic eruptions ceased, but shortly afterwards, in late Tertiary and early Quaternary time, basalt began to issue from generally inconspicuous vents and covered large areas in the upper Rio Grande and on the Cretaceous plateau in the northeast.
>
> In diminishing volume these flows continued to a recent time, but the deformational and igneous history of the Tertiary ends at the beginning of the Quaternary. Since that time the only important changes in the topography have been those effected by erosional agencies, in reducing the bulk of the mountains, in building enormous débris fans, in draining lakes, and in deepening canyons. A brief glacial epoch left its imprints on the highest range of the Territory between Santa Fe and the Colorado boundary line.

CLIMATE AND VEGETATION.

The climate of New Mexico has been described by A. J. Henry, from whose report the following extracts are taken:[4]

> Its climate is dry and equable; the maximum of sunshine is in the fall and winter; the maximum of precipitation is in midsummer, during July and August. The daily variation of temperature is very great. Beneath the cloudless sky the porous sandy soil, barren of vegetation over large areas, is quick to receive the sun's heat and quick to give it up. High winds are frequent during the early part of the year, but destructive winds are rare. The only storm of record approaching the intensity of a tornado occurred in the extreme northeast portion. New Mexico is not included in the "tornado belt."
>
> * * * The climate of the northwestern half of the State in general, comprising the more elevated and mountainous portions, partakes of the nature of the typical climate of the "Rockies," modified by geographical position. The southeastern half in general, comprised mainly of sloping table-lands having scant vegation and infrequent surface water, possesses a climate typical of the semiarid Southwest.
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> * * * * * * *
>
> The annual mean temperature for the State is 54°. The average winter temperature is 36°; spring, 53°; summer, 72°; fall, 55°. The highest temperature recorded is 110° at Roswell; the lowest, 23° below zero at Aztec. * * *
>
> There is a clearly defined "wet season," beginning rather abruptly early in July, reaching its maximum the latter part of July or early in August, and more gradually decreasing to a minimum in March, during which month only 3 per cent of the total annual precipitation occurs. About one-third of the total annual precipitation occurs during July and August. Over the Continental Divide and in the extreme north the wet season is not so clearly defined as over the southern, central, and eastern portions. In general the rains of the wet season occur in the afternoon as thunder showers of short duration. The showers are frequently torrential in character, badly washing the loose soil. * * * The average annual precipitation of the stations is 13 inches, which is believed to approximate closely the annual mean precipitation of the whole State. Over the valley of the Rio Grande, which is the driest portion of the State, there is an average of less than 9 inches a year, while over the higher mountain ranges both the winter and summer precipitation is much greater, probably averaging 25 inches and over at elevations of 10,000 feet and above. The summer showers are sometimes accompanied by severe hail, most frequently occurring over the more elevated plateau of northeastern New Mexico.

In the Silver City quadrangle differences in altitude result in considerable local differences in climate. The mountain region receives considerable rainfall, supports a forest, and is notably cooler in summer than the neighboring low-lying territory bordering the desert, which receives far less rain, supports no forest, and, lying beneath clear and brilliant skies, is

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[1] Ransome, F. L., U. S. Geol. Survey Geol. Atlas, Globe folio (No. 111), 1904.

[2] Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, pp. 25–26, 1910.

[3] Hill, R. T., Notes on the Texas–New Mexico region: Geol. Soc. America Bull., vol. 3, pp. 85–100, 1892.

[4] Henry, A. J., Climatology of the United States: U. S. Dept. Agr. Weather Bureau Bull. Q, pp. 888, 889, 897, 1906.

characterized by intense heat. Frequently during the summer cloudless, moisture-laden winds rise against the mountains, threatening masses of cloud appear, and showers fall—at times torrential downpours.

In the spring the snow lies longer on the northern slopes of the higher mountains and moisture is more gradually contributed to the soil, so as to produce good forest growth. Douglas fir, white fir, long and short leaved pine, walnut, box elder, cottonwood, live oak, Gambel oak, and aspen are among the larger trees. Scrub oak and mountain mahogany and many other varieties of bushy growths are abundant. On the southern slopes, however, insolation is greater and moisture is more rapidly evaporated, generally only enough remaining to support a more or less scrubby vegetation. Many varieties of grass grow on the border lands of the desert and on the higher gravel plains, and many species of cacti are found in the desert. Droughts and overstocking have combined to reduce greatly the value of the pasture lands, and every year many cattle perish miserably from starvation.

TOPOGRAPHY.

GENERAL FEATURES.

The Silver City quadrangle lies on the border of a mountainous region. In the area northwest of it the Mogollon Mountains and the San Francisco and Tularosa ranges tower in rugged piles to altitudes of about 10,000 feet. On the northeast the Mimbres Mountains reach equal altitudes. On the south, on the other hand, for many miles stretches a desert broken only by scattered island-like mountain masses. The quadrangle lies partly in the mountains, partly in the foothills, and partly in the desert plains.

MOUNTAINS.

There are four principal groups of mountains in the quadrangle—the lava range in the northern part; the lava range south of Santa Rita, in the east-central part; the Big and Little Burro Mountains in the southwestern part; and the range extending northwestward from Silver City to Bear Mountain. There are also several smaller groups.

The lava range at the north culminates in Black Peak at an elevation of 9,020 feet above sea level and 4,200 feet above the gravel deposits in the northwest and southeast corners of the quadrangle. Measured from the foothill region at the southern base of the range, the difference in altitude does not exceed 2,000 feet. The range is sharply dissected, being traversed by many steep-walled and picturesque canyons, but though most of the mountains are steep the range does not present an appearance of great ruggedness, for it is covered to its very summit by vegetation. Most of the roughest parts are the nearly vertical-walled canyons of the streams.

The lava range south of Santa Rita is of more moderate relief, rising not more than 1,600 feet above the gravel floor at its western side. In detail, however, it is decidedly more rugged. Imposing cliffs rise on three sides (see Pl. V) and steep, bare canyons dissect the range. Vegetation being sparse, rough and curious forms of weathering are abundant, all combining to produce an aspect of wildness and desolation. (See Pls. II and VI.)

The Big Burro Mountains, in the southwestern quarter of the quadrangle, rise to an altitude of 8,054 feet in a double peak, from which the country slopes away in all directions. The sides and lower slopes of this subconical mass are sharply dissected, but the term rugged could hardly be applied to any of this territory.

North-northeast of the Big Burro Mountains and across the gravel-filled Mangas Valley, the Little Burro Mountains rise to heights of 6,500 feet, about 500 to 700 feet above the general level of the surrounding gravel plain. The form of these mountains (which trend northwest and are about 8 miles long) is asymmetric. The western face is generally steep—here and there precipitous—and rises abruptly from the dissected gravel plain. The east side, on the other hand, merges gradually into the plain. Wind Canyon, which crosses the north end of the mountains, is vertical walled, though not deeply incised. Redrock Canyon also and several smaller ones give the hills a semblance of ruggedness, unusual with features of relatively low altitude.

The range of mountains of moderate relief which trends northwestward from Silver City culminates in Bear Mountain, a peak 8,050 feet high. These mountains are called in this folio the Silver City Range. South of Bear Mountain the range, in a broad way, is asymmetric in form, the western slopes being far steeper than the eastern, which have assumed lower angles in conformity with the dip of the sedimentary rocks that form them. North of Bear Mountain the asymmetric form is not so clearly evident, though its effects may be detected in the sharp canyon cutting which characterizes its western sides as contrasted with the gently sloping mesa which forms the eastern slope. The southern part of the mountains is not rugged and merges gradually into the gravel at the south end; the northern part, however, especially in the canyons at the north end, is somewhat rugged.

Pinos Altos Mountain, which lies in the north-central part of the quadrangle, directly west of the town of Pinos Altos, is one of the smaller groups of hills. Its highest point reaches an altitude of 8,036 feet. Lone Mountain, another of the smaller groups, is in type a counterpart of the southern portion of the Silver City Range. Its steep side is on the southwest and its northeast slope is gentle. These hills rise but 400 feet above the gravel at their base.

FOOTHILLS.

A considerable part of the quadrangle lies within the foothills of the several mountain groups. Such areas are characterized by generally low relief and with the exception of occasional hills present no striking topographic features. Stretching eastward from the Silver City Range is a rolling plainlike area out of which rise such hills as the group near Gomez Peak and the hills southeast of Pinos Altos. This plain extends beyond Fort Bayard, east of which the country becomes more hilly. The country northwest of Gomez Peak, though not mountainous, is decidedly rougher and in the northern part of the quadrangle merges into the dissected lava and gravel benches that are more fully described below. In the areas north and south of the Big Burro Mountains the topography is generally hilly.

PLAINS.

Along the southern border of the quadrangle lies the northern edge of a great gravel-covered desert that extends far to the south. Toward the mountains this desert area grows less forbidding, and near the mountains the gravel is covered in the rainy season with grass and shrubs. The desert, a dissected gravel plain, sweeps northwestward between the Big Burro Mountains and the Silver City Range and isolates the Little Burro Mountains in an island-like mass. A broad area of gravel in the valley of Bear Creek in the northwest corner and another in the valley of Mimbres River in the northeast corner of the quadrangle produce the same topographic effect.

SURFACE FORMS.

The surface forms of the region, broadly viewed, may be divided with respect to the dominant features into three groups: forms developed in Quaternary gravel, forms characterizing the Tertiary lavas, and forms developed in pre-Cambrian, Paleozoic, and Cretaceous intrusive and sedimentary rocks. The last division might be subdivided into forms in sedimentary and forms in igneous rocks. The Quaternary deposits are sloping, even-topped gravel plains, intricately carved by erosion. Where the dissected gravel sheet rises to meet the mountain sides the arroyos within it are sharply incised and are separated by flat-topped, evenly sloping ridges, the valley floors are narrow, and the gradients are relatively steep. By degrees, with increase of distance from the hills, the contours become softer, more rounded, the valley floors grow broader, the intervening ridge tops, now lower, take on curving lines, and the gradients are markedly reduced. Where the gravel sheet merges into the desert the valleys are broad and shallow and disappear in an almost featureless plain. This perfect topographic transition from a clean cut, sharply incised border to the full unbroken desert level expresses perfectly the geologic change which has taken place; an area of active erosion has merged into one of active deposition.

Hells Half Acre, in the northwest corner of the quadrangle, is a fine example of rugged sculpture in the gravel. In Welty Canyon, in the same corner, cliffs of gravel form an apparently unbroken wall, and only close inspection reveals the tortuous course of the stream bed meandering between narrow canyon walls several hundred feet high. The bluffs are curiously carved and pinnacled, and are altogether a remarkable example of the operation of erosion upon semiconsolidated material. (See Pl. IX.) On the border of Gattons Park also, in the northeast corner of the quadrangle, sharp dissection of the gravel, which in places is indurated and is essentially a conglomerate, has produced a generally rugged topography, and the tortuous steep-walled canyons are so narrow near their heads as scarcely to admit one's body. All stages of gradation may be seen from this type of extreme incision to the flat, featureless plains of the desert. For example, along the edge of the bench gravel on the west side of Mangas Valley, more rounded forms are general and the outlines become softer as the desert is approached. (See Pl. XII.)

The second distinct topographic type, that presented by the Tertiary lavas, is the result of the sharp dissection of nearly horizontal sheets of lava interbedded with water-laid tuff and gravel. The lava ranges, when viewed from a distance, appear to be immense piles of superposed subhorizontal sheets, in places presenting precipitous scarps to the surrounding areas. (See Pl. V.) Their dominant characteristic, therefore, is their flat-topped table-like appearance. In detail the varieties of form which the nearly horizontal sheets assume are striking. In certain flows the surface weathering, apparently controlled by a system of vertical joints, has produced forms that resemble a village of closely set conical towers. (See Pl. VI.) In other places huge residual masses rest on the surface of the lava. Some of these form groups or clusters, and where they occupy elevated positions above an open green dotted with trees, they create a landscape of great beauty, the pink tones of the rhyolite, the clear blue skies, and the parklike grass land each adding its attraction. This weathering into curious forms is far more common in the rhyolitic lava than in the basaltic or andesitic lavas, which, in the range south of Santa Rita, cap the mountains, as they do in much of the northern area, and weather in more rounded forms, giving a suggestion of great domes resting upon the more nearly table-like rhyolite beneath them.

The third group of topographic forms comprises the features shown by pre-Cambrian, Paleozoic, and Cretaceous rocks, and the intrusive igneous masses. The mountain masses, whose form is primarily influenced by sedimentary strata, are asymmetric—that is, they have steeper slopes on the west than on the east. This difference is due to their structure, the mountains being monoclinal fault blocks with decided easterly dips. The range at Silver City, Lone Mountain, and the Little Burro Mountains are three groups whose form is dependent on such structure. Each range is further characterized by a medial valley, more or less deeply incised, which roughly divides it into two parallel ridges. This feature, due to a soft shale, is best shown in the range near Silver City, the outline of which in ideal section is illustrated in figure 3. In the Little Burro Mountains and at Lone Mountain valleys have been formed on shale that overlies quartzite. At Lone Mountain, however, the eastern ridge is a minor feature, erosion having so thinned the overlying limestone that, though a valley is present its topographic expression is not striking.

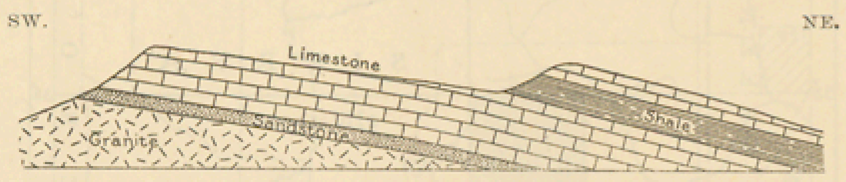

FIGURE 3.—Ideal section across the Silver City Range, illustrating the relation of the asymmetric form of the surface to the geologic structure.

Gentle northeast slopes follow the bedding of the rocks; steep southwest slopes cross the edges of the rock layers.

As the pre-Cambrian rocks of the region are largely igneous, and the minor areas of schists have not influenced topography, the ancient intrusives fall into the same class topographically as the later igneous masses. In the area in which intrusive igneous rocks have formed appreciable elevations above the surrounding country, the forms are simple—either cones or more or less symmetric ridges, both with minor irregularities. The principal peak of the Big Burro Mountains rises boldly from a relatively well-defined platform in a decidedly conelike form. It is true that a long ridge, forming here the Continental Divide, juts off in a southerly direction, but this feature does not greatly alter the fact that erosion has cut a great conelike mass largely from pre-Cambrian granite.

The group of low mountains formed by the intrusive mass at Gomez Peak north of Silver City is an even better example of this conelike shape. Bear Mountain is still another conelike peak, cut by erosion from a later porphyry intrusive stock. Pinos Altos Mountain, on the other hand, is a narrow symmetric ridge formed of dioritic rocks.

Intrusive masses do not, however, everywhere occupy elevated positions. Between Hanover and Fierro a granodiorite mass occupies a valley cut along an anticlinal axis. On Shingle, Bear, and Allie canyons there are two low-lying intrusive masses, and the great sill-like intrusion on which Fort Bayard is built occupies in the main a low-lying area.

DRAINAGE.

The Continental Divide passes through the quadrangle from its southwest to its northeast corner. All northerly drainage reaches Gila River and ultimately the Gulf of California and the Pacific Ocean. All southerly drainage flows toward the Rio Grande but, encountering the sands of a desert region, sinks beneath the surface and is lost. Mangas River and Bear Creek, with their tributaries, are the channels for the northern flow. Mimbres River and its tributaries, Rustler Canyon, Martin Canyon, Whitewater Creek and its tributaries, San Vicente Arroyo and its tributaries, and other small streams carry the southward-flowing water to the desert.

The fall of rain is insufficient anywhere in the region to produce perennial streams. A number, however, such as Bear Creek and its tributaries, Allie, Bear, and Shingle canyons, and Santa Rita Creek, are fed by springs sufficiently strong to afford a meager supply for man or beast at isolated localities. As a whole, nevertheless, flow in streams is regulated by torrential downpours, rising to floods as the storms break and sinking to trickling rivulets as the clouds disperse.

Since this intermittent flowage is one feature of a climatic condition that tends to produce rapid disintegration of the surface, through sporadic but effective removal of loose material by violent rains, most of the stream valleys contain far more waste material than the floods are able to carry off. This is especially true of areas in which there is an abundant supply of semiconsolidated gravel—areas, for example, underlain by Pleistocene deposits. Even within the mountains all the larger stream valleys are floored with a mantle of coarse gravel and sand, which only awaits a heavy downpour to join in a muddy torrent that travels in a wave down the canyon—an agent of great erosive force.

As a direct result of these conditions—that is, of intermittent rainfall and a local abundance of semiconsolidated material—many streams within the gravel-covered areas have a dual character; in their upper courses they are degrading or cutting, in their lower reaches they are aggrading or building up. The point of change from one character to the other differs with the intensity of the floods.

One who observes the valley forms of any single drainage system in the region—such, for example, as Mangas Valley and its network of small tributaries—will at once note that most of the streams have two distinct parts, in which the valley form is different—namely, a part cut in hard rock and a part cut in semiconsolidated gravel. In the Mangas drainage system the main stream lies entirely in semiconsolidated material, but all the tributaries flow for some distance over hard rock in their headwater portions and lower in their courses pass on to semiconsolidated deposits. The difference in the valleys in the two portions of the stream is striking, yet most natural. The gravel deposits as they are to-day may be considered part of a dissected sloping plain whose surface was approximately smooth when dissection began. A drainage system developed upon such a surface and in relatively homogeneous material could produce, in the main, only very regular valley forms. On the other hand, the parts of the streams that are cut in hard rock have none of this regularity, their shaping depending upon many diverse factors. Considered as to valley forms the gravel areas may be readily grouped into two classes—those where active deepening of the valley is proceeding, and those where building up or aggradation is the dominant process.

The valleys in the first class are V-shaped and narrow, the gradients are relatively steep, and there is little or no filling in the valley floors. Valleys of this type are confined to the upper parts of the streams. The valleys of the second type are broad and shallow, there is a prominent flood plain, and at the mouths of streams alluvial fans are accumulating.

All transitions between the two types may be seen. The first may be very narrow and canyon-like, the second may be so shallow that it merges imperceptibly into the desert. Mangas Valley is an excellent example of an intermediate type. Its floor is a quarter mile to a half mile wide and into it from both sides tributaries empty their load of waste material, which accumulates in numberless perfect fans at the edge of the valley.

A process of trenching, begun during Recent time, consists in a headward cutting or trenching of the flat valley floors of all the streams in the gravel areas. In cross section this feature is illustrated in figure 4, and its appearance in nature may be seen in Plate XIII. The reasons for this marked feature will be discussed under the heading "Physiography" (pp. 12–13).

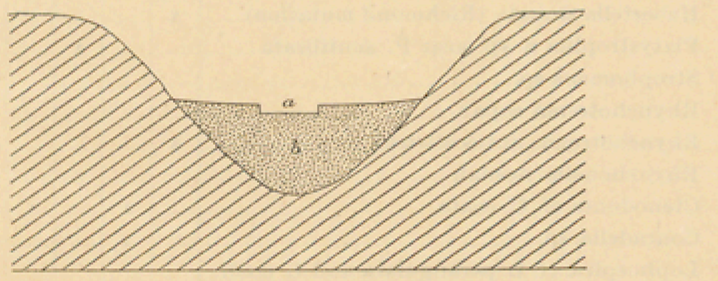

Figure 4.—Ideal section illustrating the relations of Recent stream trenching (*a*) to the valley fill (*b*) in an older valley cut in bedrock.

The gradient of Mangas Valley in the 4 miles of its headwater portion is 125 feet to the mile. In the next 11 miles it averages only 60 feet to the mile. Wind Canyon, a fairly typical larger tributary from the east, confined practically throughout its course to the gravel area, has a gradient of about 140 feet for the lower 6 miles of its course, but the gradient increases rapidly upstream.

The gradient of Bear Creek, in the northwest corner of the quadrangle, is 66 feet to the mile in the portion flowing over gravel, averaged over a distance of 10.5 miles. The gradient in the rock-cut portion immediately above the gravel is 96 feet to the mile, averaged over a distance of 5.2 miles.

In the mountains the gradients increase rapidly. Such tributaries to Bear Creek as Steamboat and Holman canyons have gradients of 600 to 800 feet to the mile in their upper parts. Enough has been said to indicate the important differences of stream type in the region. What has been said of Bear Creek and Mangas Valley would apply with modifications to the Mimbres drainage system and to the streams in the central part of the quadrangle. Much variety in detail is to be expected in an area where rock structures are very diverse.

CULTURE.

The town of Silver City, with a population of about 3,000, stands near the center of the quadrangle and is the terminus of the Deming and Silver City branch of the Atchison, Topeka & Santa Fe Railway, which extends to the main line and connects with the Southern Pacific Railroad at Deming, N. Mex., about 46 miles southeast. Within the quadrangle also are the towns of Leopold, Tyrone, Pinos Altos, Central, Fierro, Hanover, and Santa Rita. Fort Bayard, a military post to which is attached a large hospital for tubercular patients, is a mile north of the town of Central.

The Santa Rita branch and the Hanover branch of the Atchison, Topeka & Santa Fe Railway connect Santa Rita, Fierro, and Hanover with the Deming and Silver City branch at Whitewater, a junction point 5½ miles north of the southern border of the quadrangle. A branch of the El Paso & Southwestern road connects Tyrone with Deming. A narrow-gage railroad connects Pinos Altos with Silver City.

A stage line is run between Silver City and the Mogollon mining district farther north; there are stage lines between Silver City, Leopold, and Santa Rita, and all the principal towns are connected by wagon roads.

Mining is the industry of first importance. All the towns either are or have been mining centers. Silver City, as the railway terminus, has long been a supply point for surrounding mining districts.

Cattle raising is also an important industry, and despite the seasons of drought many head are shipped annually to more northern pastures.

Parts of the Gila National Forest lie within the quadrangle, and lumbering on a small scale is carried on within them.

DESCRIPTIVE GEOLOGY.

STRATIGRAPHY.

ROCK FORMATIONS.

The rocks of the Silver City quadrangle are in part of sedimentary and in part of igneous origin and range in age from pre-Cambrian to Recent. The sedimentary rocks fall into two general groups, one consisting of hard strata, of Paleozoic and Mesozoic age, and the other of unconsolidated or partly consolidated gravel and sand, of Cenozoic age, forming extensive bolsons or desert plains. The hard strata consist of quartzite, sandstone, shale, and limestone and comprise formations representing all the Paleozoic systems, though each is represented sparingly. No Triassic or Jurassic strata are known, but the Cretaceous system is represented by two formations, one certainly and the other possibly of Upper Cretaceous age. The unconsolidated deposits forming the bolsons are chiefly of Quaternary age, but the sand and gravel interbedded with the lava flows are of Tertiary age.

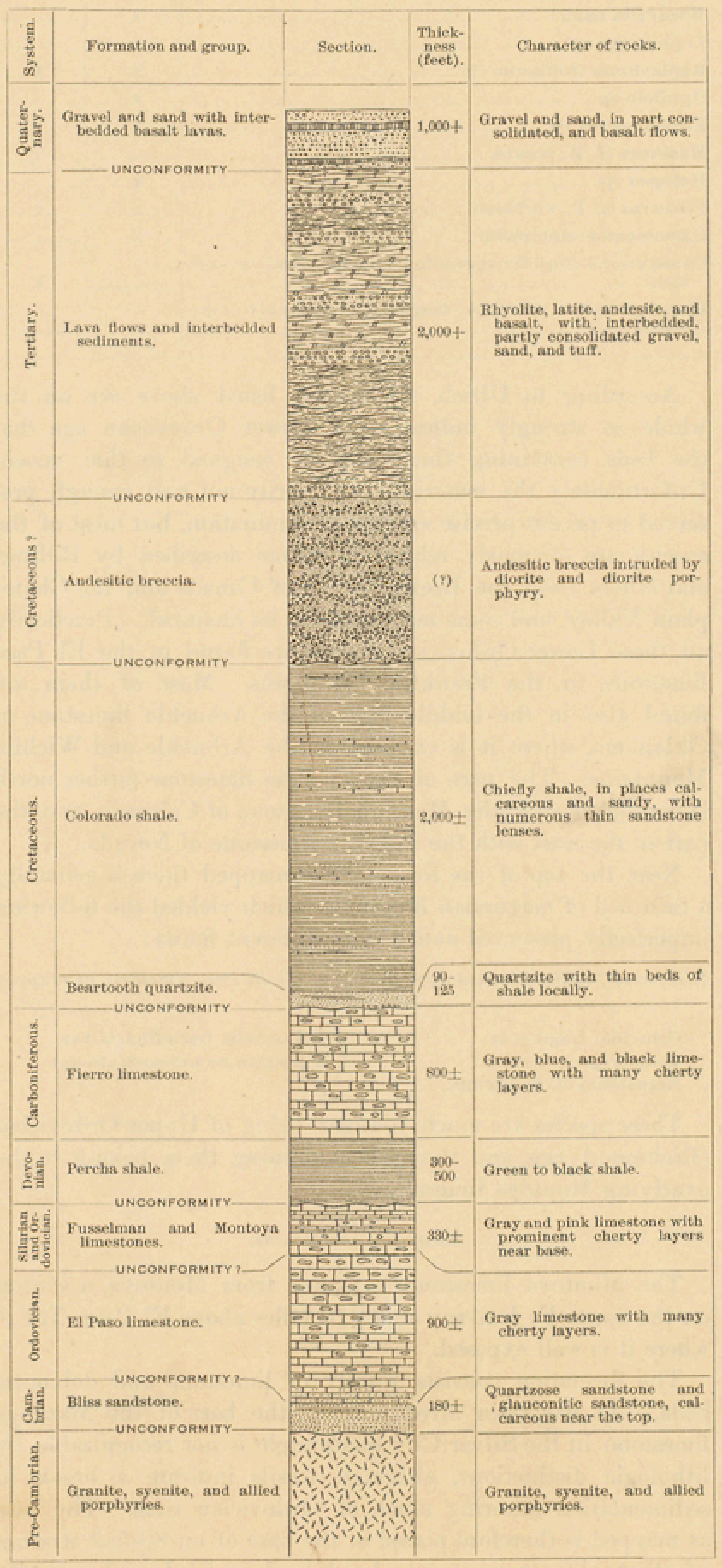

Figure 5.—Generalized columnar section of sedimentary rocks exposed in Silver City quadrangle.
Scale: 1 inch=1,000 feet.

The igneous rocks likewise fall into two general groups—one consisting of granite and associated rocks of pre-Cambrian age, and the other of a great series of intrusive and effusive rocks of Cretaceous (?), Tertiary, and Quaternary age. The intrusive rocks occur in stocks, dikes, and laccolith-like bodies and comprise granodiorite, quartz monzonite, quartz diorite porphyry, andesite porphyry, rhyolite, quartz latite, and similar rocks. The effusive rocks form an extensive series of flows and flow breccias and comprise rhyolite, latite, andesite, and basalt. Interbedded with them is tuff and detrital sand and gravel.

The general character, thickness, and order of succession of the stratified rocks is shown in figure 5.

PRE-CAMBRIAN ROCKS.

The pre-Cambrian rocks of the quadrangle comprise many granitoid varieties, some of which are gneissic, and minor ill-defined schistose and quartzitic masses, which are metamorphosed ancient sediments. The entire complex has been mapped as a unit. The pre-Cambrian rocks southeast of the Big Burro Mountains are cut by a great number of rhyolite dikes of later age, which are not mapped separately. North of the mountains are masses of granitoid rock, probably dioritic, which have been mapped with the granite.

Granite occupies a considerable area in the Big Burro Mountains and the western flanks of the Little Burro Mountains nearly to the crest line. Much of the western flank of the Silver City Range and the northern part of Treasure Mountain are also occupied by pre-Cambrian rocks.

The granite, which is typically exposed in the Big Burro Mountains, is a medium to fine grained gray biotite granite composed of dominant orthoclase with some albite, abundant quartz, and pleochroic brown biotite, with accessory apatite, titanite, and iron oxide. Coarse-grained and porphyritic varieties are also found. A specimen of coarse-grained granite from the Chemung mine contains orthoclase crystals an inch long in a groundmass of orthoclase, quartz, and chlorite, the chlorite being an alteration product of mica or hornblende. Magnetite and apatite are accessory minerals.

Intrusions of granitic magmas probably occurred at several periods during pre-Cambrian time, though certain coarse-grained granites may grade into fine-grained types, and it is possible that several stages of intrusion might be recognized and mapped.

CAMBRIAN SYSTEM.

BLISS SANDSTONE.

Definition.—The Bliss sandstone, with which the Cambrian sandstone of the Silver City quadrangle is correlated, was named from Fort Bliss, near the eastern base of the Franklin Mountains, in the El Paso quadrangle.[1] It rests unconformably on the pre-Cambrian complex. In the Silver City quadrangle the formation consists of quartzite, calcareous sandstone, and dominantly arenaceous limestone. The top of the formation is not everywhere well defined, as there is a transition zone between it and the overlying limestone. The separation has been made as nearly as possible at the horizon where the strata cease to be dominantly arenaceous, generally at the top of a thin quartzitic bed.

Character and thickness.—The character of the formation is shown by the sections given below. The base is generally a vitreous quartzite, overlain by fine-grained greenish sandstone, in many places slightly calcareous and in some places flaggy. The greenish sandstone differs in character from place to place; here it is a heavy cross-bedded quartzite, there it is a soft ferruginous sandstone. Glauconite is a conspicuous constituent of all the beds. The top of the formation is generally a thin quartzite or glauconitic sandstone, the beds above which are more calcareous and have a vermicular aspect on weathering.

The formation is probably not more than 180 feet thick and as it is a basal formation its thickness is not uniform.

Section of Bliss sandstone on west side of Silver City Range east of central portion of Treasure Mountain.

	Feet.
Sandstone, coarse, glauconitic	12
Limestone, sandy, with thin wavy bedding (fucoidal markings?)	47
Quartzite, rather coarse, massive, vitreous, slightly cross-bedded	17
Sandstone, calcareous, thin bedded, with wavy bedding (fucoidal markings?)	57
Quartzite, massive, cross-bedded, ferruginous and glauconitic, with some layers of quartzitic conglomerate	17
Sandstone, soft, glauconitic	13
Quartzite, massive, coarse, siliceous	15
	178

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[1] Richardson, G. B., U. S. Geol. Survey Geol. Atlas, El Paso folio (No. 166), 1909.

Section of Bliss sandstone on west side of Silver City Range at a point nearly east of southern end of Treasure Mountain.

	Feet.
Sandstone, calcareous, thin bedded (glauconitic sandstone layer at top)	40
Sandstone, massive, cross-bedded (somewhat calcareous in lower part)	50
Sandstone, glauconitic (not as much glauconite as below)	40
Sandstone, glauconitic, ferruginous, cross-bedded	20
Sandstone, coarse, quartzose	12
	162

Distribution.—The formation is not widely distributed. It is found along the western base of the Silver City Range, including its northwestern outliers—Treasure Mountain and the hills to the northwest. It also forms the western base of Lone Mountain and underlies several small areas in the much disturbed region between Sycamore Creek and Bear Creek.

Fossils, age, and correlation.—The only fossils collected from the Bliss formation were obtained in glauconitic sandstone that lies mostly near its base. They consist of abundant specimens of *Billingsella coloradoensis* and fragments of a Ptychoparia, as determined by E. O. Ulrich, who states that Billingsella is considered a characteristic Upper Cambrian fossil of the Mississippi Valley and that the beds are therefore of about the same age as the Cambrian quartzite and sandstone of the Franklin Mountains, in the El Paso quadrangle, the Hickory sandstone, the Cap Mountain formation, and the Wilberns formation of central Texas, the Reagan sandstone of Oklahoma, and possibly the Coronado quartzite of Clifton, Ariz.

The Bliss sandstone in the Franklin Mountains is, however, described as more dominantly arenaceous than the beds in the Silver City quadrangle, and the presence of glauconite (a prominent constituent at Silver City) is not mentioned in the description of the beds in the Franklin Mountains. Yet the natural variation to be expected in a basal formation would seem to warrant the use of the name.

ORDOVICIAN SYSTEM.

FORMATIONS DISCRIMINATED.

The Ordovician system is represented in the quadrangle by the El Paso limestone, of Lower Ordovician age, and the Montoya limestone, of Upper Ordovician age.

It was not possible to map the actual base of the Montoya limestone, as the basal beds of this formation are not readily distinguished from the upper beds of the underlying El Paso limestone, and the line as mapped is therefore drawn at a horizon about 40 feet above the base of the Montoya limestone, at the base of a persistent band of very cherty limestone about 80 feet thick, and may be easily recognized in the field. The El Paso limestone as mapped therefore includes a small part of the Montoya limestone.

EL PASO LIMESTONE.

Definition.—The El Paso limestone was named from El Paso, Tex.,[1] near which, in the Franklin Mountains, it is typically exposed. With this formation the Lower Ordovician limestone in the Silver City quadrangle is correlated.

In the Silver City quadrangle the formation is composed of limestone and a few dolomitic beds and overlies the Bliss sandstone with apparent conformity, though the fossils found indicate a considerable hiatus. Its base is at the top of a quartzitic layer that generally forms the top of the Bliss sandstone. Where the quartzitic layer is poorly developed the base is placed at the lowest horizon at which the beds are dominantly calcareous, so as to include no sandstone in the formation. The character of the beds indicates that sedimentation was continuous throughout the period of the deposition of the Bliss sandstone and the El Paso limestone, but the fossils indicate a time break. The fossils also indicate an important time break between the El Paso limestone and the overlying Montoya limestone, but no sufficient lithologic difference affords a basis for discrimination in the field. Therefore the top of the formation as mapped is placed at the base of a bed of cherty limestone, about 80 feet thick, in the Montoya, which can be everywhere easily recognized.

Character and thickness.—The formation is dominantly a gray or grayish-blue limestone, in part magnesian. The lowermost 100 feet becomes progressively less sandy from the base up. Fucoidal markings give an effect of irregular mottling, and as the formation grows more massive upward chert becomes a more prominent constituent.

The formation probably does not exceed 900 feet in thickness. Two sections, one including the entire thickness of the formation and the other nearly all of it, follow:

Section of El Paso limestone on west side of Lone Mountain.

	Feet.
Limestone	28
Limestone, very sandy, might be called calcareous sandstone; fucoidal markings, fossils	10
El Paso limestone:	
Limestone, massive, blue, cherty, containing a little sand throughout; thin bands of chert in lower part, chert more abundant higher up; fossils 65 feet above base	96
Limestone, grayish blue, gradually more massive upward	154
Limestone, blue, massive, containing a little white chert and in the lower portion sandy streaks; fossils 85 feet above base	119
Limestone, sandy, mottled with impurities which weather out in irregular narrow bands of fucoidal aspect	134

Section of El Paso limestone on west flank of 7,515-foot peak 1½ miles west-northwest of Silver City.

	Feet.
Limestone, light gray, impure, massive; fossils	59
El Paso limestone:	
Limestone, light blue to gray, mottled, impure, with massive gray cliff at top; fossils	291
Limestone, light blue, impure, mottled, fucoidal	66
Limestone, gray and light blue, sandy	70
Limestone, massive, sandy, with fucoidal markings on outcropping edges	31
Interval occupied by a dike	123
Limestone, sandy	84

Distribution.—The formation has nearly the same distribution as the Bliss sandstone. It outcrops on Lone Mountain, in the Silver City Range and its outliers, and in the country adjacent to Bear Creek north of Bear Mountain. Several square miles east of Juniper Hill and south of Bear Creek are underlain by the formation and a little of it is exposed beneath the Silurian strata at the extreme eastern edge of the quadrangle.

Fossils, age, and correlation.—The following species of fossils, identified by Ulrich and Kirk, have been collected from the El Paso limestone:

Fossils from El Paso limestone.

	Section northwest of Silver City.	Section at Lone Mountain.
Calathium anstedi		x
Dalmanella cf. D. wempeli	x	
Huenella (?) sp. (externally much like *Clarkella montanensis* and *Syntrophia rotundata*, two Upper Cambrian species)	x	x
Protowarthia cf. P. rossi	x	
Bucanella nana?	x	
Lophospira sp	x	
Raphistoma trohiscum (?)	x	x
Ophileta sp	x	
Eccyliopterus sp	x	x
Maclurea cf. M. oceana		x
Holopea sp	x	
Piloceras cf. P. wortheni	x	x
Cameroceras (siphuncle)	x	
Cameroceras (rapidly spreading and elliptical in section)		x
Unrecognizable trilobite fragments, probably two species	x	

According to Ulrich the species listed above are on the whole so strongly indicative of Lower Ordovician age that the beds containing them may be assigned to that epoch. Unfortunately the material is ordinarily not well enough preserved to permit precise specific determination, but most of the species are obviously related to forms described by Billings and others from the Beekmantown of Canada and the Champlain Valley, and some may prove to be identical. Practically all these Lower Ordovician species are found in the El Paso limestone in the Franklin Mountains. Most of them are found also in the middle part of the Arbuckle limestone of Oklahoma, where it is exposed in the Arbuckle and Wichita Mountains. The part of the El Paso limestone farther north is correlated with the Manitou limestone of Colorado, and the part to the west with the Pogonip limestone of Nevada.

Near the top of the formation as mapped there is generally a thin bed of magnesian limestone, which yielded the following imperfectly preserved and wholly different fauna:

Richmond fossils obtained near the top of the El Paso limestone as mapped in this folio.

Crinoidal fragments.
Eridotrypa mutabilis?
Batostoma cf. B. varium.
Dalmanella testudinaria var.
Zygospira recurvisostrata var.

These species are much younger, being of Upper Ordovician (Richmond) age, and the beds containing them belong to the overlying Montoya limestone.

MONTOYA LIMESTONE.

The Montoya limestone is named from Montoya, a station on the Santa Fe Railway about 10 miles above El Paso, Tex.,[2] where it is well exposed.

The formation consists wholly of limestone and dolomitic beds. As has been already noted, the base of the Montoya limestone in the Silver City quadrangle is not recognizable by lithologic distinctions, although fossils indicate a break in sedimentation covering much of Ordovician time. The base as mapped is therefore placed at the base of an 80-foot stratum of cherty limestone in which pink chert is characteristically arranged in thin, closely spaced parallel layers. This horizon is about 40 feet above the point where fossils indicate the unconformity and where the base of the formation properly belongs. Similarly, the top of the formation consists of limestone resembling so closely the beds of the overlying Fusselman limestone that the unconformity between the Montoya and Fusselman, indicated by fossils, has not been recognized. This formation is therefore mapped with the Fusselman limestone, whose top lies at the base of the Percha shale.

Character and thickness.—The lowermost 60 to 80 feet of the formation, as mapped almost everywhere, consists of pink chert-banded limestone, which may be readily recognized in the field and which is useful in working out faulted structure. Above it are alternate thin beds of smooth whitish limestone and massive blue beds. Fossils are abundant, especially in two layers that lie 60 and 300 feet, respectively, above the base. Other fossiliferous horizons are near the base. Cherty layers are scattered through the formation.

The highest Richmond fossils indicate that the formation is at least 300 feet thick. Measurements of 330 feet of strata have been made, including beds of the Fusselman limestone.

The following incomplete section affords a fair idea of the character of the formation:

Partial section of the Montoya limestone on west side of Lone Mountain.

	Feet.
Limestone, massive, blue, weathers irregularly, contains corals	62
Limestone, white	54
Limestone, massive, blue	7
Limestone, light colored, moderately thin bedded, smooth, with few if any fossils	56
Limestone, white, fossiliferous	36
Limestone, cherty, some fossils	85

Distribution.—The Montoya limestone is largely confined to the eastern slope of the mountain ranges that are made up of sedimentary rock. It descends in a broad sheet from the summit of Lone Mountain to its eastern base, where it dips beneath the Devonian shale. In the Silver City Range, at Treasure Mountain, and in the hills on the northwest it occupies a similar characteristic position. Near Bear Creek, on the other hand, in the intensely faulted region east of Walnut Creek, its position is not so regular, and south of Georgetown also its position is reversed; it dips westward into the mountain.

Fossils, age, and correlation.—The following species of fossils, determined by E. O. Ulrich, were collected from the formation:

Fossils of the Montoya limestone.

	A	B	C	D	E	F	G
Streptelasma						x	
Columnaria alveolata var.						x	
Columnaria vicina			x				
Tetradium sp. nov. (occurring in small fascicles)		x					
Favosites asper Lambe (part)		x				x	
Favosites cf. F. asper (has larger corallites and marginal depressions in tabulæ)		x		x			
Stromatocerium huronense		x					
Dicranopora cf. D. fragilis		x					
Plectorthis kankakeensis						x	
Dalmanella tersa (?)	x						
Dinorthis sp. (coarsely plicated form)			x				
Dinorthis subquadrata					x		
Hebertella sinuata (Richmond mutation)	x		x		x	x	x
Platystrophia n. sp. near P. acutilirata			x			x	x
Strophomena sp.					x		
Rhynchotrema capax					x		
Rhynchotrema anticostiensis	x				x	x	
Rhynchonella neenah			x			x	x
Ctenodonta cf. C. coata		x					
Conradella sp.		x					
Lophospira. cf. L. perangulata and L. medialis		x					

A. Lone Mountain section, just above the basal chert of the Montoya limestone.

B. Near top of ridge that stands S. 85° W. from point where Silver City road crosses Silver City, Pinos Altos & Mogollon Railroad west of Silver City.

C. A little higher on the hill and lower in the section than B.

D. Northeast slope of the northern part of Lone Mountain, about 100 feet below top.

E. Near base of Montoya limestone, about 1 mile west of Stewart Peak.

F. Montoya limestone, about 2 miles west-northwest of Silver City.

G. Just above the basal chert beds of the formation, in the SE. ¼ SW. ¼ sec. 32, T. 17 S., R. 14 W.

According to Ulrich, the presence of the characteristic Silurian species *Favosites asper* strongly suggests the post-Ordovician age of the beds that contain it. Nearly every one of the other species of the list, however, are fossils that are common in the upper part of the Richmond of the Mississippi Valley. Nearly half of them are found also in the lower division of the Medina in Ontario. It is therefore Richmond fauna and the rocks are assigned to the Ordovician system.

The Montoya limestone is to be correlated with the greater part of the Lone Mountain limestone in Nevada, most of the Fremont limestone of Colorado, and at least the upper portion of the Bighorn dolomite of Wyoming.

The Richmond fauna has been found as far north as Alaska.

SILURIAN SYSTEM.

FUSSELMAN LIMESTONE.

The Silurian system is represented in this area by the Fusselman limestone, which, for reasons already given, is mapped with the underlying Montoya limestone.

Definition.—The Fusselman limestone is named from Fusselman Canyon, in the Franklin Mountains near El Paso, Tex.,

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[1] Richardson, G. B., U. S. Geol. Survey Geol. Atlas, El Paso folio (No. 166), 1909.

[2] Richardson, G. B., idem.

where it is typically developed. As already explained, the base of the Fusselman limestone has not been recognized in the Silver City quadrangle. The top lies at the base of the Percha shale.

Character and thickness.—The formation consists of gray limestone and dolomite beds whose thickness probably does not exceed 30 or 40 feet. At places abundant fossils are found just beneath the Percha shale.

Fossils and correlation. — But a single species has been found in this formation in the Silver City quadrangle, and that has been identified by Ulrich as Pentamerus sp. This species has been collected at many places in the Far West from formations distributed over an area lying between New Mexico and western Texas on the south and northern Utah on the north. It has also been found near Fairbanks, Alaska. As the species is unknown in standardized sections its exact stratigraphic significance is uncertain. There is, however, no reason to doubt the Silurian age of the formation, the fossils found in it in the El Paso quadrangle being Niagaran species.

The formation may be correlated with the Laketown dolomite of northeastern Utah.

DEVONIAN SYSTEM.

PERCHA SHALE.

Character and limits.—Rocks of Devonian age are represented in the Silver City quadrangle by dark gray to black shales known as the Percha shale.

The Percha shale was named by C. H. Gordon[1] from Percha Creek, Sierra County, N. Mex., where it consists of dark-blue to black shales and rests on older rocks which Gordon calls the Mimbres limestone. In the Silver City quadrangle the Percha shale rests unconformably on the Fusselman limestone. The top of the formation is calcareous and merges into the Carboniferous limestone.

The Percha shale is soft and has a maximum thickness in the quadrangle of 500 feet, though it is in places much thinner.

Distribution.—At Lone Mountain and in the Silver City Range the formation occupies well-defined valleys between the resistant Fusselman limestone on the west and the bold scarp of the basal Carboniferous strata on the east. At Bear Mountain, however, it forms no such valley but lies west of the summit and forms part of the western slope. In the mountains west of Bear Mountain it lies on the western side of the hills. In the vicinity of Georgetown, at the eastern edge of the quadrangle, it passes beneath the Carboniferous beds, without giving rise to a stream valley along the strike. At all these localities the formation is a marked topographic feature and may be recognized from a considerable distance by the characteristic break on the slope of the mountain, the resistant Carboniferous beds above it everywhere standing out as a surmounting ledge or capping, beneath which the shale slopes away at a gentler angle.

The formation is exposed also in the fault zone near the junction of Little Walnut and Walnut creeks and on the east and west sides of the diorite mass between Fierro and Hanover.

Fossils, age, and correlation.—The following species of fossils, collected from the upper part of the formation, have been identified by E. M. Kindle. They are of late Devonian age.

Zaphrentis sp.
Cystiphyllum sp.
Fenestella sp.
Schizophoria striatula var. australis.
Productella coloradensis.
Productella spinigera.
Productella laminatus.
Camarotœchia contracta?
Camarotœchia endlichi.
Pugnax pugnus.
Spirifer notabilis.
Spirifer whitneyi.
Reticularia spinosa.
Athyris coloradensis.
Aviculopecten n. sp.
Bellerophon sp.
Euomphalus eurekensis?

The above species are found also in the lower or Devonian part of the Ouray limestone of southwestern Colorado.

The Devonian of New Mexico extends from the Mimbres Mountains westward to the Arizona line. In the Mimbres range its upper part contains a rich and characteristic Devonian fauna. The Devonian does not occur in the Franklin Mountains of Texas but is 200 feet thick at Clifton, Ariz.

CARBONIFEROUS SYSTEM.

FIERRO LIMESTONE.

Definition.—The Fierro limestone is named from the town of Fierro, in the northeastern part of the quadrangle. It consists of gray to blue fossiliferous limestone and includes beds of both Mississippian and Pennsylvanian age, as is shown by the fossils. The presence of the two faunas suggests an unconformity between the lower and the upper part of the formation, but even in well-exposed sections no separation can be made by lithologic differences.

The formation overlies the Percha shale in apparent conformity and is unconformably overlain by strata of Cretaceous age. Because of its lithologic differences from the underlying and the overlying beds it is generally easily recognized.

Character and thickness. — The formation comprises beds ranging in color from light gray to dark blue or purplish. West of Silver City the upper half of the section is chiefly light gray or light blue and the lower half, except where the beds are whitened, probably by intrusions, is darker blue. Except in the lower 100 feet the beds are characteristically cherty, containing either white or black chert, and even near the base of the formation the beds contain some red chert. The rock is for the most part massive, though it contains thin, more or less shaly beds. Crinoidal limestone is abundant in the upper half of the formation.

The thickness of the formation necessarily varies, for there is a known erosional unconformity at the top and probably an unrecognized one between the Pennsylvanian and Mississippian beds. A section 751 feet thick was measured. The maximum thickness of the beds in this region is about 800 feet.

The following section shows in detail the lithologic character of the formation:

Section of Fierro limestone in gulch west of Silver City.

	Feet.
Limestone, light gray, with much irregular chert	20
Limestone, dark reddish, cherty, marbled, and earthy	20
Limestone, light gray to pinkish	20
Limestone, mottled, earthy, with brownish vermicular chert, Pennsylvanian fossils at base	10
Interval occupied by a dike	13
Limestone, light, fine mottled	16
Concealed interval (fault?)	150
Limestone, light bluish, crinoidal, with chert	30
Limestone, light bluish, crinoidal, with much white chert at top	20
Limestone, light bluish, crinoidal, with some white and black chert	20
Limestone, massive, gray	40
Limestone, massive, light gray, crinoidal, with some white chert	20
Limestone, dark purplish, thin bedded below, becoming massive above	10
Limestone, thin bedded, with chert bands interbedded with calcareous shale	20
Limestone, fine grained, dark, and chert	20
Limestone, fine grained, dark, massive, and chert	40
Limestone, fine grained, dark, and chert	10
Limestone, dark, and thin chert	20
Limestone and much chert	10
Limestone and chert, shaly partings	10
Limestone, dark, and chert, in thin alternate beds	20
Limestone, dark blue, fine grained, with considerable chert	10
Limestone, dark blue, fine grained, with little chert	20
Limestone, dark blue, fine grained, with chert bands	20
Limestone, massive, dark, very cherty	20
Limestone, massive, light, with black chert	10
Limestone, fine grained, blue, with much dark chert	10
Limestone, massive, crinoidal, with considerable red chert (all beds below here are more or less bleached by metamorphism)	15
Limestone, thin bedded, earthy, with some dark chert layers	16
Limestone, massive	10
Limestone, thin bedded, shaly	10
Limestone, massive	15
Concealed	8
Limestone, rather massive, pinkish or mottled, whitish on outside	15
Limestone, massive, but inclined to weather shaly	15
Limestone, massive	13
Limestone, mottled, pinkish, more or less thin bedded and shaly	5
	751

Distribution.—The Fierro limestone is the most widely distributed of the Paleozoic formations. It is exposed at Lone Mountain and throughout the range northwest of Silver City, in areas east of Fort Bayard and north of Santa Rita, in a small area west of Gomez Peak, and on the western flank of Pinos Altos Mountain.

In the range near Silver City the formation is conspicuous, its base forming the crest of the eastern ridge and its beds occupying the eastern slope. North of Bear Mountain a considerable area is covered by the beds, which are involved in the complex structure in that vicinity. In the region east of Fort Bayard the strata occupy rolling upland broken by several hills of considerable size and abruptly terminated on the east along a scarp underlain by a northwestward-trending band of Devonian shale.

Fossils, age, and correlation.—The Fierro limestone contains an abundant fossil fauna. The following species, determined by G. H. Girty, have been collected:

Fossils of the Fierro limestone.

MISSISSIPPIAN SPECIES.

Lonsdaleia n. sp.
Zaphrentis sp.
Actinocrinus copei?
Dorycrinus lineatus.
Fenestella sp.
Pinnatopora sp.
Rhombopora sp.
Lioclema? sp.
Leptæna rhomboidalis.
Rhipidomella aff. R. oweni.
Productus mesialis?
Productus sp.
Spirifer aff. S. imbrex.
Reticularia cooperensis.
Athyris n. sp.
Conocardium sp.
Platyceras sp.
Proetus sp.

PENNSYLVANIAN SPECIES.

Triticites secalicus.
Campophyllum torquium?
Zaphrentis sp.
Chætetes milleporaceus.
Fenestella tenax.
Stenopora sp.
Meekopora? sp.
Prismopora triangulata.
Productus cora.
Productus semireticulatus.
Productus nebraskensis.
Spirifer cameratus.
Spirifer rockymontanus.
Squamularia perplexa.
Composita subtilita.
Cliothyridina orbicularis.

Mr. Girty says:

> These collections represent two widely different faunas, one of early Mississippian and the other of early Pennsylvanian age. These two faunas can readily be distinguished from each other when they are represented by adequate collections, but a few of the present collections contain only two or three doubtful or ambiguous species, and I am unable to state positively to which group they belong.
>
> As one would naturally expect, the Mississippian fauna is that of the Lake Valley limestone. The Lake Valley fauna is closely related to one found in Missouri at Fern Glen and at other points in this general region. The Pennsylvanian fauna, like many of the early Pennsylvanian faunas of the West, is very similar to the Pennsylvanian of the Mississippi Valley. The younger Pennsylvanian faunas of New Mexico and other western States present a considerably different facies, one more like the Carboniferous of Asia and the Ural Mountains.

In describing the distribution of the Carboniferous in New Mexico Lindgren, Graton, and Gordon[2] say:

> The Mississippian, or lower Carboniferous, has been recognized at several places south of latitude 34°. W. T. Lee found limestone of this age in the Ladrones Range, and Gordon believes, on the basis of evidence collected by C. L. Herrick, that the lower part of the section in the Magdalena Mountains belongs to this series. Characteristic Mississippian faunas were found by Gordon at Kingston and Hillsboro, and the horizon has for some time been known to be represented at Lake Valley, where a thickness of over 200 feet of limestone has been measured. Rocks of the same age are also present in the Silver City district. Gordon states that at Hillsboro these limestones rest upon the eroded surface of the Devonian calcareous shales, but farther west there is no evidence of unconformity.
>
> The Pennsylvanian, or upper Carboniferous, is deposited with a considerable thickness over the whole Territory and reaches its maximum in the country between Santa Fe and Las Vegas. As far south as the latitude of Socorro the Pennsylvanian consists in large part of sandstones and shales in repeated alternation with some limestone beds. But south of this line the pure limestones prevail and at the same time the total thickness appears to diminish. Everything indicates near-shore conditions in the northern part of the Territory, where some land areas probably existed even at that time.

The lower part of the Fierro limestone is of Mississippian age and is to be correlated with the Lake Valley limestone of the Deming quadrangle, adjoining the Silver City quadrangle to the southeast. The upper part of the Fierro limestone is of Pennsylvanian age and is the representative of the Magdalena group, to the east, in Sierra and Socorro counties, N. Mex., which does not outcrop in the Deming quadrangle, though found in the mountains immediately to the north.

CRETACEOUS SYSTEM.

BEARTOOTH QUARTZITE.

Definition.—The Beartooth quartzite is named from Beartooth Creek, near Fort Bayard. It consists of quartzite and a little interbedded shale. It lies unconformably on rocks ranging in age from pre-Cambrian to Pennsylvanian and is easily distinguished by the abrupt change in lithologic character. It is overlain in apparent conformity by the Colorado shale, from which also it is easily distinguished, the separation being made at the top of the uppermost quartzite bed.

Character and thickness.—The base of the formation at many places is a thin conglomerate containing black and white quartz pebbles an inch or more in diameter in a matrix of clearly washed, fine, glassy quartz grains. Kaolinized areas indicate the former presence of feldspar. The rock weathers brownish and reddish, and iron staining is rather prominent. At other places the basal beds consist of clean, clear, very small quartz grains set in a dull white matrix, at least in part calcareous. Variegated tones of white and pink are prominent. Microscopic examination shows that the rock is cemented by secondary silicification, many of the grains having grown perfect crystal faces, but in places the cement is apparently entirely clayey. Here and there the quartzite is beautifully banded by weathering in circular and subcircular patterns. A thin shale of irregular thickness is at some places intercalated near the top of the formation.

The formation ranges in thickness from 90 to 125 feet.

Distribution.—The formation is resistant to erosion and therefore tends to form isolated outliers and to occupy elevated positions. Its consequent preservation in areas where the stratigraphy is doubtful gives it a peculiar value as an aid in deciphering the somewhat complicated structure of much of the region.

In the Little Burro Mountains it forms a thin sheet on the pre-Cambrian granite, making a sharp comb at the crest of the main ridge. Northwest of Treasure Mountain and north of Bear Mountain it forms the crests of several minor ridges. East and northeast of Fort Bayard it marks the nose of a pitching anticline and forms the crest and outer slope of an almost semicircular ridge. It caps the highest hill just north of Santa Rita and west of that place forms the crest and slopes of several prominent ridges. It is also exposed at several places near Lone Mountain, on the west flanks of Pinos Altos Mountain, and west of Gomez Peak on the flanks of a structural dome along the east front of the range near Silver City, and it caps a ridge near the western border of the quadrangle.

Age and correlation.—No fossils have been found in the formation. It is similar in many respects to the Dakota sandstone, but Darton has obtained fossils belonging to the Washita

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[1] Jour. Geology, vol. 15, p. 92, 1907.

[2] The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, p. 31, 1910.

group of the Comanche (Lower Cretaceous) series from a basal Cretaceous sandstone in the Deming quadrangle immediately southeast of the Silver City area. For the present, therefore, the age of the Beartooth quartzite remains in doubt, but it is tentatively regarded as Upper Cretaceous.

COLORADO SHALE.

Definition.—The Colorado shale was named after the State of Colorado, where rocks of this age are characteristically developed. In the Silver City quadrangle the base of the Colorado shale is marked by the top of the Beartooth quartzite, a horizon easily recognized, for the quartzite is a highly resistant stratum. The top of the shale is a surface of erosion, and the full sequence of beds is therefore never present in this region.

Character and thickness.—In the Silver City quadrangle the formation consists of drab, olive-green, yellow, and brown calcareous and sandy shales, including numerous though not thick lentils of sandstone. Near the base it contains many symmetric concretions more than 2 feet in diameter. The formation is cut by an intricate network of dikes, which are too small to be shown on the map.

The great amount of intrusion which the shale has undergone, combined with the softness of the beds and their general distribution in basin-like form, has effectually prevented continued exposure and therefore measurement of their thickness. Probably the maximum thickness of the formation in the quadrangle is not less than 2,000 feet.

The following section, including the Beartooth quartzite, was measured:

Section of Colorado shale and Beartooth quartzite in a small canyon about a mile north-northwest of Silver City.

	Feet.
Colorado shale:	
Sandstone, pink and white, composed of cleanly washed grains	10
Shale, lower half sandy	48
Shale, sandy, some large concretions 2 feet in diameter near the top	22
Shale, pink and light brown	56
Shale	12
Shale, sandy	32
Shale, soft, disintegrated, pink and yellowish	21
Shale, soft, one layer with concretions	14
Shale containing a few hard calcareous layers 8 inches to 1 foot thick; the 2½-foot layer at top contains large concretions	42
Shale, hard, calcareous layer 1 foot thick at top with some concretions	27
Shale, light brown, fissile, weathers pink	36
Shale, poorly bedded, light brown	20
Shale, poorly bedded, white and brown, calcareous, some layers containing fine sand	47
Shale, calcareous, massive in upper 10 feet	34
Shale, thin bedded, brown and pink, calcareous, with lenticular concretions	30
Shale, calcareous, with closely spaced bedding planes 1 inch to 4 inches apart, in upper portion 6 to 8 inches apart	26
Shale, thin bedded, pink and brown, calcareous	21
Beartooth quartzite:	
Quartzite, 7 inches of shale at base, followed by 1½ feet of quartzite, then 5 feet of slightly argillaceous quartzite at top	20
Quartzite, lower 20 feet contains some shale	45
Quartzite, gray, fine grained, well bedded, hematite in films at top	20
Quartzite (?), concealed in part, siliceous conglomerate at base	48

Distribution.—The largest area of the formation in the quadrangle lies between the range near Silver City, with its northwestern outliers on the west, and a line passing roughly northeast through Fort Bayard on the east. Small areas are occupied by it in the Little Burro Mountains, at Lone Mountain, in a small area 2 miles east of Central, and in areas both east and west of Santa Rita. The formation is soft and breaks down easily, in consequence of which it forms no salient features of the topography.

In the region of its greatest development northeast of Silver City it is cut by countless dikes that form a network of low ridges separated by shale valleys which give diversity to what otherwise would be a decidedly featureless landscape.

Fossils, age, and correlation.—The following invertebrate fossils were collected from the shale at horizons about 100 feet and 300 feet above its base and have been identified by T. W. Stanton:

Fossils of the Colorado shale.

	A	B	C
Ostrea sp.		x	x
Gryphæa newberryi Stanton	x		
Trigonarca obliqua Meek		x	
Cardium pauperculum Meek?		x	x
Tapes? sp			x
Corbula sp		x	x
Gyrodes depressa Meek?		x	x
Pugnellus fusiformis (Meek)?		x	x

A. Four miles north-northwest of Silver City, on east fork of Silver Creek near road.

B. Four miles northwest of Silver City about 300 feet above the Beartooth quartzite.

C. About a mile north of the west summit of Lone Mountain 100 feet above the Beartooth quartzite.

The fossils obtained in the Colorado shale in the Silver City quadrangle indicate that it is a portion of the lower part of the Upper Cretaceous, the equivalent of the Benton shale of the Colorado group. Concerning the beds higher in the section, that is, above the horizons at which the fossils were found it may be said that they answer well to Cross's description of the upper part of the Mancos shale, and they may include some strata of Montana age.

TERTIARY SYSTEM.

GRAVEL, SAND, AND TUFF.

Gravel and sand, regarded as of Tertiary age, in places underlie and in places are interbedded with the rhyolite and andesite lavas. These accumulations are made up of ill-sorted sands and gravels and volcanic tuffs. Where they form the base of the Tertiary system they consist of fragments of the underlying intrusive and sedimentary rocks—porphyries, quartzites, and other rocks—but where they are interbedded with the lavas they are composed largely or wholly of volcanic material.

The beds at the base of the series have been deposited on an irregular erosion surface.

The distribution of the gravels is in a measure coextensive with the lavas. They are found in the Little Burro Mountains, in the country northwest and northeast of Silver City, and in the Santa Rita Range. As they form wedgelike sheets in the lavas their outcrops are not continuous but commonly disappear within short distances. Where the lavas above them have been removed by erosion they cover considerable areas, in places several square miles. In the mountains northeast of Silver City their outcrop is at many places terminated by faults.

These gravels accumulated during periods of volcanic quiescence and show clearly the interruptions of volcanic extrusion.

QUATERNARY SYSTEM.

GRAVEL AND SAND.

Distribution.—Deposits of more or less consolidated gravel and sand cover large areas in the quadrangle, in all about 460 square miles. Thin flows of basalt, which have not been separately mapped, are interbedded with the Pleistocene deposits.

The gravel covers much of the southern half of the quadrangle and extends northward in a tapering band across the Continental Divide and down the Mangas Valley. It also occupies large areas in the northeast and southwest corners of the quadrangle and in the basin of Bear Creek, in the northwest corner. Recent gravel is included with the Pleistocene gravel in mapping.

Character.—The material of the deposits is derived from the neighboring mountains and consists of fragments of lava or of pre-Cambrian igneous rocks or younger sediments, its character depending upon the kind of rock that is exposed in the neighboring uplands. The fragments range in size from fine dust to blocks several feet in diameter. In some places large bowlders form a part of the deposits. Most of the fragments are subangular, as would be expected in view of the proximity of their source and the mechanical nature of the rock disintegration by which erosion was aided in Pleistocene time, as it is at present.

Near Gattons Park, where the gravel is well consolidated, at one locality the pinkish matrix consists of comminuted fragments of quartz and feldspar and contains large angular fragments of the andesite-basalt series. In the southwest corner of the quadrangle the matrix is coarser. A description of individual specimens, however, can have but very local application, for the débris was deposited rapidly from areas that contributed abundant supplies, and the deposits formed were various; indeed, they are characterized by lack of homogeneity. The bedding, though discernible, lacks the continuity that is generally characteristic of sediments deposited in bodies of water but illustrates admirably the features that mark rapid continental deposition. In this connection reference may be made to an instructive paper by A. C. Trowbridge[1] describing many of the characteristics of piedmont gravel deposits.

Calcite, silica, and iron oxide, each—or a combination of each—in differing proportions, are the cementing materials which in places bind together the otherwise loosely collected fragments and make of them a resistant conglomerate.

Relation to underlying surface.—The contact of the gravel about the Big Burro Mountains is apparently a normal depositional contact. That the gravel formerly covered parts of the foothill region that are now bare and that it has been carried outward to its present position during a period of recent dissection seem certain. How much of the Big Burro Mountains was covered is indeterminable, but a well-defined rock bench that occupies at least much of the north and east sides of the Big Burro Mountains is plainly visible from any high point on the Little Burro Mountains. Probably gravel once covered the bench, but presumably the main mountain core was never covered and in fact was the source during Pleistocene time of much of the gravel that now surrounds the mountains.

In the Little Burro Mountains the conditions are somewhat different. The gravel contact along their east side is normal and follows the crest of the eastern ridge of the mountains, but for much of its length the contact on the west side is along a fault and lies at the base of a more or less precipitous mountain scarp.

Isolated patches of gravel lie here and there along the eastern base of the range near Silver City. The western boundary of the easternmost patch follows closely the strike of the Beartooth quartzite, remaining, however, a fairly uniform distance east of it. A mile or so farther north the contact of the gravel is immediately against the quartzite and follows it northward for a mile or more. Along this entire mountain front the contact appears to be along a fault at the top of or in the quartzite. It therefore seems probable that the present position of the gravel contact has been determined partly by the fault movement, which, by uplift on the west has so rejuvenated erosion that the gravel has been pushed eastward to its present position at the edge of the mountains. It is not possible to account otherwise for this extreme regularity of boundary. (See fig. 6.) The inference seems sound, therefore, that the gravel formerly covered more of the range than it does now. An examination of the boundary on the western side of the range south of Treasure Mountain leads to the same inference. A strong fault passing east of Treasure Mountain trends southeastward and is obscured by the gravel, but there is strong structural evidence that it is near the present edge of the gravel sheet—that is, that it passes through a point about a mile southwest of Silver City, as shown in figure 6, and has been an element in determining the gravel contact, for the eastern side of the fault is the uplifted block. The gravel therefore probably once extended farther east than the present contact.

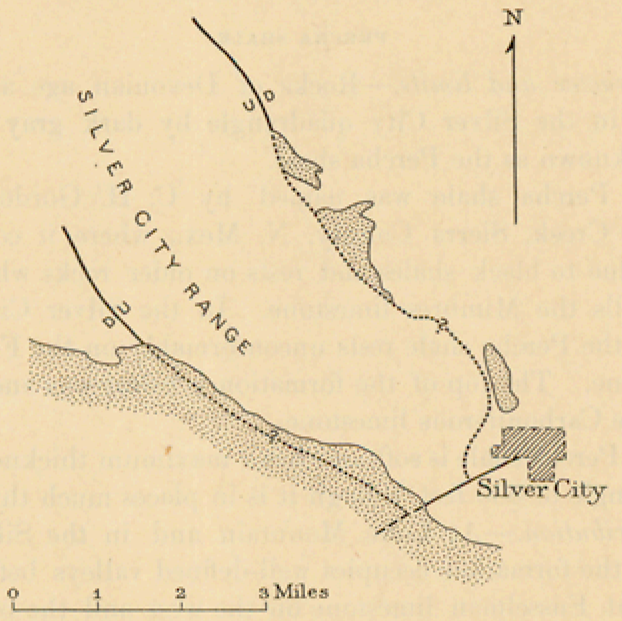

FIGURE 6.—Map of the Pleistocene gravels (dotted areas) adjacent to the Silver City Range, showing their relations to the probable fault lines at the foot of the range.

D, Downthrown side of faults; U, upthrown side. Faulting is believed to have recurred since the deposition of the gravels and to have influenced their present distribution.

Along the western contact, from Greenwood Canyon southward, the gravel lies against abrupt mountain sides. All drainage from the mountains to the gravel plain passes suddenly from a sharp rock-cut canyon to the less severely dissected gravel plain. Rejuvenation of erosion by faulting is the readiest explanation of this phenomenon, especially as the contact on the eastern side of the range, the side not so vitally affected by the uplift or tilt, is quite the opposite and a good example of an undisturbed depositional contact. It seems reasonable, therefore, to infer that the entire highland that extends northwestward from Silver City was at one time more nearly covered by gravel than at present.

An instructive line of contact is found on the eastern and northern side of Walnut Creek, in the northwest corner of the quadrangle. The southern 5 miles or so of this contact runs northward along a well-defined fault line. Turning northwestward at the northern end of this contact the line is still straight, suggesting a fault, but at Steamboat Canyon there begins a boundary line that is obviously depositional. Either the fault has died out or erosion has not yet brought the fault line to light. However, the manner in which the boundary runs upstream on to the ridge and downstream into the valley is significant, proving that the floor of deposition is a sloping plain.

A sufficient number of contacts have been described to afford a basis for some simple generalizations—first, that the gravel formerly covered a greater area than at present, and, second, that all the mountain groups in the area were once much more prominent features than at present and that as erosion proceeded the débris derived from their masses encroached upon the mountains, occupying gently sloping rock-cut surfaces.

Age and correlation.—Gilbert in 1873, while studying the region drained by the upper Gila and its tributaries, gave the name Gila conglomerate to certain valley deposits which he described as follows in the reports of the Wheeler Survey:[2]

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[1] Trowbridge, A. C., The terrestrial deposits of Owens Valley, California: Jour. Geology, vol. 19, No. 8, p. 706, 1911.

[2] Rept. U. S. Geol. Surveys W. 100th Mer., vol. 3, p. 540, 1875.

The bowlders of the conglomerate are of local origin, and their derivation from particular mountain flanks is often indicated by the slopes of the beds. Its cement is calcareous. Interbedded with it are layers of slightly coherent sand and of trass and sheets of basalt; the latter, in some cliffs, predominating over the conglomerate. One thousand feet of the beds are frequently exposed, and the maximum exposure on the Prieto is probably 1,500 feet. They have been seen at so many points, by Mr. Howell and myself, that their distribution can be given in general terms. Beginning at the mouth of the Bonito, below which point their distinctive characters are lost, they follow the Gila for more than 100 miles toward its source, being last seen a little above the mouth of the Gilita. On the San Francisco they extend 80 miles; on the Prieto, 10; and on the Bonito, 15. Where the Gila intersects the troughs of the Basin Range system, as it does north of Ralston, the conglomerate is continuous with the gravels which occupy the troughs and floor the desert plains. Below the Bonito it merges insensibly with the detritus of Pueblo Viejo Desert. It is, indeed, one of the "Quaternary gravels" of the desert interior, and is distinguished from its family only by the fact that the watercourses which cross it are sinking themselves into it and destroying it, instead of adding to its depth.

The Pleistocene deposits in the Silver City quadrangle correspond in all important features to the Gila conglomerate. Gilbert, followed by Ransome, assigned an early Quaternary age to the Gila conglomerate. Fossil bones are reported from the gravels south of Santa Rita, but none were seen by the writer. There is no reason, therefore, to assign to the beds an age other than that already suggested.

IGNEOUS ROCKS.

GROUPS DISCRIMINATED.

At least six groups of igneous rocks younger than the Colorado shale have been recognized. Named in order of age, beginning with the oldest, they are as follows:

1. A great complex of dikes of generally dark-colored porphyritic rock of dioritic and andesitic facies, with which are associated volcanic breccias and lavas of similar type.
2. Laccoliths and stocks of quartz diorite porphyry.
3. Masses of granitic, monzonitic, and dioritic rocks with associated porphyritic facies and accompanying dikes. Groups 1, 2, and 3, are probably of late Cretaceous age.
4. Great flows of basaltic, andesitic, rhyolitic, and latitic lavas, with which are interbedded tuffs, breccias, sand, and gravel, in all aggregating several thousand feet in thickness.
5. Stocklike masses of fine-grained rhyolite and quartz latite porphyry, breaking through all the older rocks and through the lava flows just mentioned. Groups 4 and 5 are Tertiary.
6. Intrusive basaltic masses and basaltic lava flows interbedded with the Quaternary gravel.

The several types will be described in the order in which they are named above.

PROBABLY LATE CRETACEOUS ROCKS.

DIORITE-ANDESITE.

Distribution.—The rocks of the diorite-andesite group, comprising also volcanic breccias and perhaps some lava flows, occupy about 30 square miles north and northeast of Silver City and are exposed also at places in the Little Burro Mountains and in a small area a mile southeast of Central. Hundreds of dikes of the same sort form a veritable network cutting the Colorado shale, but it is not practicable to show them on the map.

Rocks belonging to this group form the crest of Pinos Altos Mountain and of the line of high hills extending southward from Cross Mountain and underlie the undulating plain south and east of the hills. They are not, therefore, characterized by any particular topographic form.

Relations.—The rocks of the group really form a complex of five or six varieties of dark-colored breccias, dikes, and masses, and it would hardly be possible, except on a map of large scale and with the expenditure of much time and labor, to map them separately.

The oldest member of the group is an andesitic breccia that overlies the Colorado shale. It is cut by dikes of andesite porphyry and the two in turn are cut by other dikes of syenitic lamprophyre. That still later dikes cut the group is certain, though their sequence was not made out.

Dikes of this group cut the Colorado shale in nearly every exposure of that formation. In the area north and east of Silver City they are conspicuous and some of them are several hundred feet thick. They form many of the low ridges but also cross the valleys.

The diorite at Pinos Altos Mountain is the best example in the group of a stocklike mass of considerable size. High on the summit, however, the mass is cut by dikes, and it contains small bodies of agglomerate, made up perhaps of fragments of other rocks through which the diorite magma forced its way.

Character.—The rocks of the complex are dioritic or andesitic, exhibiting a tendency toward monzonitic facies, as shown in places by larger amounts of orthoclase.

The diorite is finely crystalline and almost black. Under the microscope it is seen to be a holocrystalline aggregate of andesine and labradorite with orthoclase. Pyroxene is abundant in well-developed crystals, and mica forms aggregates of small and large plates. A little green hornblende and considerable iron oxide are subordinate constituents. There is little or no quartz. Pyroxene tends to assume the size of phenocrysts, and areas of finer crystalline plagioclase between the larger plagioclase crystals also indicate a porphyritic tendency. The orthoclase is sufficient in amount to suggest that the rock is closely related to the pyroxene granodiorite, which is a later intrusion in the same area.

A mass of agglomerate is exposed for 200 feet in a small gulch 2 miles southwest of Central but is not mapped separately from the Colorado shale. It contains fragments of various sizes and of several different kinds of rock, weathering brown and reddish, in a brownish-gray matrix. A specimen from a fragment 2½ feet in diameter and of the same material as the matrix, when examined microscopically, showed stout, tabular phenocrysts of andesine in a groundmass of feldspar microlites and glass. Chlorite occurs in what appear to be amygdaloidal cavities. The specimen is an andesitic rock, and the mass as a whole is probably a flow breccia.

About a mile northwest of Fort Bayard the relations of several dikes to the breccia are rather clearly shown. (See fig. 7.) The breccia *a* is light greenish gray, almost aphanitic, and contains angular fragments. The microscope shows well-formed twinned phenocrysts of augite, lathlike feldspars ranging in composition from oligoclase to andesine, a subordinate amount of albite, abundant magnetite, and a little apatite. The groundmass is glassy, showing crystallization in an incipient form, and contains a little quartz in small grains. Flow structure may be seen in part of the thin section.

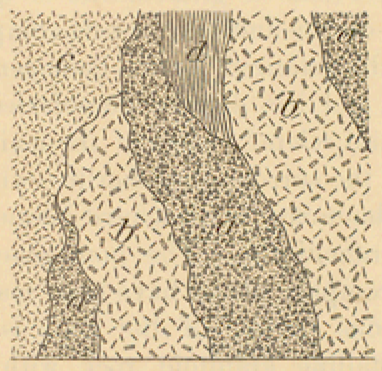

FIGURE 7.—Sketch illustrating the relations of several dikes cutting andesitic breccia in the Pinos Altos complex.

a, Andesitic breccia; *b*, andesite porphyry; *c*, syenitic lamprophyre; *d*, Cretaceous shale. Width of exposure, about 30 feet.

This breccia is cut by dike *b*, a light-brown rock of faint olive-green cast. Well-formed phenocrysts of augite and feldspar are common, the latter more abundant and consisting of both albite and oligoclase. The groundmass is fine grained and is composed largely of small laths of feldspar (probably albite) in a matrix that suggests orthoclase. Amygdules are rather common and are generally lined with yellowish-green chlorite and later filled with a zeolite. Chlorite scattered in cavities gives the rock a green tinge. Both magnetite and apatite are common. The rock may be called an andesite or andesite porphyry.

Another dike, *c*, cutting both *a* and *b*, is porphyritic and contains abundant large, well-formed dark-green pyroxenes in a fine-grained greenish matrix specked with small reddish altered feldspars. The microscope reveals large scattered phenocrysts of albite, but the greater part of the rock is made up of laths of orthoclase and albite, which, together with considerable pyroxene, magnetite, and apatite in good-sized crystals, make up the groundmass. Chlorite is abundantly scattered through the rock, mostly in small specks, though here and there it replaces augite. In places in the groundmass augite grains are abundant. The rock is a syenitic lamprophyre and was perhaps derived from the potassic magmas of the region.

Another rock from the dark-colored complex is a dark-gray to black fine-grained porphyry, with abundant glittering phenocrysts of augite set in a fine-grained granular groundmass, largely orthoclase but including also a little quartz and plagioclase and abundant small plates of biotite. The pyroxene phenocrysts are altering to green hornblende, which also occurs in small grains in the groundmass. The rock contains a few phenocrysts of albite feldspar, abundant apatite, and some iron oxide. It is a syenitic lamprophyre answering closely the description of an augite vogesite.

Other specimens prove to be pyroxene andesite. They are porphyritic rocks with pyroxene phenocrysts and feldspars ranging from oligoclase to labradorite in a fine-grained groundmass of albite or oligoclase and subsidiary orthoclase. It contains everywhere magnetite and apatite, and alteration has produced more or less chlorite, calcite, and chalcedonic quartz.

QUARTZ DIORITE PORPHYRY.

General distribution.—Rocks of the quartz diorite porphyry type occupy considerable areas in the eastern part of the quadrangle. The largest mass is that which extends from Fort Bayard eastward to a point near Santa Rita. The granodiorite or quartz monzonite dikes that cut the quartz diorite porphyry near Santa Rita point to the earlier intrusion of the quartz diorite porphyry. The correlation of the other masses with it as to date of intrusion is based solely on resemblances of type. The masses which have been mapped and of which some specimens have been microscopically examined are the large laccolith between Fort Bayard and Santa Rita, the Hermosa Mountain mass, a small part of the mass between Fierro and Hanover, the masses east of Kneeling Nun, and the areas north of Hurley. It differs from the later granodiorite and quartz monzonite chiefly in its lack of appreciable quantities of orthoclase, its generally fine grain, and its darker color.

The Fort Bayard mass.—The quartz diorite porphyry at and east of Fort Bayard shows clearly the sheetlike form of its intrusion. At Fort Bayard the Colorado shale dips westward beneath it, and one-half mile to the west the porphyry is overlain by the shale, also with a westerly dip. The laccolith, too, follows eastward around the nose of the domelike anticline of which Copper Flat is the center, retaining its position, except where disturbed by faulting, at an approximately uniform distance above the top of the Beartooth quartzite.

It is perhaps this rock, highly altered and much silicified, that makes up the hills southeast of Santa Rita basin.

The rock is greenish gray, rather fine grained, and porphyritic, showing rather small phenocrysts of altered feldspar and an altered ferromagnesian mineral, and generally some magnetite. As a whole the mass is not homogeneous either in texture or in mineral composition, but the differences observed are not important.

Examined with the microscope the rock is seen to contain plagioclase and quartz phenocrysts. The plagioclase is partly albite and partly oligoclase. Alteration to sericite and calcite interferes with accurate determination. Masses of chlorite indicate altered hornblendes. The groundmass, which is subordinate in amount, is fairly coarse, and is composed of albite, oligoclase, and quartz, with chloritized ferromagnesian minerals. Secondary amorphous silica may be recognized by its low index of refraction.

In Hanover Creek, below the old concentrator, the porphyry is much leached and epidotized. The feldspars, especially, have changed in part to epidote. Ferromagnesian minerals are entirely altered to chlorite. There is much quartz in a finely granular groundmass, with abundant epidote and perhaps some unstriated plagioclase.

About a mile east of Central the rock is dark greenish-gray mottled porphyry. It contains white feldspar phenocrysts and large black biotites embedded in a dark greenish-gray groundmass, as well as large embayed quartz phenocrysts, which, however, are not numerous. Albite, oligoclase, and andesine, considerably altered and replaced by epidote, also form phenocrysts. The biotite is much altered to chlorite and epidote, and there are small, rather fresh hornblendes. The groundmass is a fine interlocking mesh of quartz and feldspar, mostly albite. Accessory minerals are apatite, magnetite, and sphene, the last named abundant.

The intrusive mass which breaks through the Colorado shale at Hermosa Peak is about 4 miles long and a mile or more wide and has many of the aspects of the rock just described. It is light-green, rather fine grained porphyry with prominent phenocrysts of hornblende. Under the microscope rather small, not very numerous quartz phenocrysts are scattered between abundant oligoclase and albite-oligoclase phenocrysts. Hornblende in large crystals is set in the granular groundmass of quartz and plagioclase (albite-oligoclase). Epidote is abundant, and accessory apatite and magnetite are scattered through the rock.

Masses east of Santa Rita.—East of the Kneeling Nun an area somewhat more than a square mile is underlain by quartz diorite porphyry very similar to the large mass between Fort Bayard and Santa Rita. The rock is greenish-gray porphyry in which with the unaided eye large phenocrysts of quartz, white feldspar, and chlorite may be seen embedded in a dense bluish-gray groundmass.

The quartz crystals are much resorbed, the feldspars range from albite to oligoclase, and the original biotite is altered entirely to chlorite. The outlines of crystals of hornblende completely replaced by chlorite may also be seen. The groundmass is a mosaic of quartz and albite. Epidote and calcite are secondary, the epidote abundant and locally replacing feldspar phenocrysts. Apatite and magnetite are accessory. The rock is almost identical in mineral composition and general texture with the large laccolith west of Santa Rita, except that quartz phenocrysts are perhaps more abundant. The general textural resemblance between this rock and the extremely altered rock composing the rim of hills surrounding the quartz monzonite porphyry of Santa Rita is very striking.

In the remaining areas mapped as quartz diorite porphyry the rock is essentially similar to the types just described.

QUARTZ MONZONITE AND ASSOCIATED ROCKS.

GENERAL CHARACTER AND DISTRIBUTION.

Rocks of granodioritic or monzonitic type with associated porphyritic facies are abundant in the quadrangle and are economically the most important rocks in the region. They have been mapped in the Big Burro Mountains, at Silver City, near Gomez Peak, at Pinos Altos, at Lone Mountain, at

Copper Flat, between Hanover and Fierro, and in the vicinity of Shingle and Allie canyons. Quartz monzonite porphyry is the main ore-bearing rock at Santa Rita also, but it has not been mapped separately from the leached quartz diorite porphyry at that locality.

The masses have several characteristics in common. All were intruded at about the same time, later than the quartz diorite porphyry but earlier than the Tertiary planation that preceded the eruption of the rhyolite-latite-andesite series. All are rocks of granitoid aspect and cooled (at least the part now exposed) under considerable cover, probably never reaching the surface of the earth in a molten state, and all are closely allied in chemical composition. Several of the masses comprise a number of different types.

QUARTZ MONZONITE PORPHYRY OF THE BIG BURRO MOUNTAINS.

Areal extent.—The quartz monzonite porphyry of the Big Burro Mountains is a mass of rudely circular outline and 4½ to 5 miles across, extending from Tyrone nearly to the summit of the principal peak. It occupies a shallow basin, as it is less resistant to erosion than the surrounding pre-Cambrian complex, except near Leopold and Tyrone, where the porphyry has been altered and silicified.

The contact of the porphyry with the pre-Cambrian granite complex is generally not difficult to follow, but in the region of intense silicification, pyritization, and alteration near Leopold and Tyrone there is some chance for error in the location of the boundary. This difficulty is further increased by the presence of dikes of quartz monzonite porphyry later than the main mass.

These dikes, which are in many respects similar to the main mass, are numerous along the northern and western borders of the mass and a few were also noted on the southern side. The scale of the map is inadequate for their proper representation. They express the last stages of intrusion, cutting as they do both the parent magma and the surrounding rocks, and they are so like the main mass that there can be no doubt as to their origin.

Throughout most of its area of outcrop the porphyry is granitoid, is distinctly light colored, and weathers in rounded massive forms. Near Leopold and Tyrone, however, the rock is increasingly fractured, silicified, altered, and iron stained to a point where its original nature is nearly or quite obliterated. It there forms ragged, siliceous, leached, limonite-stained hills, markers of the ore bodies which are found below the surface.

Petrography.—The mass comprises both even-grained granular and porphyritic facies. The granular phase is coarsely crystalline and is composed of quartz, oligoclase, and orthoclase, with subordinate biotite and hornblende, and accessory titanite, apatite, and magnetite. Quartz is abundant in good-sized crystals. Oligoclase, the principal feldspar, is in places zonal. The orthoclase is about equal in amount to the quartz. The plagioclase crystals are well formed and many are partly inclosed by orthoclase and quartz.

A porphyritic phase contains phenocrysts of oligoclase, albite, andesine, and biotite in a mosaic-like groundmass of quartz, orthoclase, and a little twinned plagioclase. Quartz forms about half the groundmass. Apatite, titanite, and magnetite are accessory minerals.

Another specimen contains large phenocrysts of rounded and embayed quartz and of oligoclase and a few of albite. The groundmass, a mosaic, contains more orthoclase than quartz. Sericite in the feldspars and chlorite, forming from rather scant biotite, are alteration products. Large crystals of apatite and scattered specks of magnetite are present. Phenocrysts and groundmass make up about equal parts of the rock.

One of the specimens examined approaches the composition of a sodic granite by its increase in albite and resembles the mass at Silver City.

QUARTZ MONZONITE PORPHYRY AT SILVER CITY.

An intrusive mass at Silver City, of rectangular outline and about 1½ miles long from north to south and about a mile wide, cuts the Colorado shale at its northern side and the Fusselman limestone and Percha shale along its western border. On its eastern and southern sides it is overlain by the gravel. The rock is well exposed in the railroad cut.

The rock is light colored and medium grained and contains phenocrysts of feldspar and quartz in a pinkish aphanitic groundmass. With the microscope large and abundant resorbed quartz phenocrysts are seen with abundant albite and less abundant large orthoclase phenocrysts. The groundmass is a fine mosaic of quartz and orthoclase, and apatite is an abundant accessory mineral. Magnetite is present. Secondary calcite has formed, and the feldspars are considerably sericitized. The rock might be called either quartz monzonite porphyry or sodic granite porphyry.

GRANODIORITE AT GOMEZ PEAK.

Gomez Peak and the equally high hill west of it are formed by an intrusive mass of granodiorite. The rock is also well exposed in a narrow strip 1½ miles to the east and in a small hill southwest of the peak. The magma forced its way into the Paleozoic and Cretaceous strata, doming them, and cooled at sufficient depth to take on a rather coarse texture. It is gray and decidedly porphyritic, containing abundant large white and flesh-colored feldspars, many of them three-fourths of an inch or more in length, abundant smaller feldspars, and narrow laths of dark-green hornblende, in an aphanitic dark-gray groundmass. The large phenocrysts are orthoclase and the more numerous smaller ones range from andesine to calcic labradorite. The groundmass is chiefly andesine, with some orthoclase, and a little quartz, which is difficult to detect because of its resemblance to the andesine. Titanite, apatite, magnetite, and a little light-green pyroxene are accessory minerals.

Alteration rims about the feldspar are common and are probably due to differences in composition, as many small crystals are composed of an outer rim of andesine and a central core with a lower index of refraction. This rock, with its orthoclase phenocrysts, approaches chemically the monzonitic type, so common in this region.

GRANODIORITE AT PINOS ALTOS.

At Pinos Altos a mass of granodiorite or quartz monzonite has intruded the diorite-andesite breccia complex. A portion of this mass is characterized by its homogeneity, is unmixed with other rocks, and has definite boundaries. Another portion contains several related phases of the main mass, is mixed with inclusions of the surrounding diorite—which it intrudes—and its southern boundary is ill-defined because of offshooting dikes from the granodiorite. The homogeneous portion and the more or less complex phase have been mapped separately.

The homogeneous portion of the mass is a fairly coarse-grained, holocrystalline granitoid rock with a pinkish cast. Hornblende is the prominent ferromagnesian mineral. The rock differs somewhat from place to place in texture, but within the area mapped as pure granodiorite it is remarkably homogeneous. In the field it is unmistakable; in places it forms almost bare rocky knolls and cliffs, is well jointed, and weathers differently from the other rocks of the vicinity into large angular blocks whose dimensions are determined by the spacing of joint planes. The rock consists essentially of orthoclase, albite, andesine, andesine-labradorite, and quartz, with accessory magnetite, apatite, titanite, and a little zircon. The secondary minerals are chlorite, sericite, and calcite.

The rock was called granodiorite by Graton,[1] but either that name or quartz monzonite might be applied. It is certainly closely related to the masses in the Big Burro Mountains, at Silver City, Hanover, Santa Rita, and other places where the name quartz monzonite may perhaps be preferred.

Two typical specimens were examined with the microscope. One showed abundant quartz in large crystals with abundant orthoclase in large irregular masses and of later growth than the plagioclase. The plagioclase consists of albite and oligoclase in about equal amount and andesine. Hornblende in subordinate amount is partly altered to chlorite. The albite crystals are considerably altered to sericite, but the orthoclase and more calcic plagioclase are comparatively fresh. Titanite is abundant in large masses, and zircon, magnetite, and apatite are accessories. Some secondary calcite is present. The other is a coarsely crystalline granular rock of light color and pink tinge. Quartz is abundant but forms less than one-third of the rock. Orthoclase is abundant, much of it poikilitically inclosing the plagioclase, of which oligoclase in large crystals is probably the most abundant. Andesine is likewise abundant in large clear well-twinned crystals, but albite is subordinate. Hornblende is the important ferromagnesian mineral, though subordinate in amount. Titanite and apatite are both abundant, with a moderate amount of magnetite.

The less homogeneous mass comprises a number of related types presenting minor variations in composition and texture. The essential mineralogic differences are the development of pyroxene and biotite at the expense of hornblende and a lower content of free quartz. A finer grain along the borders and a general lack of textural homogeneity are also evident. It is believed that fragments of the surrounding diorite porphyry are included in the mass. Some of the types mapped together are undoubtedly offshooting dikes from the main mass, similar to it in composition and texture, though locally finer grained and porphyritic, but the more striking variations in composition are probably the result of successive but related injections of differentiated magma.

A number of specimens from the southern portion of this area were examined with the microscope. One is a holocrystalline medium-grained granitoid rock, mottled white and green. Pyroxene and mica are plainly visible and abundant. Large areas of orthoclase poikilitically inclose abundant andesine and labradorite prisms. Pyroxene and biotite crystals are abundant. Biotite surrounds apatite and magnetite grains. The apatite is abundant in large clear grains. In another specimen orthoclase incloses abundant idiomorphic phenocrysts of plagioclase, ranging from oligoclase to calcic labradorite, and also incloses pyroxene and biotite. Biotite also incloses plagioclase. Magnetite is notably associated with pyroxene, and apatite is present. Chlorite has formed from the pyroxene and in the cracks and twinning planes of the plagioclase. A third specimen contains idiomorphic prisms of andesine and labradorite in an orthoclase paste. Biotite, pyroxene, and hornblende are fairly abundant. A small amount of quartz occurs with the orthoclase, as a filling between the plagioclase prisms.

QUARTZ MONZONITE AT COPPER FLAT.

At Copper Flat a small intrusive mass is exposed by the erosion of the enveloping limestone. The rock is light colored and decidedly porphyritic and contains abundant quartz phenocrysts with well-developed crystal faces in a fine-grained groundmass.

Under the microscope the much sericitized feldspars, though not easily determined, appear to be both albite and oligoclase. Chlorite is abundant. The crystalline form of the quartz phenocrysts is easily apparent and recalls the perfect forms of the quartz crystals in the quartz monzonite porphyry dikes in the Big Burro Mountains.

GRANODIORITE NEAR HANOVER, FIERRO, AND SANTA RITA.

The anticline which extends from Hanover to Fierro has been sufficiently eroded to expose a considerable mass of rock that is principally granodiorite or quartz monzonite, with which is associated porphyritic facies, and rock of essentially the same composition is exposed in the basin in which Santa Rita stands. At both places the mass has weathered more easily than the surrounding rock, so that a basin has been formed.

The mass at Hanover still retains upon it a portion of the limestone roof. At Santa Rita the rock is in general altered and so much oxidized that, where it is mixed with surface débris, it is difficult to distinguish from the surrounding rocks. The boundary of the main mass appears to lie at the foot of the highly oxidized quartz porphyry hills east, south, and west of Santa Rita. As mapped, however, the rock is one of a number included in a leached zone comprising the mass itself, offshoots from it, and the surrounding oxidized quartz diorite porphyry. When the field work was done fresh specimens of this porphyry were difficult to find, but steam shovels have now well exposed the rock, and its character is more certainly determinable. One may recognize, however, that the rock is a light-colored leached porphyry containing phenocrysts of clouded white feldspar, quartz, and biotite embedded in a fine-grained groundmass.

Under the microscope the quartz crystals appear large, with irregular boundaries, indicating resorption. The feldspars are largely altered to sericite. The groundmass is a fine-grained mosaic of quartz and orthoclase, the latter dominant. Magnetite is not abundant, apatite is rare, and a little zircon is present. The rock resembles very closely the quartz monzonite porphyry from the Big Burro Mountains.

The rock on the dump at the Santa Rita shaft is light gray in color and porphyritic. Phenocrysts of quartz, biotite, and a white cloudy feldspar may be seen in a fine-grained dark groundmass. The rock is abundantly speckled with sulphide. When examined with the microscope the quartz is seen to be deeply embayed. Much of the feldspar is orthoclase, but both oligoclase and andesine are moderately abundant, though largely altered to sericite. The biotite plates where fresh show marked resorption phenomena. In places they are altered to chlorite. Limonite has formed from the sulphides. Apatite and zircon are rare. The groundmass is a mosaic of quartz and orthoclase in proportions of about 1 to 2.

The rocks between Hanover and Fierro are much like those just described. Granodiorite porphyry (or quartz monzonite porphyry) makes up the main mass.

QUARTZ MONZONITE NEAR LONE MOUNTAIN.

An intrusive mass of irregular outline occupies about a square mile northeast of Lone Mountain. The rock is more closely allied to the quartz monzonite than to the earlier quartz diorite porphyries and resembles in mineral composition the rock at Silver City. It cuts the Fierro limestone and occupies the same general topographic level as that formation.

The rock is light gray, porphyritic, and of medium grain. It contains phenocrysts of altered white feldspar, quartz, and biotite, embedded in a very fine grained groundmass. Under the microscope large, moderately abundant quartz phenocrysts show resorption phenomena with development of graphic intergrowth of quartz and feldspar along the borders. The feldspar phenocrysts are albite and oligoclase, and there are equally numerous biotite plates, somewhat corroded by resorption. The groundmass is composed of interlocking grains of quartz and orthoclase and magnetite and apatite.

GRANODIORITE IN SHINGLE AND ALLIE CANYONS.

The erosion of Tertiary lavas in and near Shingle and Allie canyons has exposed irregular areas of intrusive rocks which are sufficiently alike in character to be grouped together

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[1] U. S. Geol. Survey Prof. Paper 68, p. 298, 1910.

as granodiorite or quartz monzonite. Two specimens were examined microscopically. One, a rather coarse grained gray porphyry of granitoid aspect, shows, without a hand lens, large white feldspar phenocrysts, nearly a third of an inch across, abundant quartz phenocrysts, and well-formed chloritized biotite plates in a fine-grained groundmass. The phenocrysts form most of the rock. Examined under the microscope the feldspars prove to be orthoclase and plagioclase, the plagioclase mostly albite with some oligoclase. Advanced sericitization casts some uncertainty on this determination. The quartz phenocrysts are rounded by resorption, as are some of the orthoclase crystals.

There is some unaltered brown hornblende; also masses of chlorite and epidote, suggesting altered hornblende. The biotite has completely altered to chlorite. Apatite forms crystals almost large enough to be classed as phenocrysts. Magnetite is not abundant, but a few grains of titanite were noted. The groundmass is microgranular and is a fine mosaic of orthoclase and quartz.

Near the head of Shingle Canyon a finer-grained greenish rock of dioritic aspect was examined with the microscope. It has a holocrystalline granular texture. Interlocking prisms of plagioclase with some orthoclase, a little quartz, and abundant pyroxene partly altered to chlorite make up the main mass of the rock. Apatite is noteworthy and iron oxide is present. Secondary epidote may be seen. The feldspars have in part altered to sericite, but much chlorite has also formed.

North of Allie Canyon, near the gravel overlap, is a porphyritic, fairly coarse grained greenish-gray rock of granitoid aspect showing dull white feldspars, some as large as three-tenths of an inch in diameter, with abundant hornblende and chloritized biotite. Quartz phenocrysts may also be seen. Both plagioclase and orthoclase are present. The groundmass is a microcrystalline aggregate of quartz and orthoclase. Large crystals of apatite are subordinate, and calcite and epidote are secondary. The rock might equally well be termed a granodiorite or quartz monzonite porphyry.

Associated with these masses in Shingle and Allie canyons are finer-grained dikes, especially in Shingle Canyon, which, though considerably altered, show closer relationships with monzonite than with any other rock. Their age is in doubt. Rocks very similar are certainly offshoots from the quartz latite stocks of Tertiary or later age, and the inference is that these also may have been intruded at the same time.

TERTIARY LAVAS.

DISTRIBUTION.

Lavas form the prominent range of mountains that traverses the northern part of the quadrangle in a northwesterly direction. They occupy about 130 square miles of the quadrangle, this area including the foothills. The line of low mountains that trends northwestward to Greenwood Canyon, near the northwest corner of the quadrangle, and about 50 square miles of mountainous territory south of Santa Rita are also occupied by these flows. Other small areas are on the central western margin of the quadrangle, in the Little Burro Mountains, in the southwestern corner of the quadrangle, and near the central southern edge.

TOPOGRAPHIC EXPRESSION.

The determining factor in the topographic expression of the lavas and the associated sedimentary beds is that they consist of nearly horizontal superimposed sheets. Faulting and erosion account for their diversified forms.

In the range south of Santa Rita a bold vertical cliff rests upon semiconsolidated sand whose slope is decidedly less than that of the cliff. Steep-walled canyons traverse parts of this range. The overlying andesite has weathered into softer contours than the lower rhyolite, thus lessening the ruggedness of the mountains. This effect, however, is not everywhere manifest, for the andesite that caps Four A Mountain presents no such rounded contours, and thin sheets may make very perfect table-like mesas. (See Pl. VII.) The lava range at the north, viewed from any distant elevated point, likewise has the appearance of a great dissected pile of horizontal strata, and only on near approach does one observe the many peculiar forms that erosion has fashioned from the flows. The rhyolites especially are noteworthy for the odd shapes into which they have been carved by rain. Pointed cones, huge isolated bowlders, balanced rocks resembling huge and grotesque creatures, and acres of high towered and domed monuments may be seen in different parts of the lava-covered areas.

GENERAL CHARACTER AND SUCCESSION.

Three principal sorts of rock have been distinguished and mapped — light-colored pinkish-white rhyolitic lavas, with associated breccia; dark-colored andesitic and basaltic lavas; and interbedded tuffs and detrital sediments. Each sort occurs at several horizons, and the light-colored, more siliceous lavas alternate with the darker, less siliceous types.

In the range south of Santa Rita the basal member is a sedimentary bed ranging in thickness from 100 to 500 feet. The thickness of the accumulation was directly controlled, in part at least, by the unevenness of the underlying surface.

Upon this deposit of fine silt successive, nearly horizontal flows of rhyolitic and andesitic lava were poured out. One striking feature, well illustrated in the mapping and accentuating the difference between sedimentary strata and lava flows, is the thinning out of the lava flows at their edges. The lava flows thin out with increasing distance from their sources, but the sedimentary beds are thinnest near their sources.

The first flow attained in places a thickness of 600 feet and was succeeded by an andesitic flow, which terminated about the center of the mountain mass. At the extreme northeastern scarp remnants of it are 300 feet thick. It thinned abruptly southward and southwestward and was followed by a rhyolitic flow, which entered this area perhaps in two separate lobes, the edge of one of which thinned in the mountains east of Martin Canyon. The other lobe, near the eastern edge of the quadrangle, seems never to have entered the mountains east of Martin Canyon but perhaps connects with the first lobe in the area south of those mountains.

In the northern lava field the succession is essentially similar to that just described. In the region about Black Peak the successive interbedded sedimentary deposits and lava flows emphasize the periodicity of the flows of andesite. At least three periods of andesitic eruption are evident, and three periods of sedimentation, the last of which was accompanied by a second rhyolite flow. The thinning out of flows and sediments is well shown in this area also. Of special note is the thinning out of the great rhyolite flow, which beneath Four A Mountain is not less than 800 feet thick but east of Avalanche Peak has disappeared, though its thin edges may be seen in places. Such conditions are the natural result of irregular topography and great flows—that is, some areas escaped for a time only to be covered later by succeeding eruptions.

In the country northwest of Lookout Peak, and especially well exposed along Bear Creek, are considerable accumulations of rhyolite breccia, which grades upward into tuffs and detrital sediments. The brecciation of the rocks is in the main probably the result of flow, the lava partly solidifying, breaking up, and being rolled along in the current of molten rock. In the Greenwood Range, too, are areas that appear to illustrate this process. The presence of tuffaceous sediments overlying the lavas suggests the possibility that explosive material may have in part added to the markedly fragmental character of the rocks.

RHYOLITIC ROCKS.

The rhyolite south of Santa Rita at a point about $2\frac{1}{4}$ miles south of Cobre Siding is a light-bluish rough-surfaced rock with phenocrysts of glittering clear glassy feldspar, plainly visible quartz, and some biotite in an aphanitic groundmass. The rock contains abundant orthoclase, some unstriated oligoclase, and large crystals of ilmenite. The groundmass is a fine-grained aggregate of glass and feldspar. The rock may be classed as rhyolite, though it approaches quartz latite in composition.

In the tuff-gravel series near Hurley is a thin flow not shown on the map. A bed of tuff 50 feet thick is overlain by 30 feet of conglomeratic material and that in turn by a 20-foot flow. The lava is light salmon-pink cellular rock of pumiceous aspect, and contains many fragmental inclusions, some as much as an inch long. It has a glassy base, in which are scattered unstriated feldspar phenocrysts with an average index of refraction about that of Canada balsam (albite-oligoclase) and a few flakes of biotite. In the groundmass are numerous fibrous or spherulitic crystalline growths. Straight, curved, and forking figures are made up of crystalline fibers set at right angles to parallel walls. Some of the figures are spherical or ovoid and in these also the fibers are set at right angles to the inclosing walls. These incipient growths are characteristic of western rhyolitic lavas. In the tuff series southeast of the Kneeling Nun a salmon-colored, exceedingly fine grained rhyolite glass with conchoidal fracture contains myriads of them.

About 6 miles northwest of Silver City, on the main road at the Continental Divide, two flows of rhyolite, separated by a few feet of iron-stained gravel but mapped as a unit, are exposed. The rock of one is light pink and contains irregularly shaped dull-white feldspars, some of which are half an inch long, clear, glittering, smoothly cleaved feldspars, and small quartz crystals in a fine-grained groundmass. Other phenocrysts, some of them one-tenth of an inch long, are a micrographic intergrowth of feldspar and quartz. Orthoclase is the most abundant feldspar, though there is some feldspar with an index as high as that of quartz and a little striated albite. The groundmass is glassy and contains myriads of incipient crystal growths. The rock of the other flow is white and chalky but is essentially the same except that quartz is not so evident, though it is probably represented by silica in the glassy groundmass. Both rocks are rhyolite.

About a mile north-northeast of the last locality is a succession of thin flows, interbedded with gravel, one of which is especially typical of much of the rhyolite in the northern ranges. It is a lavender-colored rough porphyritic rock with feldspar and quartz phenocrysts from one-twentieth to one-tenth of an inch in diameter and copper-colored flakes of mica in an aphanitic groundmass. The unaltered feldspar, which is sanidine, has glittering, colorless, glassy cleavage faces. Examined with a microscope the glassy groundmass is seen to contain abundant microlites.

East of Pinos Altos the rhyolite flows are finely exposed. Two specimens were examined microscopically. One is rough and pinkish and contains abundant mica weathered to pure copper color and abundant porcelain-white feldspars in a pink fine-grained groundmass. The microscope shows that the feldspars are dominantly oligoclase with subsidiary orthoclase in a groundmass of glass in which spherulitic textures are finely developed. Both feldspars and glass make up the groundmass. The rock is quartz latite. The second specimen is a smooth lavender-colored rock with an aphanitic groundmass, in which are scattered small phenocrysts of porcelain-white feldspar and copper-colored biotite. Flow structure is prominent in the glassy groundmass. The feldspars are dominantly clear sanidines. The rock is typical rhyolite.

Lookout Peak is capped by a remnant of the rhyolite lava flows that cover much territory to the north. The rock is brownish red and contains small white phenocrysts of feldspar and abundant bronze-colored biotite in an aphanitic groundmass. The phenocrysts are orthoclase, in part remarkably clear and without cleavage. With a microscope curved cracks may be seen in them and inclusions suggesting those of quartz. The crystals, however, are certainly biaxial, and the index of refraction is slightly lower than that of balsam. The groundmass contains much glass and hosts of crystalline microlites. Magnetite grains are scattered through the rock and are in places surrounded by aureoles of red iron oxide.

Near the north end of the Greenwood Range considerable areas are occupied by quartz latite. These rocks are closely allied to the rhyolites, both chemically and in their appearance, and are logically grouped and mapped with them. They are light bluish-gray or dove-colored rocks, showing both flesh-colored and clear glittering feldspar laths in a microcrystalline groundmass. Some phenocrysts are a quarter of an inch in diameter, though most of them are smaller. Albite-oligoclase is most abundant, though orthoclase is also present in considerable amount. Quartz phenocrysts, too, may be seen, and the groundmass is composed of finely granular quartz and feldspar. Some biotite is present.

Similar latitic rocks occupy considerable areas several miles farther south in the Greenwood Range, where the lava is ashy white and tuffaceous and contains abundant, evenly distributed small flakes of biotite. The feldspars, which are abundant as broken fragments in a glassy groundmass, are dominantly oligoclase, with subsidiary orthoclase and quartz. Magnetite is present. The movement of the lava has left its mark on the biotite flakes, some of which are bent and twisted as if disturbed after crystallization. The fragmentary aspect of the feldspar phenocrysts is due to the same cause. The rock is quartz latite.

The hill a mile southeast of Stewart Peak is capped by a fine-grained porphyritic flow containing abundant, evenly distributed dull-white prism-shaped feldspar phenocrysts, averaging a little less than a tenth of an inch long, in a gray groundmass. With a microscope they are seen to be largely sodic labradorite in a microcrystalline groundmass of orthoclase and quartz. A little biotite, magnetite, and rods and grains of apatite are accessory minerals. Zonal growth is prominent in the plagioclase phenocrysts. The flow is quartz latite.

Rocks of this type occur at several other localities. One mass, whose relations are not certainly understood, is on the Continental Divide 2 miles south of Stewart Peak and has a length east and west of about $1\frac{1}{2}$ miles. Some of its field relations suggest an extrusive rock, like the capping of the small hill just described, a mile southeast of Stewart Peak, but its relation to the rhyolite flows against which it abuts on the south and the northeast suggests either intrusion or faulting. It is possible that the mass is an intrusive stock, of which the capping mentioned above as lying to the north is but a small extrusive remnant. This view is upheld by the fact that the two rocks are strikingly similar both in hand specimens and when examined microscopically, and both are quartz latite porphyries.

Of the breccias from the region northwest of Lookout Peak, two were examined microscopically. One is light lavender pink to chalky white and is made up of numerous angular fragments up to an inch or more in diameter. Quartz may be seen in the hand specimen. Black well-developed crystals of biotite are plentiful and small fresh crystals of orthoclase may be plainly seen with a hand lens. The groundmass is glassy. The fragmental character of the quartz is also plainly apparent and the orthoclase crystals likewise have a fragmental aspect. Evidently flow in the mass has interrupted rather advanced crystal growth and has both torn apart the phenocrysts and destroyed the homogeneity of the groundmass. The rock is a good example of a rhyolite flow breccia. The other is a flow breccia formed from a very glassy, finely crystalline base. The individual fragments are only disrupted portions of the fine-grained groundmass and no crystals of large size were seen. The rock consists of chalky pink to white angular fragments from minute particles to pieces several inches in diameter set in a red glassy groundmass. The fragments form much the greater part of the rock.

ANDESITES AND BASALTS.

Andesitic and basaltic lavas alternate with the more acid rhyolitic and latitic flows and are quite as conspicuous. Accumulations aggregating 700 feet in thickness form the major portion of the range near Black Peak. A number of flows join to make up such piles of rock and several of them are sharply marked by the interpolation of beds of sand and gravel between them. But even the sheets of lava between strata of sedimentary material probably comprise several thin flows. It is not practical to separate them, however, and the sedimentary beds are used as division planes. In the discussion of these rocks, therefore, as in the discussion of the rhyolitic rocks, various dark-colored andesitic and basaltic types are grouped together, for even in the hand specimen they can seldom be distinguished from one another. It is true that after becoming familiar with the types in the field one can recognize with some degree of assurance a difference between the main lower flow and a flow higher up in the series, but without the aid of the gravel and sand beds as horizon markers it is doubtful whether such criteria as may be at hand would serve consistently to distinguish the several types. The lowermost flow is a dark rock of deep-reddish tone showing a great number of glittering feldspars of the same general deep-red tone. Under the microscope the rock appears distinctly porphyritic. Well-formed, relatively large, slender phenocrysts of labradorite (Ab_2An_3) are set in a fine-grained groundmass, in which the prism or rodlike form is characteristic of the feldspars. Olivine in well-developed crystals and small grains also appears as phenocrysts. Many of these grains are altered to iddingsite at their borders, and some grains are altered throughout. The groundmass, which forms considerably more than half the body of the rock, contains much finely granular pyroxene with abundant fine grains of magnetite. Flow structure is plainly visible in the parallel arrangement of the tiny rods. Great clouds of inclusions are noted in the feldspar phenocrysts. The rock may be called a basalt.

On the top of Four A Mountain the lowermost flow is a decidedly vesicular and aphanitic black rock, weathering dark brown and marked by glittering crystal faces of dark glassy aspect. This flow also is distinctly porphyritic. Although essentially the same as the one from the Black Peak region, it differs in its larger proportion of pyroxene and olivine, both of which are prominent as phenocrysts and as small grains in the groundmass. Magnetite, too, takes the form of both phenocrysts and granular material. Some of the feldspars are as calcic as bytownite. The groundmass of the flow contains considerable glass as clouds of inclusions in the feldspars. The name basalt may appropriately apply to this rock.

What was regarded as the upper flow during the progress of the field work proves to be a rock mineralogically on the border line between basalt and andesite, and when compared with portions of the flow that forms the northern end of the Little Burro Mountains it shows plainly its intermediate position. The upper flow near Black Peak is a fine-grained bluish-gray rock, the weathered surface of which takes on a porcelain-like glaze. It is made up essentially of fine rods of plagioclase, some as calcic as labradorite, with abundant though subordinate grains of pyroxene and magnetite. Though a number of the feldspars assume the size of phenocrysts the rock is not nearly so well defined a porphyry as the lower flow. Scattered through it are small grains of red iddingsite derived from olivine that was apparently original. The olivine, however, is not so abundant as in normal basalt, nor do the crystals of it or those of pyroxene assume the size of well-developed phenocrysts.

The rock from the Little Burro Mountains is likewise an aphanitic blue-gray rock showing threadlike white flow lines and taking on a porcelain-like glaze on weathered surfaces. Its groundmass and general arrangement of minerals are similar to those of the rock near Black Peak, with the difference, however, that olivine is lacking, and the feldspar is less calcic, oligoclase being very abundant. Both orthorhombic (hypersthene) and monoclinic pyroxene and great quantities of apatite needles are abundant in fine grains in the groundmass. The rock may be called pyroxene andesite.

Near the middle point of the southern edge of the quadrangle there is a small area of lava which protrudes from beneath a cover of gravel. Here a basalt flow overlies a rhyolite. The basalt is an exceptionally good example of its type, and the rock fortunately is exceptionally fresh. It is chocolate-brown, aphanitic, and conspicuously vesicular, and contains both minute and rather large cavities, the largest half an inch long, though the small ones are much more numerous. Microscopically the rock is of typically pilotaxitic texture, that is, it contains a mesh of interlocking fine rods of labradorite. Abundant small grains of pyroxene with magnetite are evenly distributed throughout the groundmass, and phenocrysts of olivine in various stages of alteration to red iddingsite form a noteworthy constituent. Small grains of olivine also occur in the groundmass. Clouds of minute reddish inclusions with an index lower than that of the feldspar occur at the border of two adjoining feldspars or in triangular areas between three blades (probably a glass?).

LATITIC AND RHYOLITIC INTRUSIVES.

General character and distribution.—Certain latitic and rhyolitic stocks break through and penetrate all the overlying rocks. Possibly they were the source of lava flows, though with the possible exception of the mass a mile southeast of Stewart Peak no remnant of such later effusives was noted. That some of the stocks represent volcanic rocks quite near the surface is suggested by the well-developed flow structure which they display. (See Pl. III.) As now exposed by erosion most of the stocks, especially those of latitic character, are confined to a belt 9 miles long and 2 miles wide, extending in a northeasterly direction near Bear Mountain and Stewart Peak. In the southwestern part of the quadrangle, southeast of the Big Burro Mountains, are many intrusive rhyolitic stocks, most of them too small to be mapped. One, however, a mile and a half long, is mapped at the south end of the Little Burro Mountains. What are taken to be similar late intrusives make up much of the mountains, but surficial decomposition has gone to such lengths that it is not possible definitely to determine the petrographic character of the rock.

Petrography.—The latitic stocks exposed in the neighborhood of Bear Mountain and Stewart Peak are all of similar type but with minor differences in color due mainly to surface decomposition. On the top of Bear Mountain is a light-brown porphyry with small glittering feldspar laths in an aphanitic groundmass. Specks of magnetite are sparsely distributed throughout the rock. A conchoidal fracture is rather characteristic. Examined microscopically, feldspars ranging from oligoclase to labradorite ($Ab_{70}An_{30}$ to $Ab_{40}An_{60}$) are seen in a microcrystalline though partly glassy groundmass of quartz and orthoclase with some plagioclase. The feldspars are generally tabular and surrounded by the quartz. Distributed quite evenly throughout the rock are microscopic grains of hematite. A little chloritized biotite and a few rods of apatite are present.

The rock which forms Stewart Peak and which underlies a considerable area to the west is similar to that of Bear Mountain. An individual specimen is a light olive-green porphyry containing abundant small white glistening feldspar phenocrysts in an aphanitic groundmass, through which likewise are distributed evenly and abundantly tiny blades or plates of biotite and grains of magnetite. Microscopically the rock is not essentially different from that just described. The groundmass contains rather lathlike feldspar set in glass, orthoclase, and quartz. The phenocrysts are much the same as those of the Bear Mountain rock. Small egg-shaped and subcircular masses of brown serpentine, probably replacing the groundmass, are quite numerous. The partial absorption of feldspar phenocrysts, illustrated in their prominently rounded edges, and the same phenomenon with respect to biotite plates, along the edges of which magnetite is concentrated, are interesting minor features. Tiny specks of hematite are distributed through the rock, and a few crystals of magnetite assume the size of phenocrysts.

QUATERNARY BASALT.

Basaltic lava flows are interbedded with the deposits of gravel and represent the Pleistocene epoch of igneous activity in a region which, as has been shown, is remarkable for the diversity of its igneous history since Cretaceous time. In the desert region south of the quadrangle flows spread over the very recent deposits and are a last expression of dying volcanic activity. It is noteworthy that the Pleistocene and Recent flows are basaltic, for their immediate predecessors were siliceous, being latite porphyry stocks.

It was not in general practical to map these basalt flows. Few of them attain a thickness of 100 feet. In one area, however, in the northwest corner of the quadrangle a mass of basalt has been separately mapped. Its relations are not entirely clear. Portions of it are, without question, intrusive both with respect to the rhyolite of that area and to the Pleistocene gravel which is deposited upon the rhyolite. Petrographically the rock has the characteristics of a flow. It is probable that the mass is partly intrusive and partly extrusive. It may represent the source of a number of thin flows in the northwestern part of the quadrangle.

The Pleistocene basalt flows are well displayed in the region about L S Mesa and Hells Half Acre—in fact, in all the region of Pleistocene gravel that is tributary to Walnut Creek. They may be seen also in the region northwest of Treasure Mountain, especially in Cane Spring Canyon. (See Pl. VIII.) In this same general region a basalt dike was noted cutting Pleistocene gravel. (See Pl. I.)

The flows are normal olivine basalt. The mass mapped in the northwest corner of the quadrangle is highly vesicular, black, and fine grained, and shows stretched gas cavities with an average length of one-fourth of an inch and occupying almost as much space as the solid portion of the rock. Under the microscope the rock shows the pilotaxitic texture of fine-grained, rather glassy basalt. Labradorite laths are set in a partly glassy paste. Olivine is not abundant and fine grains of pyroxene and magnetite are scattered throughout the rock.

A basalt flow overlying rhyolite but of Pleistocene age is a dark fine-grained blue-black amygdaloidal lava, showing abundant specks of olivine scattered through the rock. Much of the abundant olivine in this rock is altered about its borders, or completely, to the ruby-red mineral iddingsite.

Other flows examined microscopically do not show exceptional variation from normal olivine basalt.

STRUCTURE.

GENERAL FEATURES.

It is at once apparent that the Paleozoic and Cretaceous strata, taken together, lie in a broad shallow syncline whose axis passes in a curving line from Pinos Altos to a point southeast of Central. The western edge of the trough is well defined by the crest line of the Silver City and Lone Mountain ranges, but the eastern part is disturbed by a series of parallel north-south folds, more or less warped by igneous intrusion and broken by severe faulting.

In the Little Burro Mountains the eastward dip of the sedimentary rocks shows that somewhere between those mountains and the western boundary of the trough just mentioned there must be a fault much like that which drops Treasure Mountain and its northern outliers to their unusual position with respect to the Paleozoic beds in the main Silver City Range.

Next perhaps in broad structural importance is the presence of vast piles of faulted, nearly horizontal beds of lava, which cover the greater part of the northern part of the quadrangle and obscure much of the older topography south of Santa Rita. (See sections A–A and H–H of structure-section sheet.)

Folding, faulting, extrusion, and intrusion have therefore played important parts in the final configuration of the geologic structure of this region. The principal structural features in the area are shown in figure 8. Each may now be described in detail.

FOLDING.

The folding is decidedly open and is probably due in part to the forces that produced the faulting and in part to earlier igneous intrusion. The region between the Silver City Range and the eastern side of the quadrangle is one of gently undulating open folds broken by intrusion and disturbed by complex faulting. Just west of Gomez Peak is a structural dome, which through erosion now appears as a core of Paleozoic limestone surrounded by a rim of Cretaceous quartzite. (See section B–B, structure-section sheet.) The presence of intrusive rock on three sides of the dome points unmistakably to the welling up of the magma that domed the superincumbent beds. This association of igneous intrusion with warping is again strikingly brought out at the eastern side of this broad synclinal trough, where Carboniferous limestone has been gently arched along the axis of a north-south fold by the intrusive mass between Fierro and Hanover. (See section C–C, structure-section sheet.) It is also evident that the intrusive rock at Copper Flat is almost centrally located with respect to a perfect structural dome. At each of these places the erosion of the igneous rock has formed a topographic depression where there was once an elevated area.

Between these two anticlines a shallow syncline extends nearly southward from the intrusive mass of Hermosa Peak to a point southwest of Hanover. A second syncline, considerably broader, occupies the area between the Fierro-Hanover anticline and the eastern border of the block. The dips along the eastern border are uniformly westward.

The structure of the beds at Lone Mountain, in the Silver City Range, and in the Little Burro Mountains, is the result of both folding and faulting. (See sections E–E and D–D, structure-section sheet.) The folding, however, monoclinal in both places, is believed to be genetically connected with the faulting and to be of a period distinctly later than the faulting produced by the intrusions described above. The evidence for this belief is as follows: The intrusive mass which forms the dome near Gomez Peak is overlain by Tertiary gravel, whereas the intrusive mass at Fierro is cut at its northern end by a fault which seems to belong to a system of faults formed after the deposition of the Tertiary gravel. Moreover, the intrusive mass is similar in petrographic type to others farther to the north and at Pinos Altos, which are earlier than the Tertiary gravel. The intrusion is therefore probably earlier than the gravel. The folds at the foot of the Silver City and other ranges, however, involve gravels of Tertiary age and must therefore be of a later date.

FAULTING.

All the faults observed are of the normal type and express an extension or stretching of the strata. The strong northwesterly faults are probably parallel to and closely connected with broad axes of folding, for, broadly viewed, the fractures may be placed in two distinct systems, one trending northwestward, the other trending northeastward. The Silver City Range, for example, and its southeastern structural analogue, Lone Mountain, where not faulted along their eastern front, are sharply flexed, some beds standing at high angles—70° or more. West of these mountains, too, partly visible at Treasure Mountain and in the hills north of it are strong faults nearly parallel to the fault on the eastern front. (See fig. 9.)

The west flank of the Little Burro Mountains also is marked by a fault which is parallel to the monoclinal axis of the range. At Georgetown, too, a strong northwesterly fault is parallel to the broad monocline which dips to the southwest.

In striking contrast to these relatively widely separated dislocations are the closely spaced and on the whole much shorter transverse northeasterly fractures. These are well exposed in the Silver City Range. The portion of the range that is limited by the three strong faults shown in figure 9 is particularly suitable for study. These three faults encompass a distinct uplifted block. It is at once evident that almost every cross fault is downthrown on the north side or uplifted on the south side. Such a system of faults involves a decided extension or lengthening of the entire block. Figure 9 shows the roughly wedge-shaped form of the mass. If such a wedge-shaped block were lifted from the body of the crust in a way that would tilt it decidedly to the north and if the force which caused the uplift were applied near its south end, say in the region just south of Silver City, it is evident that the strata would not be strong enough to allow the block to be tilted solidly, so that successive blocks would break and slip upward with the result shown diagrammatically in figure 10. In this figure the assumption is made that no horizontal movement took place along the fault planes, for all the phenomena observed in the field, except perhaps at one locality, may be explained as a result of erosion acting on such a set of fault blocks as are depicted.

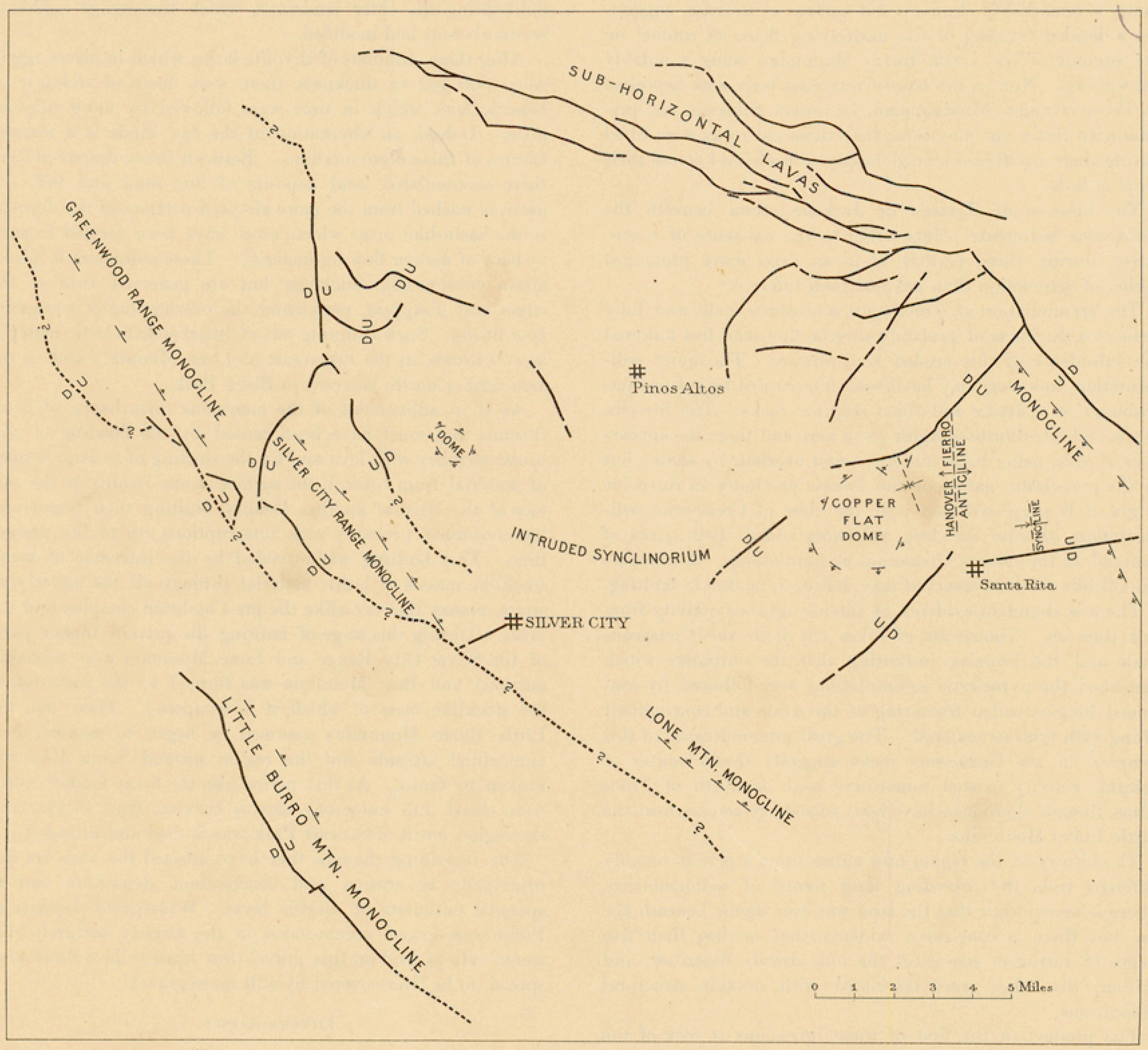

FIGURE 8.—Map of the principal faults and folds in the northern part of the Silver City quadrangle.

Heavy lines representing faults are dotted where the faults are concealed. D, Downthrown side of fault; U, upthrown side. The small arrows show direction of dip of the beds.

Several details connected with this shattered block are of more than ordinary interest. At its south end, for instance, where the northeasterly fault passing through Silver City crosses the range, the beds are very greatly disturbed. The dips are vertical, some beds being even overturned, and the strata are broken by dozens of small faults, all with their downthrow on the north. It would be difficult to find another piece of ground so shattered and yet illustrating so consistently the nature of the breaks that disrupted its continuity.

About 2 miles southeast of Bear Mountain the contact between the Percha shale and the Fusselman limestone is that of block faulting of such a nature that small triangular areas of the shale are cut out as if pressed up through the teeth of a saw. The forces that produced the faulting in this range may have initiated or possibly were initiated by igneous intrusion. Bear Mountain, a volcanic stock, has without doubt aided in the distortion of the beds at the north end of the range. This point will be discussed more fully below.

A study of the Little Burro Mountains and of Lone Mountain brings out no new fact as regards cross faulting, unless it be that in the main the downthrow of the faults at Lone Mountain is to the south, suggesting that the disturbing element causing uplift lies somewhere between Silver City and this mountain.

Near the eastern edge of the quadrangle there are several noteworthy northeastward-trending breaks. A strong fault passes northeastward between Fierro and Hanover Mountain. Along its course Cretaceous strata are lowered on the north side against Paleozoic limestone on the south. This fault passes into a sharp fold at its southwest end and terminates against a northwest fault at its north end and apparently cuts across the synclines and anticlines of this Paleozoic block.

Two faults that intersect near Santa Rita are decidedly suggestive in the interpretation of the structure and stratigraphy around that mining camp. One passes northeastward nearly through Cobre Siding, and its downthrow on the south is strikingly brought out by the discordance in level of the horizontal lavas which it cuts south of Hanover Junction. (See section F–F, structure-section sheet.) The other fault approaches Santa Rita, trending almost west. Its downthrow is also on the south, with the consequence that within the angle between these two faults only Cretaceous beds occur at the surface. The recognition of these faults, as will be shown later, necessitates a different interpretation of the structural relations of the quartzite near Santa Rita from that offered by previous workers. North of the east-west fault and west of the northeast-southwest fault the Beartooth quartzite is exposed, resting upon Paleozoic limestone. Within the angle of the faults, however, all the fine-grained quartzitic rock exposed is really Cretaceous shale that has been altered by contact metamorphism, and so far as could be determined, this metamorphosed material is the only sedimentary rock within the down-faulted block, though possibly there may be a few beds of true quartzite, for sandstone lentils occur within the Colorado shale.

The faults in the region immediately east of Walnut Creek and in the vicinity of Sycamore Canyon are particularly numerous and without recognizable system. The country is broken into a series of slices and irregular blocks, and the stratigraphic sequence is much disturbed. Intrusive volcanic stocks are conspicuous accompaniments of the dislocations.

In the lava ranges on the north most of the faults trend west-northwest, are normal, and are especially characterized by curved courses. Narrow strips of country are lifted as individual blocks bounded by converging curving faults, some of which join and split several times throughout their courses.

As was stated above several faults indicate rather certainly movements later than the period of Pleistocene deposition, though the recent movement on each of these faults was perhaps only a prolongation of a much earlier disturbance. Such a fault is the one that separates the Pleistocene from pre-Cambrian rocks at the western base of Little Burro Mountains. Near the north end of this fault, a short distance south of Wind Canyon, the gravel beds abut against the rhyolite, which with the overlying andesite forms much of these hills. (See Pl. IV.) It does not seem possible that this attitude of the beds could be brought about by any other means than a fault. On tracing this fault southward to Redrock Canyon one is again impressed with the abruptness of the contact with granite. At the canyon, though the evidence is not perfectly clear that faulting has taken place, there are certain conditions which are rather opposed to a normal overlapping contact, the most important of which is the fineness of the sediments that abut vertically against the granite. And though there is some granitic material in the gravel, the amount seems insufficient to establish a purely local origin for the pebbles. Furthermore, at a point about a mile north-northeast of Tyrone a cross fault offsets the straight contact of the main fault. In both directions, north and south, from the cross fault the gravel contact for half a mile along the main fault is straight, but at the cross fault the contact is sharply offset for about 300 feet in a direction accordant with the dip of the fault planes and the throw of the cross fault. Further, a short distance to the north of the point where the road crosses the main fault there is a vertical contact of fine gravel against broken rocks of the andesite complex, about 3 feet of fault gouge lying between the gravel and the complex. The gravel at the contact is not composed of material of the complex but of light-colored granite. Still another fact may be cited, that is, the difference in the character of the gravel contact on the two sides of the range. On the east it is much higher than on the west, and it lies upon an irregular surface of rhyolite with a crooked contact and shows very coarse material at the base of the gravel, the conditions presenting a marked contrast to the west side.

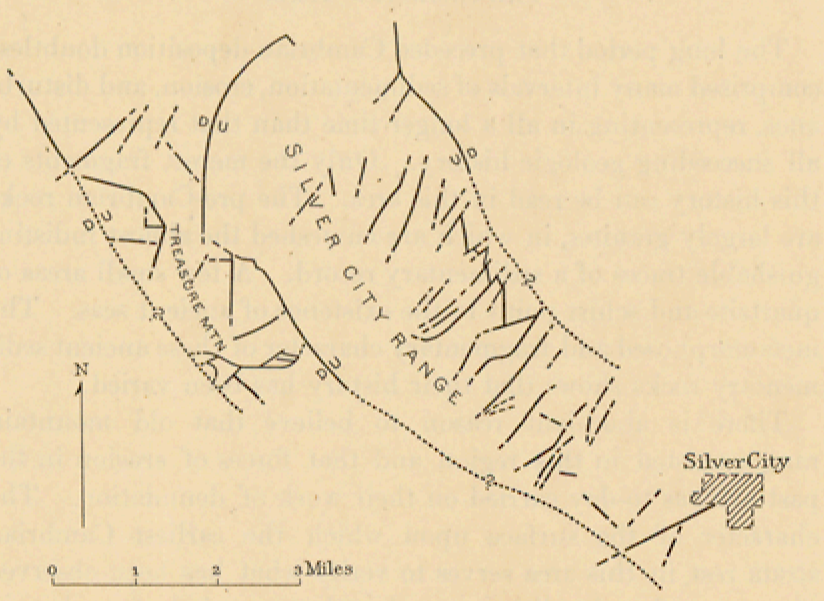

FIGURE 9.—Map of the faults in Silver City Range and Treasure Mountain, showing a major northwest-southeast system of faulting and a minor system of cross faults.

D, Downthrown side of fault; U, upthrown side.

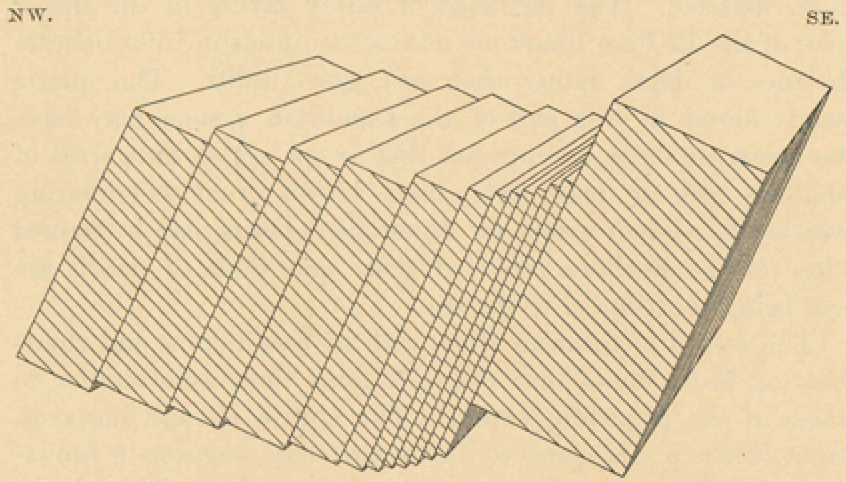

FIGURE 10.—Ideal stereogram showing nature of the movement of the smaller fault blocks of the cross-fault system in Silver City Range.

Evidence of post-Pleistocene faulting may be seen at several other localities north of Treasure Mountain and east of Georgetown, where much the same criteria for faulting as have just been pointed out can be found.

The age of movement along a plane or surface of weakness is hard to determine, for where a break has once been formed by movement a continuation of the movement is likely to take place, perhaps at intervals, through a long period of time. It is therefore impossible to determine definitely when faulting first began in this area. It is evident that faulting has taken place since the deposition of Pleistocene gravel; also that some faults break the Tertiary lava flows without apparently affecting the Pleistocene gravel; but though no fault was found that cuts Cretaceous rocks and does not cut Tertiary lavas, yet faulting might have begun before the lavas were deposited and continued along the same planes after their deposition. The absence, however, of any direct evidence pointing to this conclusion permits the tentative assumption that faulting began after the lavas had been poured out and continued at intervals along certain breaks after the deposition of Pleistocene gravel.

GEOLOGIC HISTORY.

PRE-CAMBRIAN TIME.

The long period that preceded Cambrian deposition doubtless comprised many intervals of sedimentation, erosion, and disturbance, representing in all a longer time than that represented by all succeeding geologic history. Only the merest fragments of this history can be read in this area. The pre-Cambrian rocks are largely granites, in which are enmeshed the almost indistinguishable traces of a sedimentary record. A few small areas of quartzite and schist point to the existence of ancient seas. The metamorphosed and fragmentary character of these ancient sedimentary rocks shows that their history has been varied.

There is abundant reason to believe that old mountain ranges existed in this region and that forces of erosion in the past even as to-day carried on their work of denudation. The character of the surface upon which the earliest Cambrian strata rest in this area serves to verify what has been observed at many other localities, namely, that a period of prolonged erosion and base-leveling preceded the subsidence of the pre-Cambrian land beneath the sea, forming a floor of moderate relief on which the Cambrian sands were deposited.

PALEOZOIC ERA.

The nature of the basal Cambrian strata, which are composed of quartzose, limy, and glauconitic material, shows that at the time of their deposition the sea was gradually transgressing upon a land surface of moderate relief. It is probable that as the sea advanced wave action reduced still further rather low relief and that the remarkably flat contact between the Cambrian sediments and the pre-Cambrian basement is in part a result of this action.

The subsidence whose beginning is marked by these Cambrian beds endured for a long period. As the seas gradually grew deeper or as the shore line slowly transgressed landward, limy sediments gradually became more prevalent and finally they formed the only record of deposition. Though these seas were not deep they were probably extensive. Whether the interval of time indicated by differences in the fauna of the Bliss sandstone and that of the El Paso limestone includes a period when Cambrian beds were raised above sea level and subjected to erosion can not yet be determined. Apparently there was a rather abrupt transition from the sandy limestone layers of the older formation to the more limy beds of the younger formation, but if there is an unconformity it has not been detected. The incursion of sandy layers in the upper part of the El Paso limestone marks the unsettling of a delicate balance of depth rather than any great uplift. The quartz sands found in this part of the Cambrian system may have been carried there by currents that swept across wide areas of shallow seas or may have been blown from neighboring beaches by violent winds, for limestone deposits may be formed close to the seashore provided great quantities of débris are not being contributed to the sea.

The record of Silurian time, with its fossiliferous and chert-bearing beds, shows that the conditions then were similar to those of the preceding period. The abrupt change, however, from Silurian limestone to Devonian shale suggests a fundamental difference in conditions of sedimentation. Though the bedding of the Silurian limestone and the Devonian shale seems to be concordant, there is reason to believe that the beginning of Devonian deposition was preceded by marked erosion in this southwestern area. At Bisbee, for example, as stated by Ransome,[1] Devonian beds rest upon Cambrian limestone; at Clifton, as shown by Lindgren, Devonian overlie Ordovician beds; and in the Silver City region Devonian rest upon Silurian beds. These facts and the sudden change in sedimentation marked by the deposition of Devonian shale on Silurian limestone point to decided irregularities in the Paleozoic sequence in this southwestern province, probably indicating a period of uplift and erosion.

The gradual change from shale to limestone observed at the top of the Percha shale indicates an uninterrupted period of deposition between Devonian and Carboniferous time and a decided clearing of the seas. The faunal changes are likewise noteworthy. The muddy waters in which the top of the Percha shale was laid down seemed especially adapted to Devonian forms, but when the waters became clearer they were no longer a suitable habitat for the Devonian fauna, which therefore disappeared and Carboniferous forms became prevalent. No stratigraphic break was detected between the Mississippian and Pennsylvanian beds, though differences in the fossils of these series suggest such a break.

MESOZOIC AND CENOZOIC ERAS.

The point has now been reached where, instead of picturing quiet Paleozoic seas, the imagination must depict the gradual emergence of a Mesozoic continent. No evidence is at hand to prove that the uplift was accompanied by notable structural disturbance. No certain pre-Cretaceous faults are recognized, nor has any folding been observed which might not be assigned to later periods. It must be assumed, therefore, that though the emergence was widespread, it took place in this area without other deformation than that of gentle warping and tilting. That the tilting may have been appreciable is shown by certain relations between the basal Cretaceous beds and the underlying Paleozoic rock. For example, the Beartooth quartzite shows a remarkably clean-cut flat surface at its base, suggesting a decided leveling of the underlying floor, its contact on the summit of the Little Burro Mountains being a notably flat surface. Now as the basal Cretaceous beds were deposited on Pennsylvanian, Mississippian, Devonian, Silurian, and pre-Cambrian rocks, one may infer that these old rocks were tilted during their uplift and eroded nearly to base-level across their dipping beds.

The absence of Triassic or Jurassic strata beneath the Cretaceous sediments points either to the existence of a continent during those periods or to an even more prolonged period of denudation than has just been inferred.

The accumulation of Cretaceous sandstone, shale, and limy shale to a thickness of probably several thousand feet followed the subsidence of this eroded land surface. The quiet sedimentation, however, may have been interrupted by subaqueous outbursts of andesitic and allied volcanic rocks. The breccias of the andesite-diorite complex have here and there the appearance of sills, being both underlain and overlain by shale; but as the pyroclastic nature of the breccia precludes an intrusive origin, it is suggested that near the close of Cretaceous sedimentation, or after its close, volcanoes added their quota of material to the marine Cretaceous accumulations. The apparent sill-like relation observed may, however, be due to faulting.

There is abundant evidence of intense igneous activity from this time on. Thousands of dikes cut both the Cretaceous shale and the breccias, indicating that the outbursts which furnished the pyroclastic accumulations were followed by continued long-extended fracturing of the strata and concomitant filling with igneous material. The great preponderance of this complex in the Cretaceous rocks suggests that a center of volcanic activity existed somewhere near or north of Pinos Altos, though there may have been subsidiary centers near the Little Burro Mountains.

The history of the region now enters upon a period notably different from the preceding long record of sedimentation. There is no evidence that the land was ever again beneath the sea, but there is conclusive evidence that no less than five stages of intrusion succeeded the one already described, and further, that they were associated with notable structural dislocations.

The product of the first of these intrusions is rock of the quartz diorite porphyry type, well developed around Fort Bayard and extending to the southward and eastward from that point. This individual intrusive takes the form of a sheet at some places, for example, at Fort Bayard, where it lies above and dips westward with the Cretaceous sediments. Farther west it dips beneath the Colorado shale. Moreover, it follows regularly the nose of the domelike uplift of which Copper Flat is the center. It is rather hazardous to correlate intrusive masses by lithologic features alone, but it is believed that the intrusives west of the Kneeling Nun, at Hermosa Peak, and near Lone Mountain are of the same date as the laccolith just described.

Next in order of intrusion are such masses as the granodiorite between Hanover and Fierro, the masses at Copper Flat, Santa Rita, Pinos Altos, Gomez Peak, Silver City, and the quartz monzonite mass of the Big Burro Mountains. That the mass between Fierro and Hanover and the mass at Santa Rita are later than the Fort Bayard intrusive mass is suggested by the presence in the Fort Bayard laccolith of dikes very similar in composition and general aspect to the Fierro mass. The intrusion of these later crystalline porphyries is of structural importance in that their entrance through the overlying rocks domes up the otherwise undisturbed beds. The masses at Copper Flat, Hanover, and Gomez Peak, for example, clearly illustrate such action. When these bodies of igneous rock, whose great surface exposure probably only indicates a greater subsurface extent, had cooled, there ensued a period of active erosion, which is clearly indicated by the fact that such masses as the granodiorite of Pinos Altos (which must have cooled under considerable cover, 1,000 feet or more, probably) were exposed at the surface before the outpouring of the broad floods of lava that overlap them on the north. At Pinos Altos, for example, the granodiorite passes beneath the lava cover, and the veins which cut the granodiorite are abruptly terminated by the overlying glassy rhyolite.

But little imagination is required to picture the conditions that must have existed at the beginning of this epoch of volcanic activity, which closed the Cretaceous period. There is evidence that violent explosions preceded the welling out of the vast floods of lava; that torrential rains distributed the breccias and tuffs over the uneven surface of the land. Here and there lakes were formed, into which fell the dust and the coarser ejectamenta from the active volcanic vents. Such coarse and fine accumulations are well exhibited in the region north of Lookout Peak, and the finer sediments and gravels at the base of the lava series may be seen at many places, notably east of Lone Mountain and north of it along the scarp that forms the edge of the lava floods in that region.

Then followed in Tertiary time, the eruption of great sheets of rhyolitic or latitic lava, covering hills and valleys alike and obliterating the older landscape, which the earlier explosive accumulations had modified.

After these outbursts of rhyolite-latite, which in places aggregated 800 feet in thickness, there were floods of andesitic or basaltic lava, which in time were followed by more siliceous lavas. Indeed, an alternation of the two kinds is a marked feature of these accumulations. Between the outbursts of lava there accumulated local deposits of fine sand and tuff, the detritus washed from the more elevated portions of the deposits to the basin-like areas which must have been formed in such a chaos of molten flowing material. These sediments in places attain considerable thickness but are generally thin at the edges and disappear, permitting the overlapping of successive lava floods. Such thinning out of interbedded clastic material is well shown in the range east of Lone Mountain and in the area farther north, adjacent to Black Peak.

As if in adjustment of the enormous disturbance of equilibrium that must have been caused by the flooding of this broad territory with lava and by the shifting of so large a mass of material from beneath the surface at one locality to the surface of the crust at another locality, faulting then began and has continued, probably with interruptions, up to the present time. This faulting was attended by the intrusion of many stocklike masses of latitic material through all the underlying strata, masses that cut alike the pre-Cambrian complex and the lavas. During this stage of faulting the present higher parts of the Silver City Range and Lone Mountain were probably outlined, and Bear Mountain was formed by the intrusion of the stocklike mass of which it is composed. Then, too, the Little Burro Mountains assumed or began to assume their monoclinal attitude and the region around Santa Rita was broken by faults. At this period also the lavas farther north were sliced into numerous narrow curving fault blocks, and the region north of Stewart Peak was faulted and intruded.

The remaining changes that have affected the area are due principally to erosion and concomitant deposition and to sporadic outbursts of basaltic lavas. Widespread deposits of Pleistocene gravel accumulated in the already maturely dissected valleys, and on this gravel thin basaltic lava flows were spread, to be later covered by still more gravel.

PHYSIOGRAPHY.

It has been pointed out that during a long period before the subsidence of the land that was formed of the pre-Cambrian complex of rocks erosion had worn the surface down to a smooth plain, which had been beveled across beds of hard and soft rocks alike. This surface has not only been completely buried and only partly laid bare again but has been much deformed. The tilted edge of the plain is preserved in the Silver City Range along the base of the lowest Cambrian strata and it dips eastward beneath the mountains, but the numerous faults of the range have broken the plain into a series of steps that, in their present disconnected form, bear no relation to the original low-lying plain of pre-Cambrian time.

A second period of widespread erosion occurred in the period between the close of Carboniferous and the beginning of Cretaceous time. The entire Paleozoic section was exposed by erosion, which at some places cut into the pre-Cambrian plain. This period of erosion was closed by Cretaceous deposition. The nature of the basal Cretaceous sediments and the fact that they are deposited on all the Paleozoic formations and on the pre-Cambrian complex shows that though at one time, after the uplift of the Paleozoic rock, the topography of this region may have been diverse, yet a thorough planation afterward took place, thorough enough to obliterate all but some remnantal Paleozoic forms. The present topography is therefore in no direct way dependent on any pre-Cretaceous sculpture.

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[1] Ransome, F. L., U. S. Geol. Survey Geol. Atlas, Bisbee folio (No. 112), p. 12, 1904.

The earliest topographic feature that has left a definite impression on the present land forms is a plain of erosion that was developed after the uplift of the Cretaceous sediments and before the outflow of Tertiary lavas. So far as this plain is concerned, however, it is apparent that later diastrophism, particularly the intense faulting of Tertiary time, as well as Quaternary erosion, greatly altered the older surface. The effect of the erosion is well shown in the dike-cut Cretaceous area that stretches eastward and northward from Silver City. The dikes, which are composed of much more resistant material than the soft shaly beds which they cut, undoubtedly determined in part the sculpture of the Tertiary erosion surface, and it is therefore not unreasonable to suppose that the broad features of the present relief were outlined and fairly well developed before they were covered by the flood of lava. For instance, Pinos Altos Mountain stands well above the plain south of it and Hermosa Mountain and the group of low hills about Gomez Peak must be due to differential erosion, for these hills are composed of holocrystalline, rather coarsely granular porphyries, which could have formed only at considerable depth beneath the surface and must therefore have been uncovered by erosion before the lavas spread over the surface. The granodiorite at Pinos Altos, too, which is overlapped by the lava, proves this point conclusively.

After the lavas were poured out there ensued a period of faulting, which, probably continued more or less interruptedly down to recent times. The Silver City Range and its southern outlier, Lone Mountain, owes its elevated position to this faulting, and the same is true of the Little Burro Mountains. As a natural result of this uplift the lavas over broad areas have been stripped from the underlying rocks. Keeping in mind the acceleration of erosion in elevated areas, one can readily understand how these ranges took their present form. The Silver City Range is an asymmetric sedimentary mountain mass, broken by faulting and modified by intrusion, resting upon an uplifted block of pre-Cambrian granite and schist.

Its relatively gentler eastward slope, which accords more or less perfectly with the dip of the sedimentary beds, contrasts sharply with its steeper western scarp, carved across the edges of the sedimentary formations. The fact that much of the western part of the range is a dissected sloping mountain flank cut in pre-Cambrian rocks indicates plainly that erosion, though not able to keep pace with the elevation of the mass, was yet able to obliterate all traces of a definite fault scarp.

Bear Mountain, at the north end of the range, an intrusive stock of latite porphyry, probably owes its elevated position to superior hardness.

The lavas form a subhorizontal blanket of igneous rock, which probably once covered all of the area. They consist ot a number of successive lava flows, with which were laid down locally and at several stages accumulations of sand and tuff. If this rough table-land of lava be imagined as broken by faults and at the same time continuously undergoing active erosion, then the principal factors which produced its present configuration can be understood. Out of this platform the Black Peak Range has been carved. Though the fault scarps that outline the crest of the range west of Scott Peak are on the whole subdued by erosion to steep mountain sides, yet an actual break may be seen at one place on the northern fault, where a nearly vertical slickensided surface forms a small cliff 10 or 15 feet high. In the main, however, but little topographic expression of the faults remains. Erosion has dissected the area into an irregular range of sharp relief. Steep-walled canyons are numerous, and many sharp ridges and peaks surmount the higher lands. Four A Mountain is an exception, its top suggesting the slightly modified remains of an old flow.

There are certain rock benches cut by erosion in these lavas for which an explanation will be offered in the description of the Pleistocene gravel.

Many observers have commented on the fact that numerous mountain ranges in the southwestern part of the United States rise abruptly from sandy desert plains, like islands from the sea. The streams that flow down their canyoned sides pour out débris in a series of great fans whose edges coalesce to form sloping plains. The process of aggradation is in full play. An inspection of the Pleistocene deposits in most of the Silver City area, however, indicates clearly that a decided change has taken place along their edges. Though the deserts farther south are still areas of active aggradation, or building up, much of the corresponding part of this quadrangle is being actively eroded. Yet there is abundant evidence that these gravels once formed an unbroken sheet that lapped up on the mountains they surround. One who stands upon the Big Burro Mountains and looks northward over the valley of Mangas River can not fail to be impressed, even astonished, at the intricacy of the carving by which the even-topped sheet of sand and gravel is cut into innumerable gullies and canyons.

An interesting question immediately arises in connection with this intricate carving of these Pleistocene deposits: When and why did erosion become so manifestly active? The answer may be read in certain prominent physiographic features of the neighboring hard rocks. These features may be best observed from an elevated viewpoint. One looking northwestward from the summit of Four A Mountain may see a remarkably fine example of a rock bench, which slopes gradually from the foot of the lava range on the northeast to the edge of the gravel sheet on the southwest. This bench is about 2½ miles wide. It has three important characteristics: First, its inner border terminates abruptly against a steep mountain flank; second, it slopes evenly away from the mountains and is continued in the gravel without break; and third, it is sharply incised by canyons that pass into the gravel.

Across the gravel toward the southwest there is a narrower but similar bench, which, when viewed from the top of the Little Burro Mountains, appears strikingly accentuated, forming the broad slope at the foot of the Big Burro Mountains. A more dissected bench may be seen on the west side of the Greenwood Range. These benches may be explained by following to its end a cycle of erosion proceeding under the special conditions imposed by subaerial filling of inclosed basins of wide extent in an arid or semiarid climate.[1]

It is assumed, first, that inclosed basins were formed by a disturbance of level, such, for example, as that which produced the Basin Range system, with its partly buried mountains and detritus-filled inclosed valleys, continental warping probably being the underlying cause. Next is assumed a climate so arid that evaporation would keep pace with the rise of water in these basins and thus augment subaerial accumulation. These two conditions being assumed, it is apparent that a basin would be progressively buried from its center outward, and that this process of progressive burial would permit erosion to act with greater effect upon each succeeding portion of the basin; that is, the last part to be buried would have undergone the greatest erosion. If the basin were of great extent it is believed that the last part to suffer burial would have become a nearly planated surface. This end seems inevitable for the following reasons: First, the edge of the accumulating gravel sheet—below which (vertically) erosion could not extend—determines a local base-level, and, second, the territory above the gravel would constantly tend to become reduced to the level of the gravel. But this level is slowly rising, therefore the end product of such a cycle would be a sloping, evenly cut rock plain.[2]

There is another feature for which a reasonable explanation may not so readily be offered. That is the sudden change of gradient where the rock plain abuts against the mountain flank—the oversteepening, to speak technically, which this mountain scarp represents. An explanation may perhaps be found in the character of the stream channels where they leave the canyons of the mountain and flow out upon the plain. They build great fans over which, in shifting channels, the stream spreads the débris from the hills. The cross section of such a fan is convex upward, and at intervals the stream shifts from one place to another. At certain times it flows along the mountain side, where it cuts laterally. The stream will therefore, like a lathe tool, tend to undercut the mountain and may thereby produce the oversteepening. This process has probably been proceeding since the very early stages of basin filling, and if it is considered in connection with the tendency toward planation discussed above it may seem sufficient to account for all the relations of the benches.

A possible origin of the rock benches having thus been suggested, their dissection may perhaps be explained by rejuvenation of drainage due to warping, sufficient evidence for which seems to lie in the Quaternary faulting, which may be noted at many places. This warping may have only local significance, however, and the faults may be only an expression of some very broad movement of uplift.

Certain interesting features may be explained by such a rejuvenation of drainage. Between Silver City and Central the gravel boundary is an irregular line. The Pleistocene gravel rests upon the Colorado shale, intrusive rocks, Tertiary gravel, and lava. A transverse east-west shallow depression borders the edge of the gravel sheet and interrupts the otherwise normal slope from the mountains. This depression, which is shown in Plate XI, is no more than a shallow etching of the floor on which the gravel once rested. The fact that the gravel must have covered the area is attested by the outliers which extend northward from the main contact and by other physiographic features. After the rejuvenation of drainage caused by the uplift on the north, the edge of the gravel sheet was eroded back to a position of stability in adjustment to the new conditions of drainage. Such a pushing back of the gravel sheet was accompanied by a dissection of the sheet by the rejuvenated streams. Then, it is believed, the exposed floor of the gravel sheet was lowered, the amount of the lowering being limited by the level of the streams—that is, it was carried down to the level where the stream became aggradational as opposed to degradational in crossing the gravel sheet. It might be asked why was not the gravel edge likewise lowered on the interstream areas. Possibly because the gravel sheet, when pushed back to this position of stability on the interstream areas becomes more resistant than the hard rocks upon which it rests. The theoretical considerations that lead to this belief have been well presented elsewhere.[3]

It may therefore be concluded that the plainlike area that stretches eastward from Silver City is another expression of the same process to which are imputed the rock benches described above; indeed, it is an especially illuminating example, for the surface truncates hard and soft rocks alike. The lowland is but a later etching of this plain.

Another feature connected with the rejuvenation of drainage, well displayed on the western sides of the Greenwood Range and the Little Burro Mountains, is the abnormal boundary between the gravel and the hard rock and the canyon cutting with which that boundary is associated. The canyons here are steep walled, are cut in rock, and pass abruptly into the gravel sheet at the edge of the mountains, the boundary of the gravel being an abnormally straight line. The natural explanation of this condition is that the mountain masses have been uplifted along faults. The boundaries, instead of passing in a crooked line from the ridge tops forward and downward into the stream channels and back and upward again to the ridge tops, are essentially straight, unaffected by the considerable relief of the country over which they pass. They run without altering their courses down into the streams and up to the tops of the high ridge on the opposite sides. Between the streams they pass along the side of a steep scarp. Though no definite fault planes can be seen, there is little or no doubt that faults exist along both mountain flanks.

Any attempt to explain this relation of the gravel by some hypothesis other than faulting encounters serious difficulties. There are two other ways in which gravel might reach such a position: First, it might be supposed to have been deposited against an old cliff line by a stream flowing lengthwise of the scarp, in the direction now followed by Mangas River, or, second, the cliff line may represent the end of a lava flow. The first hypothesis is untenable on the grounds that such a cliff, in association with the marked rock bench which surmounts it, could not have been eroded since the outpouring of the lavas by a stream whose headwaters, 10 miles to the south, must have been near or on the Continental Divide; nor could such a stream have deposited the gravels which now surmount the Continental Divide. Moreover, such a cliff, if it were cut by a stream flowing past it, would be broken by side canyons approaching the main stream at an angle. The canyons which exist approach it at right angles, Greenwood Canyon, indeed, being slightly reversed. The second hypothesis is untenable because the lavas may be seen on the opposite side of the valley; the flow does not terminate along the cliff.

Further support to the view that this feature is due to a concealed fault is seen in the gravel contact on the eastern side of the Greenwood Range. The L S Mesa shows clearly how the slope of the gravel merges into the nearly flat surface of the lava, and toward Hells Half Acre a decided tilt to the eastward (a tilt too great for normal deposition) is a noticeable feature of the gravels.

Most of the sharp canyons that dissect the more or less well-defined benches described are therefore probably due largely to recent faults which are concealed by overwash of gravel.

Still later changes occurred in the topography of the region, which may best be studied in the stream valleys cut in the Pleistocene gravel. It is evident that at some very recent date the valleys of many of these streams were deeper than they are now, for they are floored with a later deposit of sediment, finer than that in which the main valley is cut. Quite as noticeable as this feature is the evidence of present cutting in this later sediment, to be observed on every hand in the fresh trenches which are working rapidly up the valleys.[3] Figure 4 (p. 3) is an ideal cross section showing the late fill and present-day trenching, and Plate XIII shows a very recent trench in a tributary of Mangas Valley.

One more important fact should be noted. The side streams which show these recent trenches show also that the sediment now being transported down these valleys is coarser than that which composes the valley fill—is, in fact, as coarse as the material in which the original older valley was cut.

Why have the valleys been filled with fine sediments and why are the present trenches being cut? By examining the changes going on at the present day an answer may be found to these questions. After any violent rainstorm one may observe two processes in active operation. First, the sediments in the upper parts of the valleys are being eroded and carried away; and second, the same sediments are being deposited in the lower parts of the valleys. The Mangas Valley and its tributaries show the process to perfection. At the mouths of all the side streams delta-like fans are being deposited, and a most casual inspection of one of these fans will show that its upper part is composed of coarser material than its lower part.

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[1] Paige, Sidney, Rock-cut surfaces in the desert ranges: Jour. Geology, vol. 20, No. 5, pp. 442–450, 1912.

[2] Lawson, A. C., The epigene profiles of the desert: California Univ. Pub., vol. 9, No. 3, pp. 23–48, 1915.

[3] Rich, J. L., Gravel as a resistant rock: Jour. Geology, vol. 19, No. 6, pp. 492–506, 1911.

If these simple facts are applied to the interpretation of the history of the recent filling of the valleys, the inference is that after the first dissection of the great plains—and there may have been several—there ensued a period during which erosion could not have been so active, for at localities where coarse gravel was at one time being moved, fine sediment was later deposited.

ECONOMIC GEOLOGY.

ORES MINED.

ORIGIN OF THE ORES.

In this region, as in many other regions that have been repeatedly subjected to the effects of igneous activity, deposits of many valuable minerals have been formed. Gold, silver, lead, copper, iron, and zinc have all been mined in the region and much valuable turquoise has been produced. Prospecting for meerschaum has been carried on for a number of years with varying success. Only the salient facts concerning the geologic relations of these deposits will be presented, and deposits of several types can receive only superficial attention, as they were not under exploitation at the time of the writer's visit.

Before the ore bodies are described the dates of their formation in geologic time will be stated, as well as their connection with the geologic history of the region. In the following table the geologic events that have a bearing on ore formation are chronologically arranged and correlated with the several ore deposits which they have influenced.

Relation of geologic events to ore formation in chronologic order.

	Geologic events.	Type of deposit.	Minerals.	Periods of enrichment.	Character of enrichment.
Tertiary and Quaternary (spanning volcanic period).	Post-Cretaceous peneplanation combined with Recent erosion, resulting in formation of placers.	Placers near Pinos Altos.	Gold alloyed with silver	Reconcentrated during Recent time.	Enriched placers.
Tertiary (postvolcanic) ?[a]	Injection of quartz and other veins along faults and dikes.	Veins in fault fissures at Fierro and Santa Rita and in Little Burro and Big Burro mountains.	Sulphides of lead, zinc, copper, and iron with gold and silver and manganese-bearing minerals.	Enrichment during Pleistocene and Recent times.	Native copper, oxides, carbonates, and chlorides. Bromides with enrichment of gold (?) by manganese-bearing solutions.
	Postvolcanic faulting and subsequent mineralization of fault planes during intrusion of latitic porphyry stocks and dikes, with replacement of limestone.	Replacement of limestone by solutions at Chloride Flat, Georgetown, Lone Mountain, and Fleming Camp. Primary introduction of sulphides in faults.	Sulphides of lead and silver. Sulphides of iron and copper.		
Post-Cretaceous and prevolcanic.	Fracturing and mineralization of granodioritic and monzonitic intrusive masses.	Primary mineralization at Santa Rita and in Burro Mountains and vein formation at Pinos Altos.	Cupriferous pyrite at Santa Rita and Big Burro Mountains. Sulphides of iron, copper, lead, and zinc, with gold and silver, at Pinos Altos.	Enrichment of upper portions of deposits, probably begun during Tertiary peneplanation and continued with interruptions up to the present.	Native copper, oxides, carbonates, and silicates. Enriched sulphides.
	Intrusion of granodioritic or monzonitic rocks.	Replacement of limestone near Hanover and Fierro and Copper Flat.	Magnetite, hematite, and zinc sulphide. Copper and iron sulphide.		
	Intrusion of quartz diorite porphyry.				
	Intrusion of diorite and dioritic porphyry.	Replacement of limestone near Pinos Altos.	Sulphides of zinc, copper, lead, and iron, with associated gold and silver.		
Pre-Cambrian ?		Small sulphide veins.			

[a] See discussion in text, pp. 6, 12.

Several interesting generalizations may be deduced from a review of the data.

(1) Except a few doubtful deposits, which are not important in this district, all the ore bodies are of post-Cretaceous age and appear to be divisible into two groups, probably of early Tertiary and post-Tertiary age. In each group several more or less clearly defined distinctions are possible.

(2) The formation of all the ore deposits was connected with igneous intrusions, either immediately with the intrusive rock or with solutions that probably represented products of its crystallization. All the intrusives with which the deposits are genetically connected, except one, are of the granodiorite-monzonite group, either in a form that cooled at considerable depth or in the form of fine-grained porphyries that cooled nearer the surface. The connection between mineralization and potassic igneous rocks has been recognized throughout an extensive province in the southwestern United States. The replacement deposit at the Cleveland group of claims, near Pinos Altos, apparently formed at the time of the intrusion of diorite and diorite porphyry, is the exception, but even this rock is closely related to the granodiorite. Fracturing on a greater or lesser scale in all rocks other than limestones, which are notably porous, was a necessary forerunner of ore deposition.

(3) Enrichment served to increase the value of many of the ore bodies that now sustain the production of the region and was perhaps of prime importance in adding value to the richer deposits already mined. Certainly it was effective in enriching some of them. Conditions favorable to enrichment prevailed throughout the period of post-Cretaceous peneplanation and during that of Quaternary erosion.

CHARACTER AND EXPLOITATION OF THE ORES.

REPLACEMENT DEPOSITS IN LIMESTONE.

DEPOSITS NEAR PINOS ALTOS.[1]

Geologic relations.—The Fierro limestone forms a part of the west flank of the Pinos Altos Mountains. The area of limestone is a rectangular mass about 1½ miles long, from north to south, and less than a mile wide. The strata dip eastward and are unconformably overlain by the Beartooth quartzite. A few feet of limy shale overlie the quartzite. The limestone is cut off on the west by a normal fault, which drops the Colorado shale and parts of the igneous complex against it. On the north, south, and east it is bounded by intrusive igneous rocks of the andesite-diorite group, portions of which are intruded into it. A normal fault passes northeastward across the center of the area, the western block being downthrown, so a block of sedimentary rocks that is broken and limited in part by faults lies in the midst of intrusive rocks.

An excellent opportunity to examine the ore bodies of the replacement type was afforded in a development tunnel on the Cleveland group of claims, and on claims adjoining on the west. The ore is an intimate intergrowth of sphalerite, chalcopyrite, pyrite, quartz, and ferriferous carbonate, though the proportions of these constituents may differ considerably from place to place. The sphalerite is well crystallized and in places is arranged in roughly linear fashion, in chains of tetrahedrons, giving the appearance of banding. If broken transverse to this banding the mass appears to be an irregular mixture of its component minerals. An examination of the sphalerite with a hand lens shows that intergrown with it are finely crystallized iron and copper sulphides.

An examination of the tunnel and drifts suggests that the ore has replaced definite beds of the limestone in a fairly regular manner. It appears that there are two distinct ore layers, separated by 4 to 15 feet of limestone. The lower layer is about 12 feet thick; the upper layer is at least 25 feet thick. The layers are cut by basic dikes and are displaced by faults.

On the surface there are extensive gossans composed of a mixture of limonite, smithsonite, azurite, and earthy material with a dark-brown material containing manganese, copper, and iron. Some of the smithsonite may be considered ore. A number of these gossans crop out at an altitude greater than that of the sulphide bodies developed underground and may represent the protruding edges of higher replaced ore-bearing beds.

Other deposits that have many of the characteristics just described lie west of the Cleveland group, where the replacement of the limestone appears to be more irregular and perhaps has no definite relation to the bedding planes. Galena is an important part of the ore mixture, which is reported to contain more silver.

Origin of the ore.—The ore forms beds or irregular masses in the limestone and is probably related genetically to the basic rocks that have intruded the limestone. The question might be raised whether the small dikes or the large intrusive mass caused the mineralization, for the little evidence available is conflicting. As against the introduction of ore by the smaller dikes it may be said that the dikes in the Cleveland tunnel cut the ore bodies. On the other hand, near the face of the Cleveland tunnel a small patch of ore lies directly against a dike, suggesting its local origin, but the patch was not completely exposed and the ore material may have entered from the roof. The fact that some of the dikes cut the limestone with no apparent contact effect on it might be considered an argument against the idea that they are genetically connected with the ore. Therefore, though it is admitted that the intrusion of the main mass and that of the smaller dikes were probably very close in point of time, it is believed that the major effects of mineralization were produced by the larger body. It is therefore a fair assumption that more ore will be found as the main igneous mass on the east is approached, and also that other ore layers or bodies may be encountered below as well as above the exposed layers.

CHLORIDE SILVER ORES AT CHLORIDE FLAT, FLEMING CAMP, GEORGETOWN, AND LONE MOUNTAIN.

Rich ores of silver have been mined at Chloride Flat, Georgetown, Fleming Camp, and Lone Mountain. At Chloride Flat the ores are still being exploited on a small scale. Notes of L. C. Graton[2] have been drawn upon to fill out details in the following account.

General geologic relations.—The geologic relations of the ores at Georgetown, Chloride Flat, and Lone Mountain are very similar. The ores occur in limestone near or at the base of either the Percha shale or the Beartooth quartzite (as at Fleming Camp). At Georgetown and Chloride Flat the relations are similar, the ores occupying irregular open cavities, seams, and cracks in the limestone immediately below the shale and associated with igneous dikes. At Lone Mountain, however, the ore is chiefly in fractures in the limestone.

At Fleming Camp, although the ore is also near the underlying Fusselman limestone, it is said to have occurred largely in pockety cavities in the Beartooth quartzite, which here unconformably overlies the limestone, the Percha shale having been removed by pre-Cretaceous erosion.

Georgetown.—At Georgetown a scarp is cut in the Paleozoic rocks, exposing westward-dipping Carboniferous, Devonian, Silurian, and Ordovician strata cut by dikes. Transverse faults cut the scarp, and on the east a strong fault trending northwestward cuts off the strata by lowering Pleistocene gravel against them.

The ore lies at the base of the Percha shale, in the top of the Fusselman limestone. The ore was mostly cerargyrite, but included some native silver and argentite. Bromyrite and pyrargyrite are also reported. Certain pockets are said to have contained cerusite with silver, and some vanadinite is said to have been found. The limestone is in general much silicified, contains numerous vugs and open cavities, and shows plainly the effect of circulating solutions. Many large cavities are lined with calcite crystals and some large caves contain stalactites and stalagmites of calcite. Small stringers of quartz are common, and in places a network of narrow seams gives the rock an appearance resembling honeycomb. The ore cavities are pockety, and the stopes are of all shapes and run in all directions. The bunches of ore were in some places connected by narrow leaders of low-grade ore.

The workings of the district are above ground water, and the greater part of the ore has been oxidized. The original ore was doubtless, in part at least, an argentiferous galena, but most of the silver was probably deposited as some rich silver mineral, such as argentite, for lead was not a noticeable constituent of the ore. The silicification of the limestone and the deposition of the ores are believed to have been due to solutions that were genetically connected with and accompanied the porphyry dikes.

There is some doubt as to the age of these dikes and therefore as to the age of the ore bodies. As has been pointed out in the discussion of the igneous rocks of the region, the eruption of latite porphyries that are very similar in mineral composition to the granodiorite-monzonite group followed the outbursts of Tertiary lava and are therefore considerably later than the more coarsely crystalline monzonite types, and it is not certain which of these rocks may be represented at Georgetown. There is good reason to believe that the dikes which cut the shale near Chloride Flat are of later postvolcanic intrusion, but one can not be certain of this at Georgetown.

Chloride Flat.—Chloride Flat lies about 1½ miles nearly west of Silver City. The flat valley is a result of the erosion of the soft Percha shale which lies between the Fusselman limestone on the west and the Fierro limestone on the east. The strata dip about 25° NE. and form the range on the north. They are cut by dikes and sills of porphyry.

The ore-bearing horizon, as at Georgetown, is in the uppermost part of the Fusselman limestone, immediately beneath the Percha shale. Where ore occurs the limestone was much altered and such of the calcium carbonate as was not converted to crystals of calcite is now replaced by quartz, galena, argentite (?), and various oxidized compounds of lead and silver, as well as abundant hematite and pyrolusite and some magnetite and limonite.

The silver was produced mainly from silver chloride, from which the district derived its name; also by native silver and from a mineral which, as described, appears to have been argentite. Lead was not an important constituent of the ores.

The ore bodies are extremely irregular. Many of them lay directly below the shale that formed the roof, but narrow shoots or streaks led off to bodies at slightly lower depth. As at Georgetown, the ore bodies may be attributed to the influence of dikes, and the localization of the deposits just below the shale may be due to the effect which that comparatively impervious rock had in arresting the upward passage of solutions, thereby favoring precipitation at the top of the limestone.

The rock of one of the dikes that cut the Percha shale several miles north of Chloride Flat is a fine-grained latite porphyry, and the dike is believed to be an offshoot from one of the latitic stocklike masses of postvolcanic age which cut the great flows north and west of Bear Mountain.

Fleming Camp.—About 6 miles northwest of Silver City, at a camp called Fleming, silver mining was carried on until 1893. Some work was done on the slopes of Bear Mountain; also on Treasure Mountain, a ridge of northwest trend about 2½ miles southwest of Bear Mountain, at the south end of which was the Old Man mine. At this point the Beartooth quartzite overlies the Fusselman limestone. Treasure Mountain is an isolated and much fractured fault block.

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[1] Paige, Sidney, The ore deposits of Pinos Altos, N. Mex.: U. S. Geol. Survey Bull. 470, pp. 109–125, 1910.

[2] Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, 1910.

The ore is reported to have occurred in many irregular pockety bodies in the quartzite. It is said to have been mostly silver chloride which was accompanied by some native silver and some argentite. The quartzite near the old stopes contains, in places, finely disseminated pyrite and is traversed by numerous drusy veinlets of quartz.

Lone Mountain.—Lone Mountain comprises an isolated group of hills about 6 miles southeast of Silver City. Rich silver ore was discovered about 1871 and successful operations were carried on for about 3 years.

The principal deposits were on the southwest side of the mountain. The main ore-bearing rock is the Fusselman limestone, which lies below the Percha shale, but the ore instead of being found immediately below the shale, as at Chloride Flat and Georgetown, occurred chiefly in fractures that crossed the limestone. Some brecciation has taken place along these fractures, and the limestone has been somewhat silicified. Limonite is plentiful and evidently resulted from oxidation of pyrite. Gypsum occurs sparingly. Silver chloride was the most common ore mineral, but the richest ores contained curved bundles of native silver wires and also argentite. The veins are narrow and the values were not persistent. It is reported that most of the ore mined was very rich, though some concentrating ore was extracted.

Ore deposition at Lone Mountain was probably related both in time and origin to the porphyry intrusion. The absence of much lead and the richness of the narrow veins, together with the reported presence of argentite, makes it seem possible that the argentite may have been the principal silver carrier in the unoxidized ore.

CONTACT-METAMORPHIC DEPOSITS.

MAGNETITE AND HEMATITE NEAR HANOVER AND FIERRO.[1]

Geologic relations.—The geologic structure in the Hanover-Fierro basin is simple. Here a mass of granodiorite porphyry and allied rocks has intruded a sedimentary series, in large part limestone of Carboniferous age. On the western border of the mass a thin strip of Devonian shale crops out.[2] The intrusive mass occupies the axis of an anticline trending north and south. On the south a sharp fault takes the place of the fold and on the north a strong fault, trending northeastward, drops Cretaceous strata against the limestone.

Metamorphism.—The intrusion of the porphyry mass into the overlying sediments was accompanied or closely followed by intense local metamorphism of the country rock and by less though marked local alteration of the intrusive body itself. The metamorphism was distinctly a contact phenomenon and was confined strictly to the border zone or such localities as are probably near igneous rocks.

The nature of the metamorphism in different parts of the area is not the same. The southern part is especially characterized by a definite border zone, of irregular width, occupied by a typical contact rock, consisting in large part of epidote, garnet, and pyroxene (hedenbergite), with quartz, calcite, pyrite, magnetite, and sphalerite. On the outer edge of the contact zone on the west side the change from limestone to hedenbergite accompanied by garnet is markedly abrupt. (See Pl. X.) The hedenbergite occurs in radiating crystalline aggregates in which there are masses of garnet. Near the contact with the igneous rock at one place the limestone is replaced by a mass of epidote, quartz, and some titanite. The condition thus described is characteristic of that part of the area which has been mapped as contact rock, though pyroxene is more abundant on the western border. In places there are zones of garnet, which occurs in abundant large, beautifully crystalline masses of the pure mineral, the crystals being generally in rhombic dodecahedrons.

Toward the north silicification is more pronounced, and epidote-garnet zones are rare and only slightly developed. The beds nearest the contact, however, are metamorphosed like those in the southern part of the area, for under the microscope sedimentary beds of extremely fine texture show aggregates of epidote and garnet, with abundant apatite in places, and on the north some beds that probably were originally shale are now composed of extremely fine grains of quartz, feldspar, and abundant pyrite, and are of the nature of hornfels. On the eastern border, near the center of the area, there is a distinct banding of the metamorphic minerals, which follows the stratification of the sediments. Here are found magnetite, quartz, and abundant apatite, and the quartz contains numerous needles of rutile. Metamorphism is not confined to the sedimentary rocks. The porphyry has undergone changes of the same nature as those that have affected the limestone, though to a less degree. A peculiar alteration of marked intensity has taken place in the small intrusive mass that crosses the railroad about half a mile south of Hanover, where the feldspars of the porphyry, which were probably originally similar to the main mass between Hanover and Fierro, have been completely replaced by an aggregate of scapolite, zoisite, epidote, and garnet. The form of the phenocrysts is still perfectly apparent. The formation of this lime-sodium silicate close to the limestone contact suggests the influence of wall rock on the magma, though possibly the only material derived from the magma was chlorine.

Epidote and garnet are contact minerals in the granodiorite, but the greatest change seems to be the acquisition of abundant magnetite, probably replacing hornblende, as this mineral is almost entirely lacking where magnetite is plentiful. There is some evidence also that in places the magma shows a finer crystallization near the borders. In some other areas the intrusive rock undergoes changes quite as pronounced as those of the rock intruded. In the Velardeña district of Mexico[3] metamorphism is believed to have followed intrusion and to have been produced by ascending hot solutions that traversed fractures in the solidified magma. In the Hanover district evidence as to the conditions that existed is not at hand, but the sediments doubtless afforded an easy avenue of escape for circulating solutions, and the solutions, concentrated along the contact, were probably more efficient in altering the limestone than in replacing the igneous rock.

The ores.—The ores are in the main arranged about the periphery of the intrusive stock, at or near its contact with the sedimentary beds. Except at two localities, one in the northwestern part and the other in the northeastern part of the area, the ore bodies lie next to the contact. They are generally irregular lenticular masses of magnetite, accompanied by hematite. Where these masses are exposed at the northern and southern pits of the Union mine their length is very great as compared with their width and depth. At the Jim Fair mine a shorter, comparatively thicker lens is exposed. Besides these large bodies there are numerous outcrops that indicate the same mode of occurrence—that is, in lentils of various width and thickness, swelling and pinching and probably presenting similar irregularities in depth.

Ore that is termed by the miners "soft ore" occurs along the contact. It is characterized by magnetite disseminated as finely and coarsely crystalline material through the limestone, and its commercial value depends on local concentration.

The hard ores have been worked on a large scale at the two pits of the Union mine and at the Jim Fair mine. This mine has in recent years been considerably extended southward. The principal work on the soft ores has been done immediately south of the southern Union pit.

The principal ore of this contact deposit is magnetite, though at the Jim Fair mine considerable hematite has been extracted. Chalcopyrite and sphalerite are associated with the magnetite, but the relative quantities of the three minerals are not known Limestone and contact rock form the most abundant gangue material. In the hard ores the magnetite is generally massive and granular, but the magnetite of the soft ores in many places shows a fine development of the rhombic dodecahedron.

Origin of the ore.—Primarily the ores must be among the "effects" of the porphyry intrusion. Leith and Harder[4] have shown that at some localities contact metamorphism precedes the deposition of magnetite.

Most of the ore bodies are irregular lenses occurring at or near the contact. Barrell and others have pointed out the possibility of shrinkage in sedimentary strata due to metamorphism. Leith and Harder[5] estimate that a horizontal radial shortening of 200 to 500 feet, depending on the depth of the laccolith, was possible as a result of cooling in the Iron Mountain mass. This mass is of the same order of magnitude as the one at Hanover. It might therefore be argued that lenses, large and small, represent the filling of such shrinkage spaces, and that the magnetite is distinctly an "after effect."

Certain other relations may be significant. For example, where metamorphism is not especially pronounced in the limestones—that is, where zones of garnet, epidote, and pyroxene are lacking—soft ores of magnetite have formed. Because of its wide dissemination and its perfect crystallization, the presence of magnetite suggests the introduction of highly mobile solutions of iron precipitated by reduced pressure and temperature. On the other hand, where contact rock occurs soft ores are lacking and hard ores are found next to the intrusive rock. The inference might be that they were unable to impregnate the limestone at such places because of the compactness of the walls and that they are later than metamorphism.

Leaving aside the consideration of the precise time relation of the formation of the magnetite to the contact metamorphism, we may suppose that the following condition existed. On coming to place, the heated magma impregnated certain strata of the surrounding rocks with solutions that were probably above the critical temperature of water. Adjustments due to the cooling of the porphyry, to changes of volume in the intruded sediments, and to gravity served to make the contact zone a favorable place for the passage of superheated gases. Magnetite, which several investigators have shown might be precipitated from iron silicates by reactions with lime,[6] collected, replacing limestone, filling openings, and replacing in part the porphyry.

SULPHIDE AND CARBONATE ZINC ORES AT HANOVER.

The deposits of primary zinc ore are in limestone close to the quartz monzonite or granodiorite porphyry contact. They are essentially contact deposits. Graton says:[7]

> Bodies of almost solid sphalerite containing a very little pyrite and galena and associated with a bronzy mineral in radiating blades—probably the lime-iron pyroxene, hedenbergite — replaces white, coarsely crystalline limestone. A considerable amount of ore is said to have been shipped from these bodies along the contact; part of the ore was oxidized to the carbonate, and less commonly to the silicate, calamine, but most of that is now exhausted.

In 1910 carbonate zinc ores were being mined in the Carboniferous limestone near the porphyry contact close to the town of Hanover.

The ore fills or partly fills open cavities and cracks of all sizes, from minute veinlets to large fissures. The cavities are ovoid or pipelike, or form irregular tortuous passages throughout the limestone.

The ore fills kettle-shaped open cavities and is deposited in laminæ between which lie fine films of impurities. On the upper part of some of the cavities there is a coating of secondary calcite crystals. At some places the manner in which successive layers of smithsonite have grown outward from the walls of cracks points to open fissure filling; at other places large chambers have been entirely filled. The principal ore mined is smithsonite, which occurs in botryoidal incrustations built up in layers and more or less mixed with impurities and is therefore of various colors.

These oxidized zinc ores were without doubt derived from primary deposits of sphalerite, which were formed at the contact of the porphyry intrusion. Surface waters that attacked the sulphide carried the zinc as sulphate and redeposited it as carbonate.

STOCKWORKS OF ENRICHED CUPRIFEROUS PYRITE IN QUARTZ MONZONITE AND GRANODIORITE PORPHYRY.

DEPOSITS IN THE BURRO MOUNTAINS.[8]

Relations and exploitation.—Important deposits of disseminated copper ores are found near the Big Burro Mountains. The ores are associated with an intrusive mass of quartz monzonite or quartz monzonite porphyry, which breaks through the pre-Cambrian complex on the northeastern flanks of the mountains.

Four companies were developing the field in 1910—the Burro Mountain Copper Co., the Chemung Copper Co., the Savannah Copper Co., and the Mangas Development Co.

Origin of the ores.—As these deposits have been described before,[9] only their geologic relations will be considered here. The geologic processes involved in the formation of these chalcocite ore bodies, broadly stated, are three—(1) The intrusion of a mass of quartz monzonite porphyry into pre-Cambrian granitic rocks; (2) the intense fracturing of parts of the mass and the adjacent granite and the subsequent introduction of pyrite and chalcopyrite, the chalcopyrite probably very finely disseminated and intergrown with the pyrite; and (3) the enrichment of the deposits by downward-percolating surface waters. To these processes might be added a fourth—the subsequent leaching of parts of the deposits.

The intruded mass.—The quartz monzonite porphyry forms a mass of rudely circular outline about 5 miles long and 4 miles wide, its larger diameter extending northeastward from a point near the crest of the Big Burro Mountains to a point near the mining camp of Tyrone, where Pleistocene gravel hides its eastward extension. Intense fracturing, silicification, and oxidation of the rocks, together with offshooting monzonite porphyry dikes, made it impracticable to establish exactly the boundary near Tyrone on a map of the scale here used. More detailed work, done since the map was printed, has shown that the boundary runs more nearly eastward from a point just north of Leopold. Fracturing and mineralization affected the neighboring granite, and commercial ore is found north of the contact.

Fracturing.—The second important condition affecting the position of the ore deposits is the intensity and the distribution of the fracturing of the quartz monzonite and the granite. Where the rock is solid and unaltered it contains no ore, but where it is intensely fractured it contains ore. The fractured part of the quartz monzonite is fairly well defined and shows a distinctly traceable gradation from a zone of close fracturing to areas of essential solidity. The area of fractured rock has the form of a triangle pointing southwestward, its point lying about 1½ miles southwest of Leopold and its base being formed

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[1] Paige, Sidney, The Hanover iron-ore deposits, New Mexico: U. S. Geol. Survey Bull. 380, pp. 199–214, 1909.

[2] More recent detailed work by A. C. Spencer has disclosed the presence of Devonian and earlier beds on the eastern border also.

[3] Spurr, J. E., and Garrey, G. H., Ore deposits of the Velardeña district, Mexico: Econ. Geology, vol. 3, p. 698, 1908.

[4] Leith, C. K., and Harder, E. C., Iron ores of the Iron Springs district, southern Utah: U. S. Geol. Survey Bull. 338, pp. 25–27, 1908.

[5] Idem, p. 20.

[6] Clarke, F. W., The data of geochemistry, 3d ed.: U. S. Geol. Survey Bull. 616, p. 345, 1916.

[7] U. S. Geol. Survey Prof. Paper 68, pp. 313–314, 1910.

[8] A detailed description of these deposits is now in preparation by the writer, for publication by the United States Geological Survey.

[9] Paige, Sidney, Metalliferous ore deposits near the Burro Mountains, Grant County, N. Mex.: U. S. Geol. Survey Bull. 470, 1911.

by a line passing from Tyrone to Oak Grove. The zone of greatest fracture lies between Leopold and Tyrone and forms roughly the northwest side of the triangle. Data now at hand indicate that mineralization is not so extensive northwest of this zone. Southeastward from this zone the fracturing fades away over an area having the form of a half-opened fan, one side of which lies along the zone of greatest fracture, the handle of the fan lying southwest of Leopold, and the fan so opening that the northeast edge of it swings through an arc across the base or northeast side of the triangle. On the southern edge of this imaginary triangle the fractured rock merges imperceptibly into essentially solid quartz monzonite.

A study of the mines shows clearly that the depth to which oxidation has penetrated the rocks increases northeastward from Leopold to Tyrone and that toward the south the dip and strike of the fractures shift. In the region about Tyrone the strongest fractures observed in the mines strike northeastward and dip at different angles to the south. There are, it is true, innumerable fractures that do not follow this rule, notably vertical ones, which cut the southward-dipping system, but most of the fractures trend northeastward, and their planes have a southerly dip. On the other hand, the dominant fractures on the southern border of the fractured zone strike eastward and dip northward, though in this area there are other fractures of different trend.

Mineralization.—The present state of mineralization of the ore bodies may be attributed to three processes—primary mineralization, enrichment, and leaching.

Primary mineralization consisted in the deposition of cupriferous iron pyrite (probably finely intergrown chalcopyrite and pyrite) and in places quartz. The pyrite was formed after the quartz monzonite had been fractured. The solutions that carried the sulphides not only deposited their burden in the innumerable fractures but soaked into the body of the rock. Deposition was greatest along the lines of easiest passage—the well-defined fissures. At the close of the period of deposition of the primary ore the mass of the rock consisted of a network of veins and veinlets of cupriferous iron pyrite and quartz and a little chalcopyrite. The feldspar of the rock was altered to sericite and the ferromagnesian minerals were chloritized.

The ore bodies were formed from this stockwork of pyrite veins by enrichment. An opportunity for such enrichment was probably afforded during the post-Cretaceous prevolcanic stage of erosion and again during the Pleistocene and Recent cycle of erosion, in which were laid down those widespread deposits of gravel and sand that now fill the Mangas Valley and the country to the east and south. It was perhaps during this later cycle that effective leaching or impoverishment of preexistent chalcocite ore bodies took place.

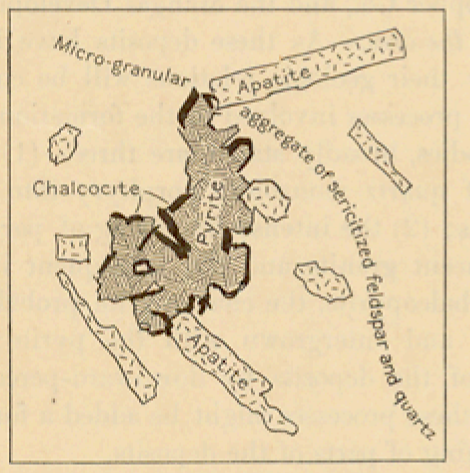

FIGURE 11.—Sketch of microscopic slide of rock showing chalcocitization of pyrite.
Thin section of specimen from mine of Chemung Copper Co.

The processes of enrichment are well known and consist of the oxidation of the unaltered pyrite near the surface by surficial waters and of the deposition of chalcocite at lower levels by downward-percolating water, which carried mainly copper in a sulphate solution.

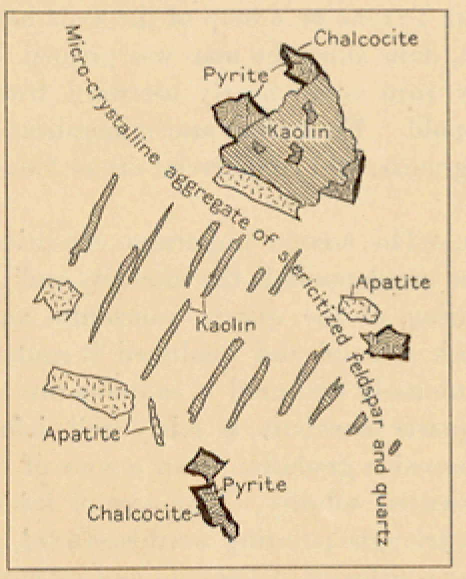

FIGURE 12.—Sketch of microscopic slide of rock showing kaolin with pyrite.
Thin section of specimen from mine of Chemung Copper Co.

A microscopic examination of a number of thin sections cut from sulphide-bearing rocks in the mine of the Chemung Copper Co. shows rather plainly certain stages in the formation of the chalcocite. The relations of chalcocite to pyrite and to the groundmass of sericitized feldspar and quartz, mainly secondary, is shown in figures 11 to 14. Apatite is abundant in places and and kaolin is a prominent alteration product.

Some specimens of the rock contain grains of unaltered pyrite, near which are grains of chalcocite, some without traces of the original pyrite and some showing partial replacement.

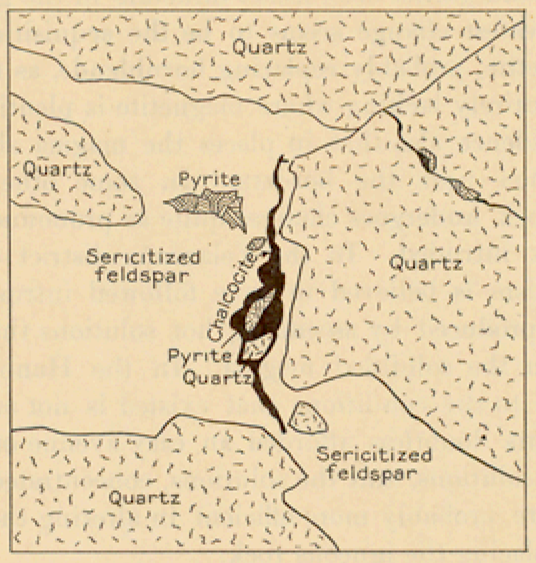

FIGURE 13.—Sketch of microscopic slide of rock showing the replacement of pyrite by chalcocite.
Thin section of specimen from mine of Chemung Copper Co.

It is a characteristic feature of this district that much of the ore-bearing rock that lies near the surface has been thoroughly leached of its copper—that is, all the copper has gone downward and only a siliceous, ferruginous stockwork remains near the surface. In places this leaching has been carried to great depths—700 feet or more. This process of leaching, though a step in the formation of a secondary chalcocite ore body, is unfortunately also capable of impoverishing an ore body and has in fact impoverished bodies of ore at a number of places in the territory examined. Portions of strong veins of chalcocite are leached, nothing remaining of the original mineralization except a network of veins of limonite. The disseminated stockworks also are in places so impoverished as to preclude their extraction at the present price of copper. This late leaching is well shown at some places where fractures cut across eastward-dipping veins. (See fig. 15.)

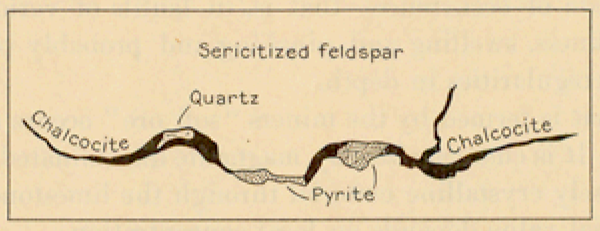

FIGURE 14.—Sketch of microscopic slide of rock showing the replacement of pyrite by chalcocite.
Thin section of specimen from mine of Chemung Copper Co.

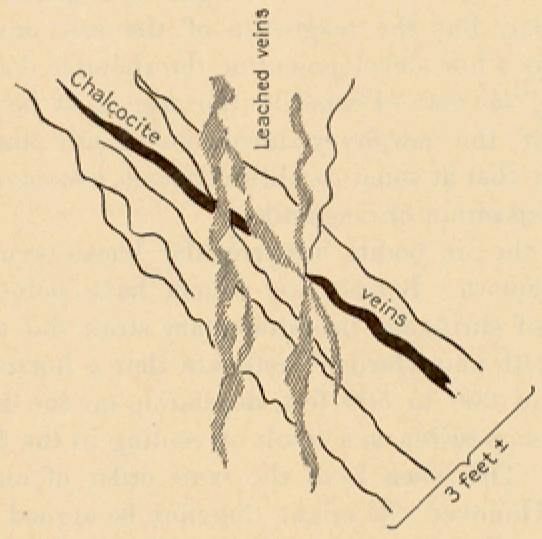

FIGURE 15.—Sketch section in mine of Chemung Copper Co., showing leaching of eastward-dipping chalcocite veins at intersection of vertical leached veins carrying iron oxide.

The thickness of the blanket of barren ground overlying the ore bodies is extremely irregular. In the country southeast of Leopold it ranges from a few feet to 500 feet. There is reason to believe that the topography of the surface near Leopold affects the upper limit of the ore there. For example, an ore body at a certain level will pass horizontally into leached ground as it approaches a gulch on the surface; that is, the leaching is deeper directly beneath stream channels. Near strong veins and faults, too, leaching attains greater depth than in the adjacent ground.

The thickness of the chalcocite zone also is irregular. At some places southeast of Leopold unaltered sulphides are struck at a depth of 380 feet, above which lies 186 feet of enriched ground. The leached ground is therefore 200 feet deep. At one place a drill struck unaltered sulphides at a depth of 250 feet; at another unaltered sulphides were found at a depth of 300 feet. Some of the ground containing chalcocite is 200 to 300 feet thick, and in the Tyrone country leaching has penetrated to depths of 700 feet or more.

The permanent water level also is irregular, standing 300 to 500 feet beneath the surface. It may differ as much as 200 feet in a mile.

All these facts indicate that the ore bodies are very irregular in shape and size, for the depths to which enrichment has penetrated and the amount of leaching that followed such enrichment vary from place to place.

Broadly considered, the best developed ore bodies fall into two classes—those that are directly connected with veins and those that are not. Of the bodies of the first class several were worked extensively in the territory southeast of Leopold and yielded rich ore. In the mines near Leopold and Tyrone also a large quantity of rich ore has been extracted from veins. The bodies of the second class include irregular blocks of ground grading off at the edges into rock too poor to be of commercial value. This grading off into lean material is in some places due to a change to unaltered sulphides, in others to a change to leached material. A number of the ore bodies are several hundred feet in length, breadth, and thickness.

The material that is considered ore in these mines ranges in copper content from 2.5 to 3 per cent, and the price of copper and the cost of mining will determine when the extraction of an ore body ceases to be profitable.

To summarize, the following geologic facts are important in their bearing on the extent and distribution of the chalcocite ore bodies near Tyrone and Leopold.

Ore is found both in the quartz monzonite porphyry and in the granite.

The distribution of the ore is directly dependent on a system of fractures, which cover roughly a triangular area whose point lies southwest of Leopold. The more highly fractured region lies between Leopold and Tyrone. The number of fractures diminishes toward the south, and in this direction there is also a diminution in the richness of the disseminated ores, though not necessarily of the individual veins.

The primary deposition of ore has been governed principally by the fractures. Dikes within the ore-bearing zone, if fractured, may carry ore; if not fractured they do not carry ore. The richest ore bodies are found in the zone of greatest fracture or along well-defined veins. The richest ore is found at the junction of several systems of veins. Ore will not be found in areas of solid, relatively unoxidized quartz monzonite.

The ore bodies are essentially enriched cupriferous pyrite deposits in veins and in stockworks.

The depth to unaltered sulphides is variable and in general increases toward the east. The enriched ore lies mainly above the level of unaltered primary pyrite; but individual enriched veins may pass below that level.

The ore bodies have been locally impoverished by leaching, and though in general commercial ore lies beneath a leached area, yet here and there leaching extends to depths below the principal ore horizons.

SANTA RITA ORE DEPOSITS.

General features.—In the Santa Rita district faulting has brought Cretaceous shale and quartzite against Carboniferous limestone, and contact metamorphism by intrusive rocks has changed the shale and sandstone lentils to a quartzitic rock.

The following brief account of the porphyry chalcocite ore bodies deals chiefly with their major structural features and relations in the district; with the several masses of intrusive rock, as nearly as they were made out in the time that could be devoted to their study, and, in the very simplest terms, with the mineralogy of the disseminated porphyry ores.

Igneous rocks.—What is known of the age and the petrography of the several intrusive masses in this district has already been stated. The larger intrusive masses mapped in the district are the laccolith-like quartz diorite porphyry mass that extends from Fort Bayard eastward to Santa Rita and appears in isolated patches, such as that east of Kneeling Nun and near Lone Mountain, and the granodiorite or quartz monzonite porphyry masses that are prominently exposed between Hanover and Fierro and in the Santa Rita basin. This rock is later than the quartz diorite porphyry and is intrusive into that rock. A third intrusive may be indicated by an oxidized and silicified rim of quartz porphyry that forms the hills east, south, and west of the Santa Rita basin, but the writer regards this intensely altered porphyry as similar in original composition to the mass east of the Kneeling Nun. It may be either a quartzose facies of the quartz diorite porphyry or a separate intrusive. The granodiorite or quartz monzonite porphyry in the Santa Rita basin seems to be intrusive into the rock that forms the silicified oxidized rim of the hills mentioned above, and this intrusion may have affected the distribution of the ore bodies; but more work is necessary to establish this relation.

The boundaries of the quartz monzonite porphyry in Santa Rita basin could not be shown on the map. The area separated on the map from the quartz diorite porphyry mass comprises both the altered quartz monzonite porphyry as a central core and the rim of oxidized silicified quartz porphyry above referred to. When the boundary between these two rocks is finally drawn on a map of large scale the quartz monzonite will probably be shown as confined to the territory bounded by the foot of the oxidized porphyry hills.

Sedimentary formations and structure.—The sedimentary formations of the district are the Fierro limestone and its metamorphic equivalents, represented by a variety of contact rocks; the Beartooth quartzite, deposited unconformably upon the limestone; and the Colorado shale, containing sandstone lentils and their metamorphic equivalents, represented by fine-grained siliceous rocks of quartzitic aspect.

The otherwise simple structure has been complicated by igneous intrusions, with metamorphism, and by faulting.

Granodiorite and other igneous rocks have been intruded into sedimentary rocks with intense contact metamorphism. The failure to recognize a particular form of this metamorphism—the alteration of soft Cretaceous shale and sandstone to dense quartzite-like rocks—has heretofore been a cause of confusion.

Two major faults and a number of minor ones have disturbed the otherwise rather simple relations of the sedimentary section. One of these faults passes northeastward a short distance west of Cobre Siding. Its downthrow is to the east and it may be traced from the lava ranges on the south to a point some distance north of the Ivanhoe mine. The other fault enters Santa Rita from the east. Its downthrow is on the south and it may be readily traced for several miles. The result of these two breaks is to form a downthrown block in which, near Santa Rita, only silicified Cretaceous shale or sandstone and intrusive rocks are exposed. When once this structural relation is recognized the confusion caused by an attempt to correlate various quartzitic beds disappears, for all the so-called quartzite within this fault block near Santa Rita consists of silicified shale or of layers of sandstone that lie above the Beartooth quartzite.

Metamorphism.—The intrusion of the granodiorite or quartz monzonite porphyry into the sedimentary and igneous rocks of the district resulted in pronounced contact metamorphism.

The Fierro limestone has undergone the greatest change. No one can doubt the great transfers of material which are evident in the formation of garnet, epidote, pyroxene, pyrite, pyrrhotite, chalcopyrite, sphalerite, magnetite, and specularite. Silica, iron, sulphur, and other elements have passed into the limestone. The map shows the areas in which the limestone has suffered the greatest change. The distance that silicate solutions traveled from the magma at some places can be closely determined, the pure limestone being completely altered up to a sharp line. The metamorphism of the limestone at Santa Rita is of the same character as that already described about the iron-ore deposits of Fierro.

The Colorado shale at Santa Rita has been altered to a resistant porcelain-like rock that becomes, on weathering, light yellowish and is fractured and seamed with innumerable siliceous and limonitic veins. Metamorphism was produced probably as much by the later solutions, after the intrusion of the porphyry, as by contact with the igneous masses. Under the microscope the rock is seen to be made up of an even-grained aggregate of quartz and sericite specked with iron oxide. Epidote is fairly abundant. The present condition of the rock was probably largely produced during that period of alteration which was accompanied by the introduction of pyrite. The rock generally breaks with a decidedly blocky fracture and may be distinguished from the porphyry which intrudes it by the lack of quartz phenocrysts. It may generally be distinguished from the Beartooth quartzite by its fine grain and yellow color where weathered, and by its blocky cleavage.

The changes in the intrusive rocks of the region were in large part the result of solutions that probably followed closely the cooling of the mass and that traversed the numberless fractures in the rock produced by stresses whose cause remains undetermined. The older intrusive rock, the quartz diorite porphyry, has been very severely metamorphosed by the quartz monzonite porphyry intrusion. The prominent iron-stained hills east, south, and west of the central core at Santa Rita are composed of this altered quartz diorite porphyry or of a quartzose phase of it. Countless seams and cracks traverse the rock. Great quantities of secondary silica entered it through numberless veinlets, and the generally oxidized red appearance of the hills indicates the original pyritization. The rock is generally light colored, stained with iron oxide, and intensely fractured and silicified. It contains quartz phenocrysts and altered crystals of feldspar that are changed to a dull white or dirty color. The microscope shows large resorbed phenocrysts of quartz, generally abundant, and completely sericitized and epidotized feldspar in a groundmass of quartz and sericitized feldspar. The ferromagnesian minerals have entirely disappeared. The rock is not only sericitized but is in places kaolinized. It contains altered feldspar phenocrysts composed of nearly clear colorless kaolin; also very abundant secondary amorphous silica. The quartz monzonite porphyry, which is an important carrier of disseminated copper, is also much altered. The changes that have taken place in it are those which accompanied first the pyritization and later the oxidation of the rock. Abundant sericite has formed in the feldspar, the biotite is chloritized, and kaolin is present. Sulphides are especially conspicuous. The rock is much seamed and fractured but has not received the enormous accessions of secondary silica which seem to have made the surrounding hills of quartz diorite porphyry so resistant.

Mineralization.—That the porphyry copper ores at Santa Rita as a whole lie within the quartz monzonite porphyry intrusive is strongly suggested by the results of numerous churn-drill records. It does not follow, however, that ore may not occur outside the borders of this mass. The ore bodies were formed by the enrichment of a copper-bearing pyrite, which occurred in the closely fractured porphyry and was probably also disseminated through the porphyry lying between the fractures. At some places, as at Whim Hill, very rich concentrations are found in strong fractures.

The surface plan of the ore body as outlined for commercial purposes is shown in figure 16. The latest estimates show that there is 90,000,000 tons of ore averaging slightly above 1.8 per cent copper. The ore minerals are chalcocite, cuprite, native copper, and some carbonate. The carbonate will become progressively less abundant as work proceeds. The local abundance of native copper is a striking feature of the ores and indicates the thoroughness of the oxidation.

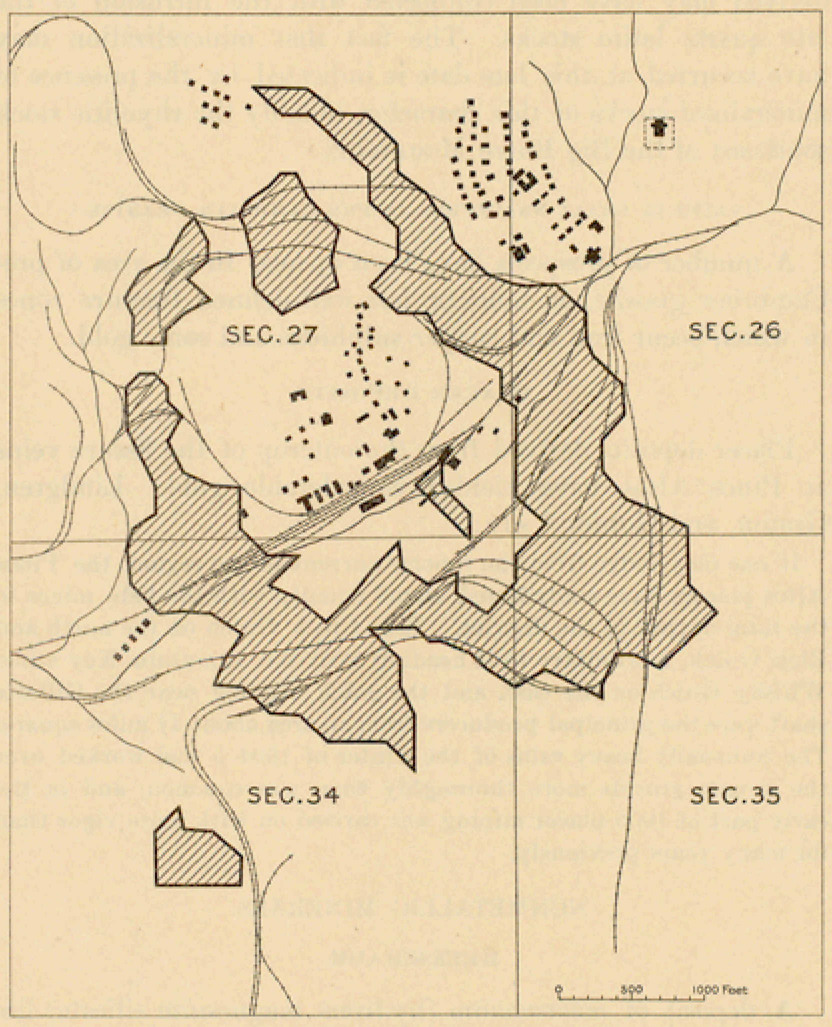

FIGURE 16.—Ore bodies (shaded areas) of Santa Rita as developed in May, 1913.

The zone of leached ground above the ore bodies seems remarkably shallow when the depth and completeness of oxidation are considered. Mr. Sully, the manager of the Chino Copper Co., reports that carbonates have been found at a depth of 327 feet and metallic copper at a depth of 1,020 feet.

An examination of a number of graphic cross sections of the ore bodies constructed from drill records shows clearly the extensive alteration of the original pyrite by oxidation. The fact that some of these oxidized bodies have chimney-like forms and descend below the main chalcocite zone or along its border suggests that channels for descending oxidizing water were open at such places. The cross sections also show clearly that the normal mineral succession in descending order is, carbonates, oxides and native copper, and chalcocite. Local exceptions to this succession are readily explained by assuming a freer circulation of descending waters at those places.

The geologic history of the region throws some light on the enrichment of these ore bodies. The intrusions of the quartz monzonite porphyry type are believed to have taken place about the end of Cretaceous deposition, certainly before the period of erosion that preceded the Tertiary lava flows. The mineralization of the porphyries of the Santa Rita district also took place before this period. Therefore the ores were doubtless enriched to some degree long before the lava floods covered them up and arrested leaching. The time that has elapsed since the lavas were removed has not been sufficient to permit the deep leaching that has occurred at other localities. The ground water in this region must once have stood at a height very different from that which it now occupies (100 feet from the surface in abandoned workings),[1] for, as stated above, the chalcocite zone descends many hundreds of feet.

The original pyritization was caused by solutions which, probably soon after the intrusive mass had cooled, gained access to the porphyry and the inclosing rocks through innumerable fractures whose mode of origin has not been determined.

VEINS.

VEINS IN GRANODIORITE AND DIORITE PORPHYRIES AT PINOS ALTOS.

The geology of the Pinos Altos district is simple. Here a roughly elliptical mass of granodiorite intrudes a complex of diorite porphyry and associated dikes, and veins that were formed in both masses cut across their contact without interruption. On the north rhyolitic and other lavas of later age than the veins cover the intrusive masses. The diorite porphyry forms the crest and much of the main mass of Pinos Altos Mountain. The granodiorite is found along the lower eastern slope and in the territory on the east. The important fissure veins of the district trend from nearly north to northeast, most of them between N. 18° E. and N. 30° E., one nearly north, and one N. 55° E. They cut both diorite porphyry and granodiorite and cross the contact between.

The veins dip steeply both to the east and to the west. They may be traced on the surface for considerable distances, some for a few hundred feet, others for nearly a mile. All die out horizontally by splitting into ramifying veinlets. The distance between the walls of the veins differs in different deposits and also in a single deposit, ranging from a few inches to 6 feet or more. The walls are generally firm.

The veins as a group are characterized by a decided similarity in mineral content. All contain quartz, pyrite, chalcopyrite, calcite, gold, and silver, and most of them contain also rosin-colored, brown, and black sphalerite and galena. Some contain barite and rhodochrosite.

The veins are without doubt the result of open-fissure filling; tensional stresses were powerful enough to fracture the rocks and to keep open the fractures formed; and there is evidence in the veins that fractures closed by vein filling were reopened by renewed fracturing.

The process of open-fissure filling is strikingly shown by a specimen from the Pacific vein taken from the dump at the Hearst shaft. (See fig. 17.) The specimen covers the entire width of the vein and its polished surface is therefore a perfect cross section. It exhibits five distinct layers on each side of the center, each layer having an almost perfect counterpart on the opposite side of the vein. The first layers, those next the walls, contain quartz and pyrite. Their inner sides are outlined by the crystalline terminations of quartz prisms, presenting a fine example of comb structure. The next layers are composed of sphalerite and chalcopyrite. The chalcopyrite is more abundant toward the inner side and in fact forms two subsidiary layers that are separated by a thin sheet of sphalerite. The next layers, which are thin, contain quartz and chalcopyrite. Next to them are thin layers of sphalerite, followed in turn by thicker layers of quartz that contain fine grains of disseminated chalcopyrite and that in places fail to fill the middle of the vein, leaving an open crystalline cavity.

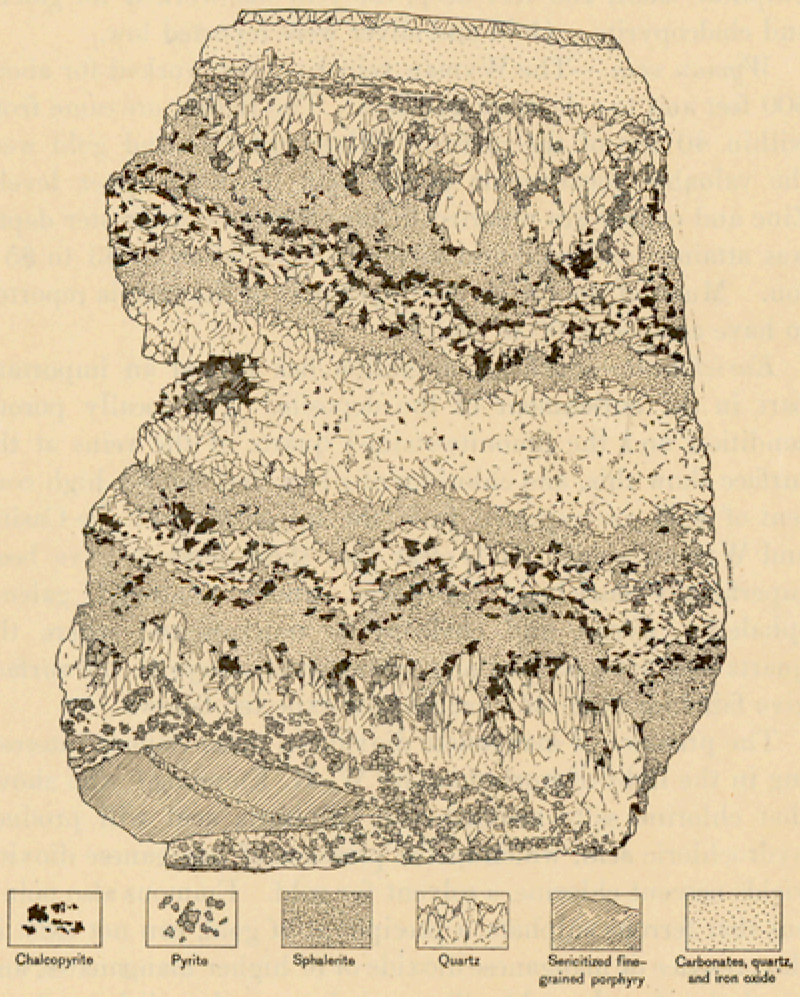

FIGURE 17.—Section of vein showing comb structure.
From Pacific vein at Pinos Altos. Full thickness of vein, natural size.

What is known of the details of individual veins has already been published[2] and need not be repeated here.

VEINS IN PRE-CAMBRIAN IGNEOUS ROCKS IN LITTLE AND BIG BURRO MOUNTAINS.[3]

Little Burro Mountains.

Well-defined quartz fissure veins traverse the pre-Cambrian granite of the Little Burro Mountains, about 1¾ miles north of Tyrone post office. The four principal veins have a northerly or northeasterly trend. The easternmost is known as the Contact vein. Next toward the west, in the order named, are the Wyman vein and the Casino vein. The westernmost vein, so far as the writer knows, is not named.

The Contact vein occupies a fault fissure. The Casino fissure, too, shows some evidence of movement.

Contact vein.—The Contact vein trends N. 60° E. for about 500 feet and then trends N. 10° E. for the remaining distance

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[1] Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, p. 316, 1910.

[2] Paige, Sidney, The ore deposits near Pinos Altos, N. Mex.: U. S. Geol. Survey Bull. 470, pp. 109–125, 1910.

[3] Paige, Sidney, Metalliferous ore deposits near the Burro Mountains, Grant County, N. Mex.: U. S. Geol. Survey Bull. 470, pp. 131–150, 1910.

over which it can be traced. The vein has been opened by several short drifts and crosscuts.

The gangue mineral in the Contact vein is quartz, generally massive, though it contains drusy cavities. The metalliferous minerals are pyrite, a little chalcopyrite, a mixture of manganese oxides (probably pyrolusite and psilomelane), and a silver and lead-bearing sulphide, which is very finely disseminated in the quartz, is intergrown partly with pyrite, and appears in blotchy, grayish-black, cloudlike aggregates. Tests that were made, although not conclusive, indicate that the mineral is finely granular argentiferous galena. Gold also is present, probably associated with the pyrite. The content of copper is not great enough to make that metal commercially valuable. In places where the vein follows the fault plane manganese oxide is conspicuously abundant.

The vein ends at the south at a strong fault, which passes along the west face of the Little Burro Mountains. At its north end it becomes ill defined, and there is some evidence that it passes into a system of smaller fractures, finally dying out entirely.

The ore varies considerably in value. Assays up to 126 ounces of silver and $5 in gold are reported.

Casino vein.—The Casino vein dips steeply to the east and may be readily traced on the surface. The fracture is not a clean break throughout. In places considerable country rock is admixed with quartzose material in alternate thin layers, the whole being impregnated more or less with metallic sulphides. At a 110-foot shaft near the south end of the vein, where an old surface stope may be seen, the quartzose material ranges in width from 5 to 10 feet. At one locality in this stope 3 feet of material, mostly quartz, is separated from the hanging wall by 2½ feet of brecciated vein matter. A clay gouge next to the hanging wall suggests faulting. The gold and silver on this vein are said to decrease toward the north, and the zinc, lead, and copper to increase. Still farther north, at the Copper Sulphide shaft, 100 feet deep, the vein was worked for galena and chalcopyrite. Gold and silver were reported low.

Wyman vein.—The Wyman vein has been worked for about 500 feet and to a depth of 110 feet. The richest ore came from within 40 feet of the surface. Silver chloride and gold were the valuable constituents of the vein in these upper levels. Zinc and copper are reported to have increased as greater depth was attained and gold and silver to have fallen to $3 to $5 a ton. Much of the ore in the upper part of the vein is reported to have assayed $200 to the ton.

Enrichment.—Surficial alteration has played an important part in the enrichment of the deposits. The locally porous condition and the limonite-stained quartz of the veins at the surface show this, and chlorides of silver that carry a high content of gold are reported from the upper parts of the Casino and Wyman veins. It is clear that these deposits have been superficially enriched. However, where unaltered galena, sphalerite, pyrite, and chalcopyrite outcrop and where the quartz has not a stained or porous aspect assays at the surface give fair indication of what may be expected below.

The presence of manganese dioxide in these veins is interesting in the light of work done by W. H. Emmons,[1] who shows that chlorine salts reacting with sulphuric acid will produce hydrochloric acid, which in the presence of manganese dioxide yields nascent chlorine, a solvent for gold. Emmons also points out that ferrous sulphate, a precipitant of gold, can not exist in the presence of manganese dioxide or of higher manganates, and concludes that the gold will travel downward until it reaches a point where no new sources of oxygen are available and the excess of acid in the solutions is removed by reactions producing kaolinization. At this stage iron sulphate becomes increasingly prominent and is effective as a precipitant of gold.

Chlorides are reported from the upper levels of the vein described, and abundant manganese dioxide may be seen in places on the surface. An explanation of the enrichment of the vein seems therefore to lie in the chemical reactions indicated above.

Big Burro Mountains.

A strong quartz vein cuts the pre-Cambrian granite 3 miles south of the summit of the Big Burro Mountains. The lode strikes about N. 85° E. and dips steeply to the south. It can not be traced east of the gulch that lies east of the shaft, but it cuts the country rock on the west. A 150-foot shaft has been sunk and drifts run westward along the lode, which is exposed by four crosscuts and is reported to be 30 feet wide at the bottom of the shaft. In a second shaft, 50 feet deep, the lode is 15 feet or more wide. The hanging wall is a narrow dike, probably rhyolite. Pyrite, chalcopyrite, secondary chalcocite, galena, and hematite are present. The ore is said to carry gold, silver, copper, and lead to the value of $10 a ton. Much of the vein has a barren appearance and contains considerable hematite. The valuable metals are associated with the sulphides. The size and extent of the surface outcrops of this vein suggest considerable persistence in depth.

VEINS IN FAULTS NEAR FIERRO AND SANTA RITA.

A number of mines are located on strong mineralized fault fissures. Such, for example, are the Ivanhoe and Ninety mines, south of Santa Rita, and the Hanover mine, near Hanover. None of these mines were in operation nor accessible at the time of the writer's visit and nothing can be added to what has already been published,[2] except, perhaps, to point out the possibility that the deposits are later in age than the contact-metamorphic deposits in the limestone, which are due to the intrusion of igneous rocks. They occupy fault fissures along which there has been movement that faulted the Tertiary lavas so that the solutions from which these deposits were derived may have been connected with the intrusion of the late quartz latite stocks. The fact that mineralization may have occurred at this late date is indicated by the presence of mineralized stocks of this character, notably the rhyolitic stock southeast of the Big Burro Mountains.

VEINS IN SMALL FRACTURES IN PRE-CAMBRIAN GRANITE.

A number of prospects have been opened in the area of pre-Cambrian granite, on more or less well-defined fracture zones in which occur iron and copper sulphides and some gold.

PLACER DEPOSITS.

Placer deposits derived from the outcrop of the fissure veins at Pinos Altos have yielded considerable gold. Lindgren, Graton, and Gordon[3] say:

> If one may judge from the reports current in the region, the Pinos Altos placers have contributed about equally with the lode mines to the total output of the district. Bear Creek Gulch on the north and Rich Gulch, a tributary to it heading near the Mountain Key mine, Whisky Gulch on the east, and the gulch heading near the Gillette shaft were the principal producers from an area about 1½ miles square. The unusually heavy rains of the winter of 1904–5 had worked over the stream gravels more thoroughly than was common, and in the early part of 1905 placer mining was carried on with more vigor than for many years previously.

NONMETALLIC MINERALS.

MEERSCHAUM.

A deposit of meerschaum (hydrous magnesium silicate) lies about 12 miles northwest of Silver City in the canyon of Bear Creek, about half a mile above the mouth of Walnut Creek. The country rock is the El Paso limestone. At the time of the writer's visit but little meerschaum was to be seen, but soon afterward a deposit was discovered in the creek bottom which yielded blocks of meerschaum several feet long.

Geology. — The deposits lie in a much disturbed region. The El Paso limestone is here only a narrow band, limited on the east and west by well-marked north-south faults. The movement that caused these major dislocations served likewise to fracture the limestone severely. Through the fractures thus produced, both large and small, waters have circulated and within them meerschaum has been deposited. D. B. Sterrett, of the United States Geological Survey, visited these deposits in 1907. His account of the occurrence of the meerschaum follows:[4]

> The meerschaum occurs in veins, lenses, seams, and balls in the limestone. All but the balls are fillings of fractures and joints, which do not seem to be confined to any definite direction. The veins are filled with chert, quartz, calcite, clay, and meerschaum. Chert is the most important gangue mineral and occurs in the veins with meerschaum in bands, lenses, and nodules. Both the crystallized quartz and calcite were observed in small veins, in which also there was a small amount of meerschaum. The largest vein seen contained considerable reddish clay, with chert and meerschaum.
>
> The mineral occurs in two different forms, (*a*) in nodules of irregular shape and (*b*) somewhat massive, with a finer and more compact texture than the nodular form. Some of the veins and seams are filled with massive meerschaum having practically the same texture as that in the nodules, though not in nodular form. In other veins there is both compact massive and nodular meerschaum, generally embedded in red clay.
>
> The nodules range from less than an inch up to several inches in diameter and are of all shapes, with small, rounded knots and bumps protruding from the surface, which is generally coated or stained with the inclosing clay. The nodules are exceedingly tough and have to be vigorously beaten with a hammer before they will break. The fracture of this kind of meerschaum is very uneven and the texture is fibrous, or rather leathery and porous. The color is pure white except where iron stains have worked in from the red clay matrix. Small fragments from the nodules sometimes float for a while when dropped into water, though the greater part sink. Some of the meerschaum that was not light enough to float became so after it had been heated. After absorbing water this meerschaum, like that from other localities, becomes somewhat mushy and has a soapy feeling.
>
> The massive meerschaum is finer grained, less leathery, and heavier. It is very tough, however, and some pieces break with a conchoidal fracture. Small fragments floated on water a minute or two after heating. This variety does not absorb water so rapidly as the nodular varieties.
>
> The occurrence of meerschaum in balls was observed chiefly in one layer of limestone 5 or 6 feet thick. The balls ranged up to 2 or 3 inches in diameter and were distributed through the limestone. In some places they were plainly connected with one another either by merging or by veins; in other places they were apparently unconnected with other bodies of meerschaum. These balls, so far as observed, did not contain meerschaum of commercial value but were composed partly of calcite and another fine-textured white mineral. Some whole balls were composed of these minerals; others contained a core or breccia of chert or dark limestone.
>
> *Chemical properties.*—A chemical analysis made by George Steiger, of this Survey, on selected mineral showed the composition of the meerschaum to be approximately that called for by the chemical formula previously given ($2H_2O+2MgO+3SiO_2$) [hydrous magnesium silicate]. In the following table are given (1) the results of Mr. Steiger's analysis, (2) the theoretical composition:

Analyses of meerschaum.

	1	2
SiO_2	57.10	60.8
Al_2O_3	.58	
Fe_2O_3	Trace.	
MgO	27.16	27.1
CaO	.17	
CO_2	.32	
Water	14.78	12.1
	100.11	100.0

Physical properties.—The meerschaum is very similar in appearance to that from Asia Minor as it appears on the market ready for carving. The Asia Minor meerschaum is a little lighter and more spongy than the surface material here, owing in part, probably, to the fact that it has been dried before shipping.

Value.—The value of the New Mexico meerschaum has not yet been proved. Numerous outcrops of seams and veins of various sizes have been located. Whether valuable meerschaum will be found below the surface can be learned only by opening some veins to a depth where surface movement and weathering have not affected the mineral.

TURQUOISE.[5]

Turquoise deposits famous for the beauty of the gems they produce lie about 1½ miles north of Tyrone, or 10 miles southwest of Silver City. The mines are not now producing. The turquoise is found both in pre-Cambrian granite and in quartz monzonite porphyry. The rocks in the vicinity have been fractured and mineralized. The country rock of the turquoise deposits is also fractured and the most important deposit occupies a fairly well defined fracture zone trending northeastward.

The turquoise occurs in veins and veinlets and as nodular masses in the altered granitic and monzonitic rocks, always in the upper portion of the zone of weathering and associated with copper minerals characteristic of that zone. The rocks carrying the turquoise are sericitized and filled with quartz veinlets.

A good description of the turquoise has been published by Zalinski[6] and may be repeated here.

> The turquoise was found in two forms, as vein turquoise filling cracks in the altered granite and as nuggets or concretions embedded in kaolin.[7] * * *
>
> The Elizabeth pocket extended from the second level to the surface, a distance of 40 feet to 60 feet, and the same quality of turquoise was found for 150 feet or more along the vein. The distance between walls is 40 feet.
>
> Some good turquoise was developed on the third level and sparingly on the fourth, but here turquoise of the best quality was not plentiful and is associated with malachite and chrysocolla. It appears that an excess of copper gives the material a green color and also decreases the hardness. Whether depth is an important factor in the genesis or formation of ideal turquoise can not be determined, but at the present time all of the fine turquoise is found at depths of 100 feet or less. * * * The vein turquoise fills cracks and fractures in the rock and is from one-sixteenth up to three-fourths of an inch in thickness. Most of it, however, is probably from one-eighth to three-eighths inch, but it has been found up to 1½ inches thick. * * * The nuggets or concretions are usually in the softer portions of the vein and along seams, entirely embedded in kaolin. They have various shapes and sizes—reniform, botryoidal, etc., and make the finest gems.
>
> Vein rock from near the Elizabeth pocket showed a medium fine to coarse grained structure, traversed by a more than usual amount of quartz in veinlets and bands up to one-half inch or more wide; these are sometimes open and contain cavities lined with quartz crystals. Vein turquoise sometimes contains small quartz crystals penetrating the turquoise from the sides of the vein. Bordering these quartz bands is kaolinized feldspar. The quartz often gives way to bright blue turquoise, which partly or entirely fills the vein or occurs in isolated specks. Vein turquoise is often separated from the granite on one or both sides by quartz and also occurs in direct contact with the rock without quartz filling. * * *
>
> The character of the turquoise varies from place to place along the vein, and different kinds are also found closely associated.

Zalinski came to the conclusion that the turquoise was deposited by ascending solutions—that is, that the deposits are primary. The writer, however, believes that the mineral is a product of the zone of oxidation and was formed by descending surface waters.

---

[1] The agency of manganese on the superficial alteration and secondary enrichment of gold deposits in the United States, a paper read before the American Institute of Mining Engineers at the Canal Zone meeting, November, 1910.

[2] Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, 1910.

[3] Idem, p. 301.

[4] Sterrett, D. B., Meerschaum in New Mexico: U. S. Geol. Survey Bull. 340, pp. 466–473, 1908.

[5] Paige, Sidney, The origin of turquoise in the Burro Mountains, N. Mex.: Econ. Geology, vol. 7, No. 4, pp. 388–391, 1912. Zalinski, Edward, Turquoise in the Burro Mountains, N. Mex.: Econ. Geology, vol. 2, No. 5, pp. 464–492, 1907.

[6] Idem, pp. 475–476.

[7] Much of the so-called kaolin in the rock sections examined by the present writer proves to be sericite.—S. P.

The conclusions reached in the writer's paper cited above[1] are briefly as follows:

1. The deposits are found in the zone of weathering, are strictly confined to the uppermost portion of the zone of weathering, and are associated with copper minerals characteristic of the zone of weathering (malachite and chrysocolla).
2. Physiographic evidence proves the existence of long periods of erosion under such conditions that if we assume the deposits as deep seated we are confronted with two difficulties, the one to account for the invariable and significant position of all the turquoise of this region with respect to a planated surface, the other to show why the deposits have not either been removed by erosion or altered by the long processes of weathering to which they must have been subjected. To assume that the planated surface has accidentally arrived at the depth where original deep-seated deposition took place would hardly be an argument.
3. There is nothing inherent in the chemical composition of the mineral to exclude it from an origin in the zone of weathering. In fact there are many hydrous phosphates of a more or less analogous composition which have undoubtedly originated in this way. (Negative argument.)
4. A search for the source of the material found in the turquoise indicates that the solutions producing primary mineralization in this region were probably inadequate. Apatite was not attacked and copper was introduced in very sparing quantity. On the other hand, in the zone of weathering apatite has been removed and a concentration of copper is the normal process.
5. Seeking the possible solutions from which the turquoise might have formed, we have some chemical data to show that phosphates of alumina probably did not exist in the solutions which caused the primary mineralization of this region. On the other hand, we have in the zone of weathering a potent solvent for all the constituents found in the turquoise—sulphate solutions formed by the oxidation of pyrite known to have been present. Likewise the constituents of the turquoise were present at the time oxidation began to be effective.
6. Chemical laboratory experiments in the cold agree with the assumption that if the sulphuric and phosphoric acid radicle are present in a weak acid solution which gradually becomes neutralized, the phosphoric acid first will combine with alumina. Mineralogic evidence observed in rock sections indicates that such processes have taken place and that the depletion of phosphoric acid and alumina by leaching resulted finally in the precipitation of sulphates of potassium and iron probably derived from sericite and pyrite.

WATER RESOURCES.

UNDERGROUND WATER.

By N. H. Darton.

A large part of the Silver City quadrangle lies in the mountains or in areas of rocks in which the ground-water conditions are too irregular to be ascertained by geologic observations. In the southeastern part of the quadrangle, however, is an extensive district occupied by a thick sheet of bolson deposits which contain a widespread underflow of water. This water is derived mainly from the local rainfall, but a part of it is the underground drainage of the San Vicente Arroyo and other watercourses. The bolson deposits consist of gravel and sand and some fine-grained layers, and their capacity for holding water appears to be great although it differs considerably from place to place.

One of the best tests of the water was made by the Chemung Copper Co. in the San Vicente Arroyo, 3 miles northwest of Whitewater. A shaft was sunk near the west center of sec. 34, T. 19 S., R. 13 W., to a depth of 250 feet, and drifts were extended for some distance on either side. It is reported that in sinking the shaft a No. 4 pump, raising 300 gallons a minute, was required to keep pace with the influx of water. When the operation was completed the water rose within 136 feet of the surface. Later, a 12-inch hole was bored to a depth of 550 feet, all in water-bearing sand and gravel, and the water from this hole rose in the shaft 20 feet or more.

Wells at intervals along San Vicente Arroyo and on the adjoining plains obtain satisfactory supplies of water at depths of 100 to 170 feet. In the arroyo southeast of Whitewater the surface of the water rises gradually, and near the boundary between Grant County and Luna County it is within 50 feet of the surface of the ground. The water conditions have been tested at several places north of the arroyo, notably in two wells in sec. 3, T. 20 S., R. 12 W., which are 140 and 145 feet deep, respectively, and in which the water stands within 95 feet of the surface.

The warm springs that occur at intervals from Apache Tejo to Faywood Warm Springs produce a large volume of water of underground origin. These springs lie along a northwestward-trending line and the high temperatures of their waters indicate that they rise from a considerable depth, presumably along a fault. At Apache Tejo the Chino Copper Co. has dug a deep pit along the principal orifice of these springs and has developed a greatly increased supply, now estimated at about 4½ second-feet. This water is pumped to Hurley for use in the concentrator.

At Silver City an attempt has been made to obtain an artesian water supply in the limestone, but to a depth of 1,500 feet there had been obtained only a very small flow, which was found at 1,390 feet. Possibly the Bliss sandstone and Beartooth quartzite contain water and at a few points might yield flows or pump supplies.

SURFACE WATERS.

In considering surface run-off from areas of small rainfall, such as the Silver City quadrangle, it should be noted that an annual rainfall of at least 20 inches is necessary to supply the ordinary losses due to evaporation and vegetation. Where the rainfall is less than that amount there will be run-off only during and after periods of great precipitation.

As already stated, the average rainfall for the Silver City quadrangle is about 13 inches, and the rainfall at the higher altitudes is only 25 inches. The streams are therefore intermittent, and their flow depends on the intensity of the rainfall and on the melting of accumulated snow in the mountains.

Gaging stations have been maintained on streams crossing the area as follows:

Mimbres River near Faywood, sec. 7, T. 20 S., R. 10 W.
Cameron Creek at Fort Bayard, sec. 25, T. 17 S., R. 13 W.
Stevens Creek near Fort Bayard, sec. 12, T. 17 S., R. 13 W.
Lampbright Draw near Santa Rita, sec 19, T. 18 S., R. 11 W.
Whitewater Creek at Hurley, sec. 13, T. 18 S., R. 12 W.
Cameron Creek near Hurley, sec. 27, T. 18 S., R. 13 W.
Rio de Arena (Whisky Creek) near Hurley, sec. 21, T. 18 S., R. 13 W.

The records made at these stations are fragmentary except those made on Mimbres River near Faywood, extending from 1908 to 1910 and from 1912 to 1914, and on Cameron Creek at Fort Bayard, extending from 1907 to 1910. The records for these two stations show that the maximum flow usually occurs during summer, when intense storms are most frequent and the snow on the higher peaks is melting. During the remainder of the year the stream beds are not unusually dry. The annual variation in discharge is also great.

The records taken on Mimbres River at Faywood show a flow ranging from 0 to more than 1,000 second-feet. The mean annual flow in 1910 was 4.5 second-feet; from May to December, inclusive, 1908, the mean flow was 54.8 second-feet.

The mean flow of Cameron Creek at Fort Bayard from 1907 to 1910, inclusive, was 0.7 second-foot; the minimum was 0, and the maximum was less than 100 second-feet.

Most of the streams in the area flow in shifting beds and carry large quantities of silt during flood stages.

The following condensed tables show in greater detail the monthly and annual variations in flow:

Monthly discharge of Mimbres River near Faywood, N. Mex., for 1908–1910, 1912–1914.

Month.	Mean discharge in second-feet.	Run-off in acre-feet.
1908.		
May	11.6	713
June	9.7	577
July	126	7,750
August	124	7,620
September	63.0	3,750
October	50.3	3,090
November	23.9	1,420
December	30.3	1,860
The period	54.8	26,800
1909.		
January	17.2	1,060
February	9.54	530
March	8.91	548
April	3.15	187
May	2.21	136
June	1.25	74
July	5.92	364
August	11.4	701
September	3.57	212
October	4.47	275
November	6.90	411
December	2.26	139
The year	6.40	4,640
1910.		
January	5.11	314
February	4.41	245
March	2.34	144
April	2.20	131
May	1.80	111
June	2.47	147
July	5.92	364
August	26.9	1,650
September	2.60	155
October	0	0
November	.17	10
December	0	0
The year	4.52	3,270
1912		
May	9.0	553
June	8.1	482
July	35.6	2,190
August	42.9	2,640
September	36.2	2,150
October	11.5	707
November	11.0	655
December	10.0	615
The period	20.5	9,990
1913.		
January	12.9	793
February	2.56	142
March	7.61	468
April	57.2	3,400
May	4.01	247
June	3.40	202
July	3.14	193
August	8.91	548
September	5.91	352
October	2.16	133
November	7.79	464
December	20.7	1,270
The year	11.3	8,210
1914.		
January	19.4	1,190
February	6.01	334
March	3.96	243
April	3.97	236
May	3.70	228
June	11.0	655
July[a]	----------	----------
August	86.2	5,300
September	26.7	1,590
October	63.3	3,890
November	21.9	1,300
December	200	12,300
The year	----------	----------

[a] High water during July; gage out of order.

Note.—Weighted mean discharge of period 1908–1912, 17.8 second-feet.

Monthly discharge of Cameron Creek at Fort Bayard, N. Mex., for 1907–1910.

Month.	Mean discharge in second-feet.	Run-off in acre-feet.
1907.		
January 19–31	2.54	65.5
February	1.02	56.6
March	1.00	61.5
April	1.00	59.5
May	1.00	61.5
June	1.00	59.5
July	1.31	80.6
August	2.35	144
September	.50	29.8
October	.50	30.7
November	.50	29.8
December	.50	30.7
The period	1.10	710
1908.		
January	.50	30.7
February	.52	29.9
March	.50	30.7
April	.50	29.8
May	.50	30.7
June	.50	29.8
July	1.06	65.2
August	2.05	126
September	.50	29.8
October	.50	30.7
November	.50	29.8
December	.50	30.7
The year	.68	49.4
1909.		
January	.5	31
February	.5	28
March	.5	31
April	.5	30
May	.5	31
June	.5	30
July	.77	47
August	6.57	404
September	.2	12
October	.2	12
November	.2	12
December	.2	12
The year	.93	680
1910.		
January	.2	12.3
February	.2	11.1
March	.2	12.3
April	.2	11.9
May	.2	12.3
June	.22	13.1
July	.61	37.5
August	.23	14.1
September	.13	7.7
October	0	0
November	.07	4.0
December	0	0
The year	.18	136

Note.—Mean discharge of period 1907–1910, 0.72 second-foot.

December, 1914.

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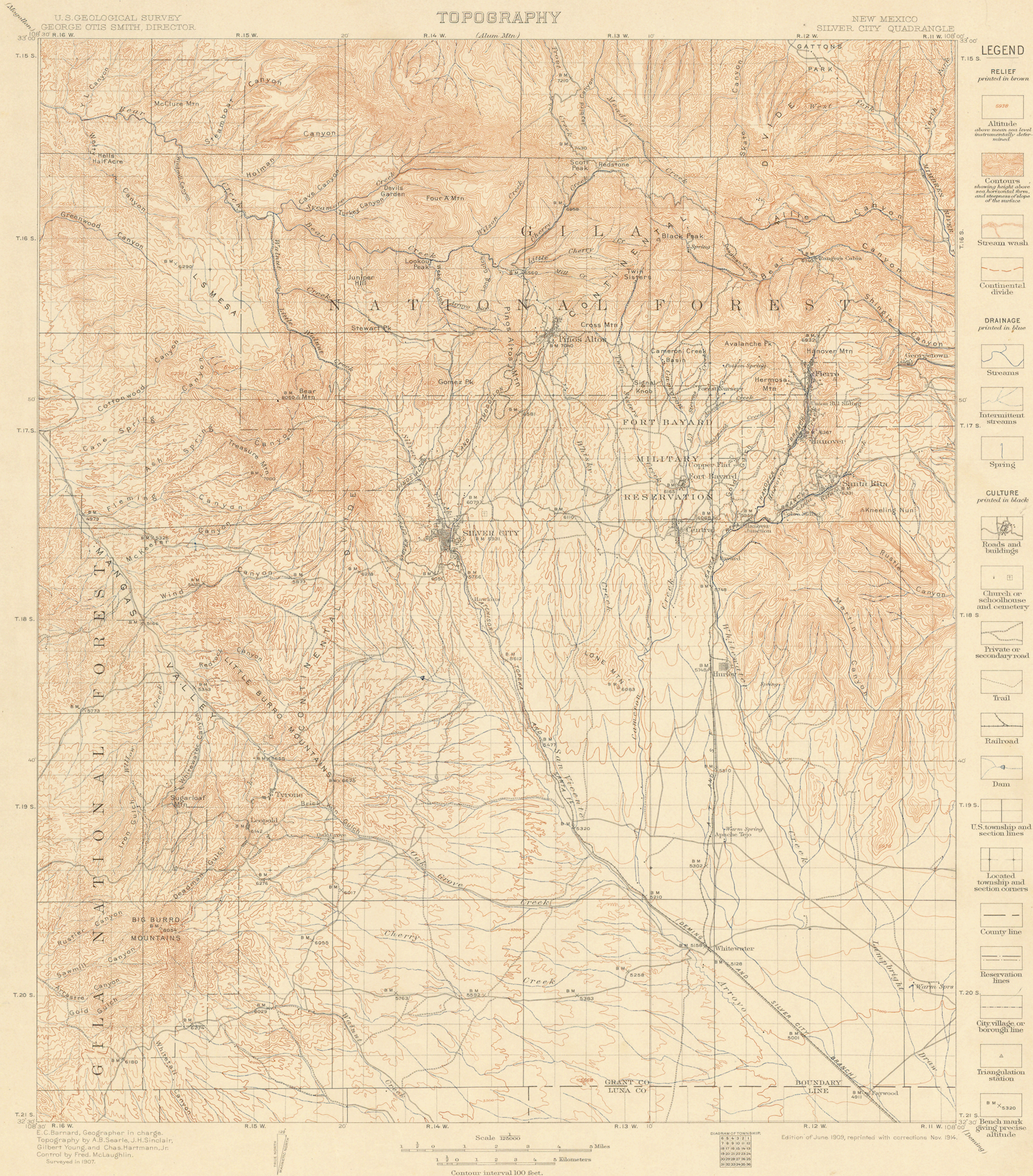
[1] Paige, Sidney, op. cit., pp. 391–392.

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

TOPOGRAPHY

NEW MEXICO
SILVER CITY QUADRANGLE



E.C.Barnard, Geographer in charge.
Topography by A.B.Searle, J.H.Sinclair,
Gilbert Young, and Chas.Hartmann, Jr.
Control by Fred. McLaughlin.
Surveyed in 1907.

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 100 feet.

Datum is mean sea level.

DIAGRAM OF TOWNSHIP.

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

Edition of June 1909, reprinted with corrections Nov. 1914.

U.S. GEOLOGICAL SURVEY
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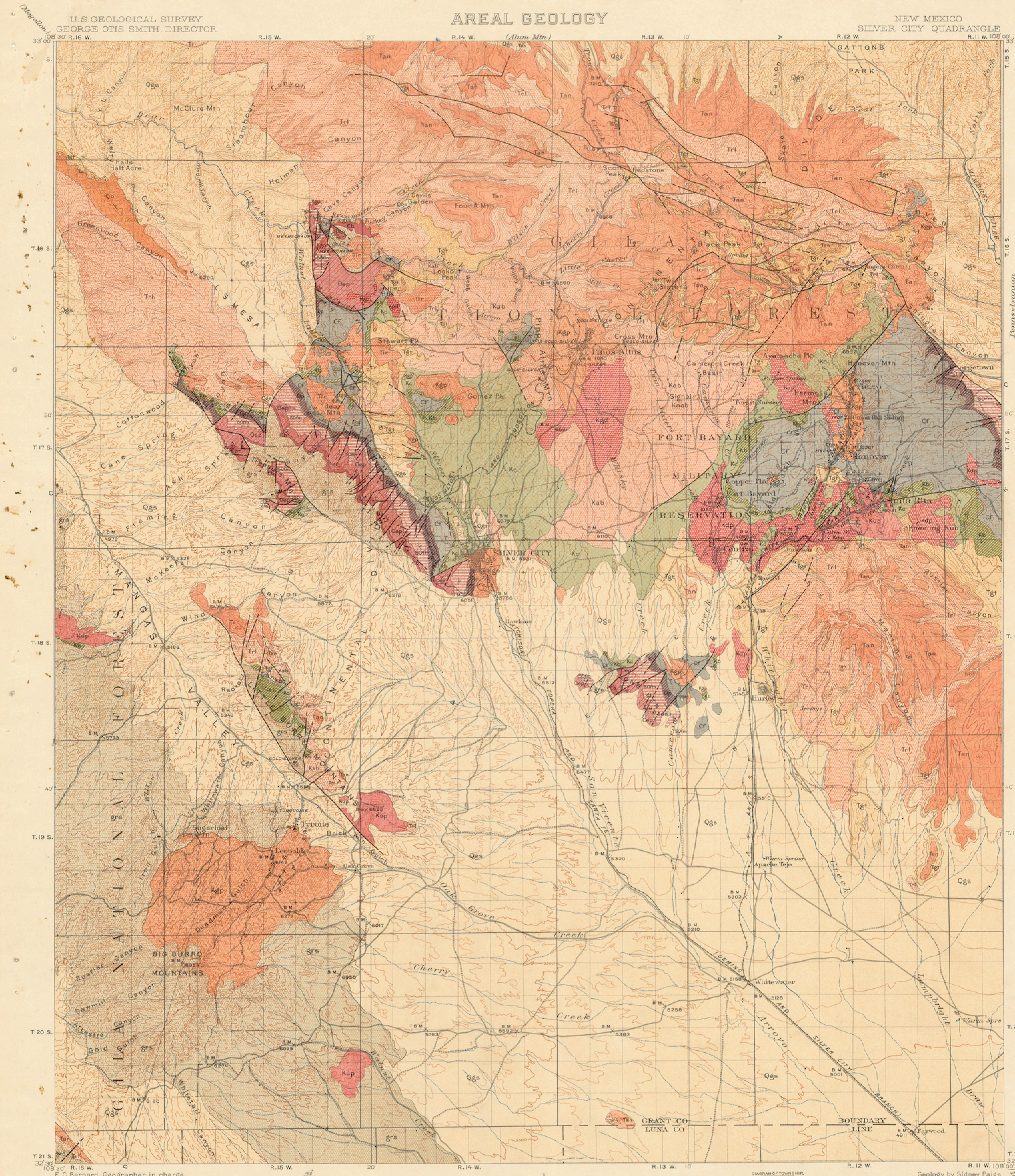
AREAL GEOLOGY

NEW MEXICO
SILVER CITY QUADRANGLE



E.C.Barnard, Geographer in charge.
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APPROXIMATE MEAN DECLINATION 1907.

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

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Geology by Sidney Paige, assisted by John L. Rich.
Surveyed in 1910.

map

LEGEND

SEDIMENTARY ROCKS

(Areas of subaqueous deposits are shown by patterns of parallel lines, subaerial deposits by patterns of dots and circles; metamorphism is indicated by hachures combined with the line patterns)

QUATERNARY — *Pleistocene and Recent*

Qgs — Gravel and sand *(including semi-consolidated sandstone and conglomerate)*

TERTIARY

Tgt — Gravel, sand, and tuff *(partially consolidated and interbedded with Tertiary lavas)*

UNCONFORMITY

CRETACEOUS — *Upper Cretaceous*

Kc — Colorado shale *(shale, thin sandstone, and calcareous shale; some beds of Montana age may be included)*

Upper? Cretaceous

Kb — Beartooth quartzite *(quartzite with thin beds of shale locally)*

UNCONFORMITY

CARBONIFEROUS — *Pennsylvanian and Mississippian*

Cf — Fierro limestone *(gray, blue, and black limestone with many cherty layers)*

Cfm — Contact-metamorphosed Fierro limestone *(altered by igneous intrusion at Santa Rita and Hanover)*

DEVONIAN — *Upper Devonian*

Dp — Percha shale *(green to black shale)*

UNCONFORMITY

SILURIAN / ORDOVICIAN — *Upper Ordovician*

SOfm — Fusselman and Montoya limestones *(gray and pink limestone with many cherty layers; Fusselman, Silurian in age; Montoya, Upper Ordovician in age)*

ORDOVICIAN — *Lower Ordovician*

Oep — El Paso limestone *(gray limestone with many cherty layers; a few beds which contain a Richmond fauna and belong to Montoya limestone included at the top in mapping)*

UNCONFORMITY ?

CAMBRIAN — *Upper Cambrian*

€b — Bliss sandstone *(quartzite, sandstone, calcareous sandstone, and glauconitic sandstone)*

IGNEOUS ROCKS

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

QUATERNARY

Qb — Basalt *(flows, with interbedded gravel and sand)*

TERTIARY

Tir — Intrusive rhyolite and quartz latite *(stocks and dikes)*

Trl — Rhyolite and latite *(lava flows)*

Tan — Andesite and basalt *(lava flows)*

PROBABLY LATE CRETACEOUS

Kup — Undifferentiated porphyries

Kgp — Granodiorite, quartz monzonite, and allied porphyries

Kgd — Granodiorite and more basic rocks at Pinos Altos

Kdp — Quartz-diorite porphyry

Kab — Andesitic breccia, andesite, and diorite porphyry

PRE-CAMBRIAN

grs — Granite, syenite, and allied porphyries *(includes fragments of schist)*

Faults

Concealed faults *(covered by younger deposits)*

Strike and dip of stratified rocks

⚒ *Active mines*
Copper unless otherwise indicated, also gold, silver, iron, and zinc

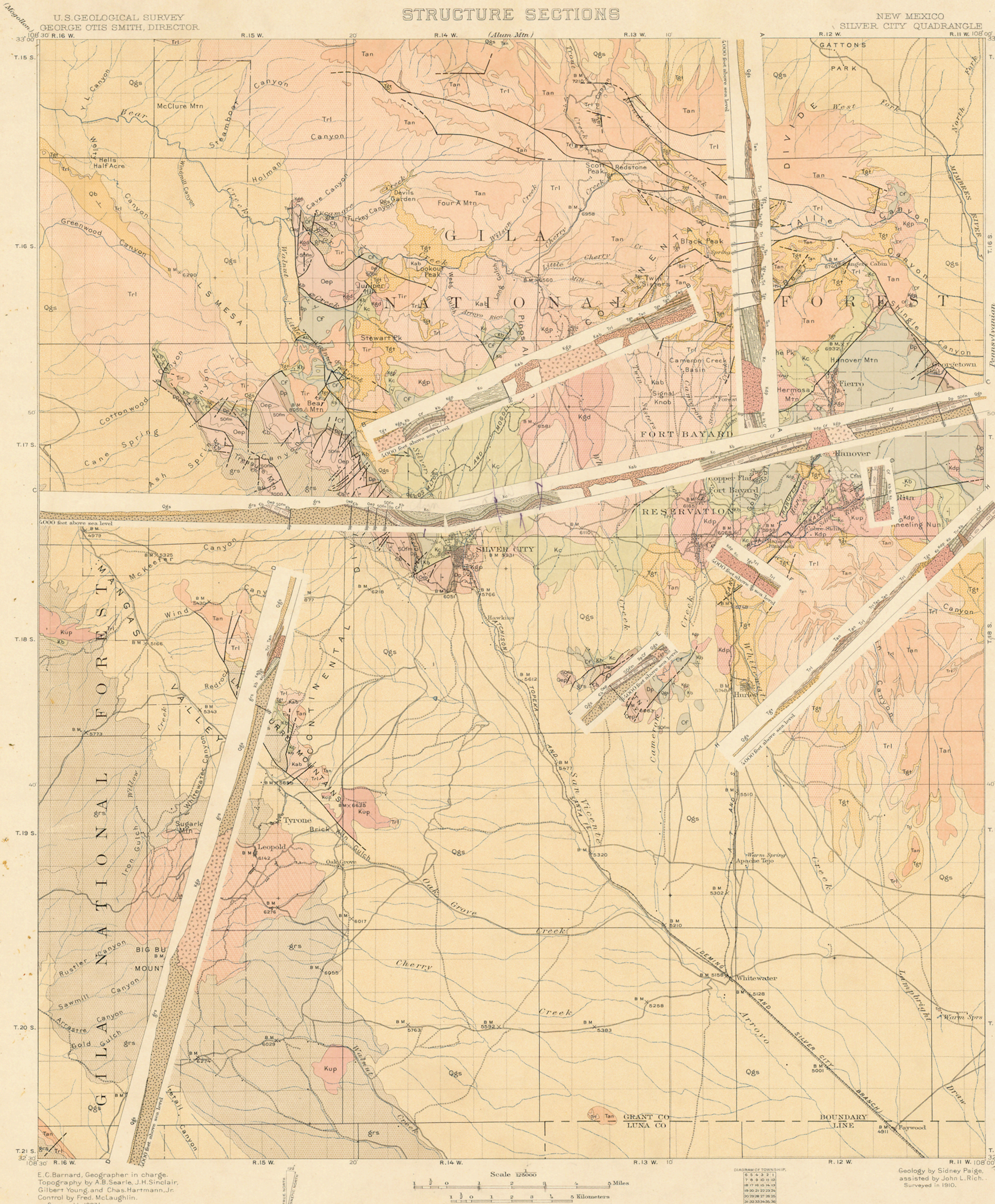
x *Inactive mines and prospects*
Copper unless otherwise indicated, also gold, silver, iron, meerschaum, and turquoise

Economic data: *Gold, silver, lead, copper, iron, and zinc have been extensively mined in igneous rocks and in limestone altered by intrusions; turquoise, in veins in granite and quartz-monzonite porphyry. Meerschaum occurs in pockets in altered El Paso limestone. Underground water is available at moderate depth in the bolson areas in the southeastern part of the quadrangle.*

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

STRUCTURE SECTIONS

NEW MEXICO
SILVER CITY QUADRANGLE



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TRUE NORTH
MAGNETIC NORTH
12°
APPROXIMATE MEAN DECLINATION 1907.

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

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Edition of Dec. 1914.

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Geology by Sidney Paige,
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Surveyed in 1910.

LEGEND

SEDIMENTARY ROCKS

SHEET SYMBOL · SECTION SYMBOL

QUATERNARY — Pleistocene and Recent

Qgs · Qgs
Gravel and sand
(including semi-consolidated sandstone and conglomerate)

TERTIARY

Tgt · Tgt
Gravel, sand, and tuff
(partially consolidated and interbedded with Tertiary lavas)

UNCONFORMITY

CRETACEOUS — Upper Cretaceous

Kc · Kc
Colorado shale
(shale, thin sandstone, and calcareous shale; some beds of Montana age may be included)

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Beartooth quartzite
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Fierro limestone
(gray, blue, and black limestone with many cherty layers)

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Contact-metamorphosed Fierro limestone
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Dp · Dp
Percha shale
(green to black shale)

UNCONFORMITY

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Fusselman and Montoya limestones
(gray and pink limestone with many cherty layers; Fusselman, Silurian in age; Montoya, Upper Ordovician in age)

Lower Ordovician

Oep · Oep
El Paso limestone
(gray limestone with many cherty layers; a few beds which contain a Richmond fauna and belong to Montoya limestone included at the top in mapping)

UNCONFORMITY?

CAMBRIAN — Upper Cambrian

€b · €b
Bliss sandstone
(quartzite, sandstone, calcareous sandstone, and glauconitic sandstone)

IGNEOUS ROCKS

QUATERNARY

Qb
Basalt
(flows, with interbedded gravel and sand)

TERTIARY

Tir · Tir
Intrusive rhyolite and quartz latite
(stocks and dikes)

Trl · Trl
Rhyolite and latite
(lava flows)

Tan · Tan
Andesite and basalt
(lava flows)

PROBABLY LATE CRETACEOUS

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Undifferentiated porphyries

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grs · grs
Granite, syenite, and allied porphyries
(includes fragments of schist)

Faults

Concealed faults
(covered by younger deposits)

Strike and dip of stratified rocks

ILLUSTRATIONS

PLATE I.—BASALT DIKE THAT CUTS PLEISTOCENE GRAVEL.

The soft gravel has weathered away, leaving the hard dike standing like a wall.

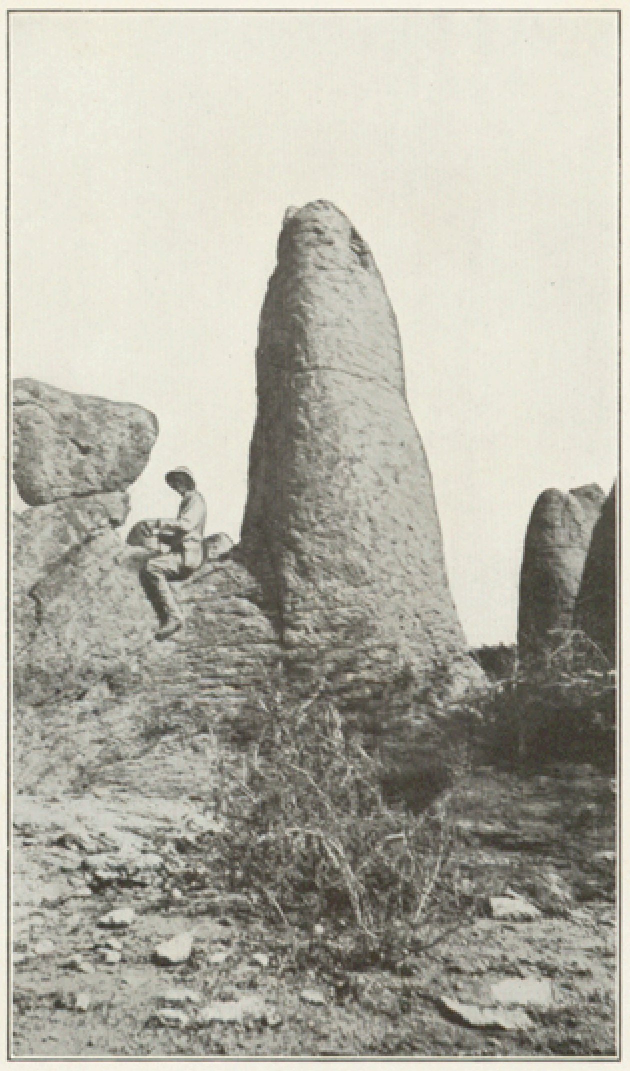

PLATE II.—PINNACLE OF RHYOLITE LAVA FORMED BY WEATHERING SOUTH OF SANTA RITA.

Near view of one of the pinnacles shown in Plate VI.

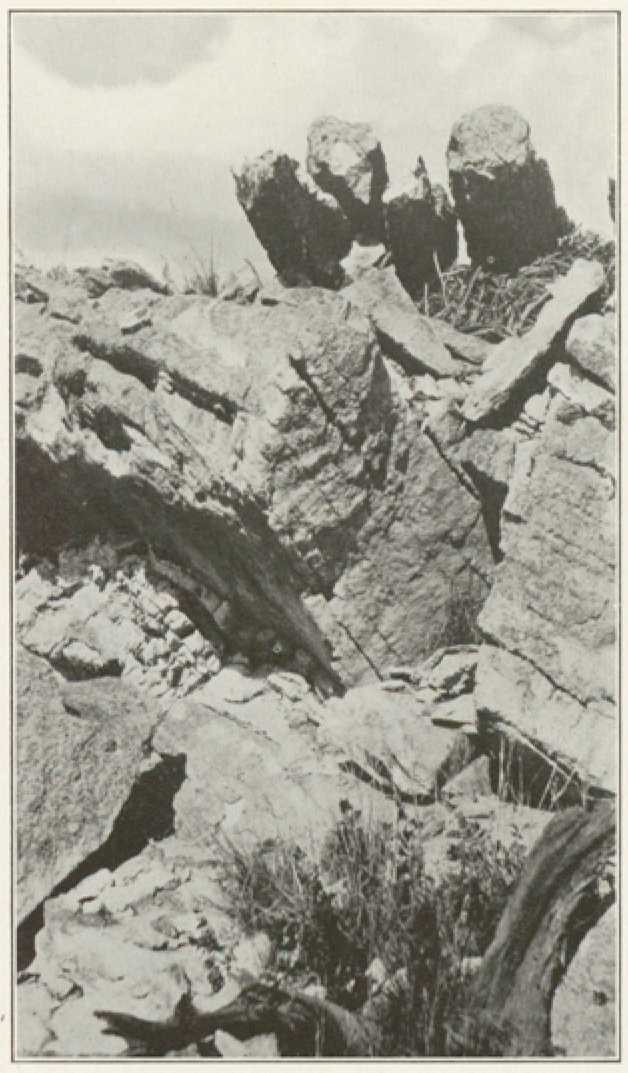

PLATE III.—FLOW STRUCTURE AT EDGE OF INTRUSIVE RHYOLITE PORPHYRY STOCK WEST OF FORT BAYARD.

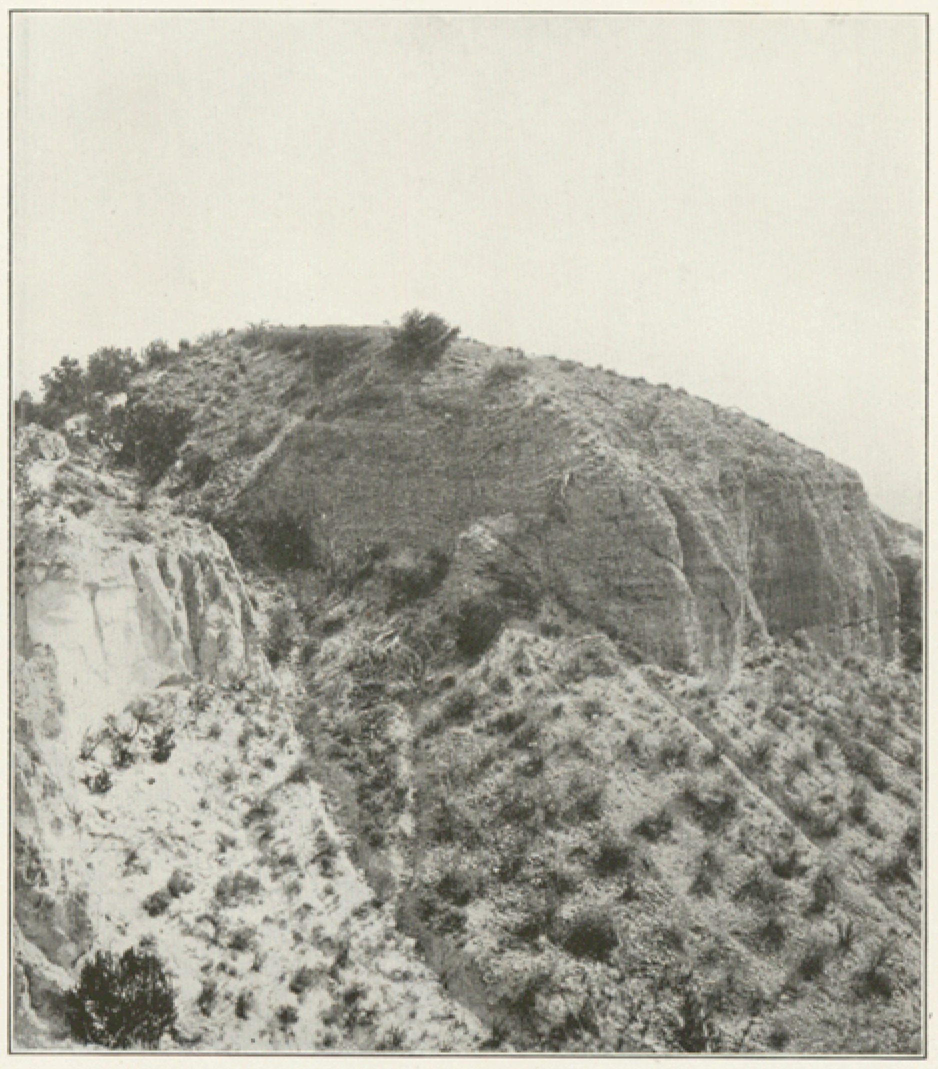

PLATE IV.—PLEISTOCENE GRAVEL FAULTED DOWN AGAINST RHYOLITE SOUTH OF WIND CANYON IN LITTLE BURRO MOUNTAIN.

Fault passes up ravine between white rhyolite cliff on left and gravel hill at right.

PLATE V.—PRECIPITOUS SCARP ALONG FRONT OF RANGE SOUTHEAST OF THE KNEELING NUN FORMED BY CAP OF FLAT-LYING RHYOLITE LAVA.

View looking southeast. Roughly columnar structure of the lava is shown in the near cliff.

PLATE VI.—PECULIAR PINNACLED WEATHERING OF A HORIZONTAL SHEET OF RHYOLITE LAVA SOUTH OF SANTA RITA.

The pinnacles are about 20 feet high.

PLATE VII.—LOW MESA NORTHEAST OF LONE MOUNTAIN FORMED BY A CAPPING OF THIN ANDESITE LAVA IN TERTIARY GRAVEL AND TUFF.

The bench on the slope of the mesa is produced by another intercalated lava bed.

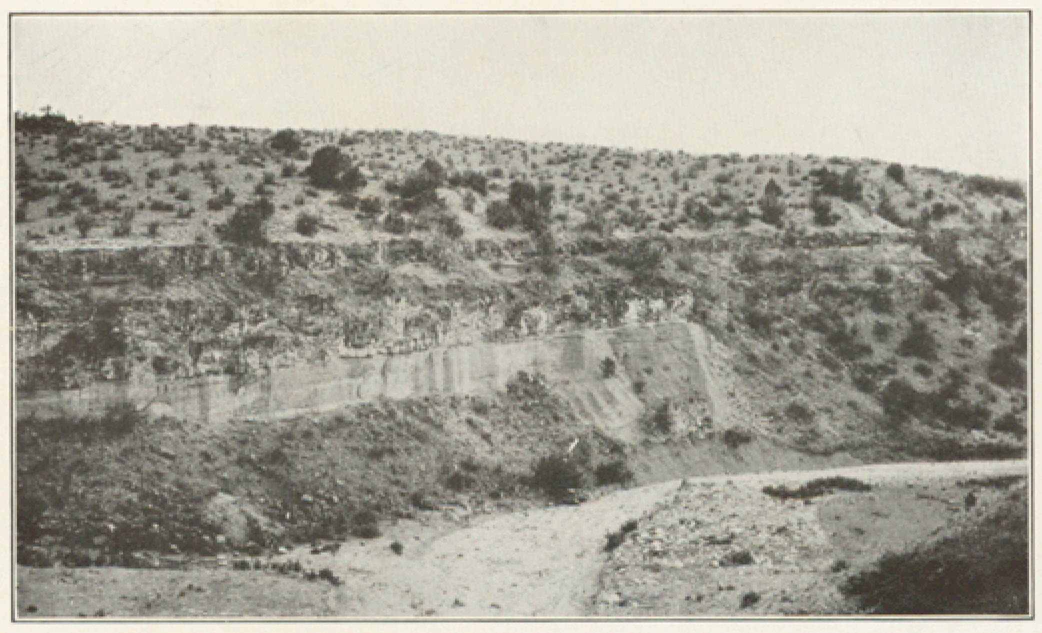

PLATE VIII.—BASALT FLOWS INTERBEDDED IN PLEISTOCENE GRAVEL IN VALLEY OF BEAR CREEK.

The basalt flows form the upper rough cliffs, Pleistocene gravel the smooth lower cliff and the upper slope.

PLATE IX.—TILTED PLEISTOCENE GRAVEL FORMING CLIFF AT HELLS HALF ACRE.

View looking southeast,

PLATE X.—LIGHT-COLORED LIMESTONE ALTERED TO IRREGULAR DARK MASS OF HEDENBERGITE (PYROXENE) BY CONTACT METAMORPHISM NEAR HANOVER.

PLATE XI.—VIEW ACROSS THE LOWLAND EAST OF SILVER CITY TOWARD THE PLEISTOCENE GRAVEL MESAS.

The lowland was once covered to the level of the mesa by the gravel and the mesas are the remnants.

PLATE XII.—OPEN VALLEY CHARACTERISTIC OF LOWER PART OF VALLEYS IN PLEISTOCENE GRAVEL PLAINS.

View looking south toward Lone Mountain, in distance.

PLATE XIII.—RECENT STREAM TRENCHING IN A TRIBUTARY OF MANGAS VALLEY.

Typical of Pleistocene gravel-filled valleys of the region.

and still smaller ones *stages*. The age of a rock is expressed by the name of the time interval in which it was formed.

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

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

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

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

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

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

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

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

Symbols and colors assigned to the rock systems.

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

SURFACE FORMS.

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

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

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

THE VARIOUS GEOLOGIC SHEETS.

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

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

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

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

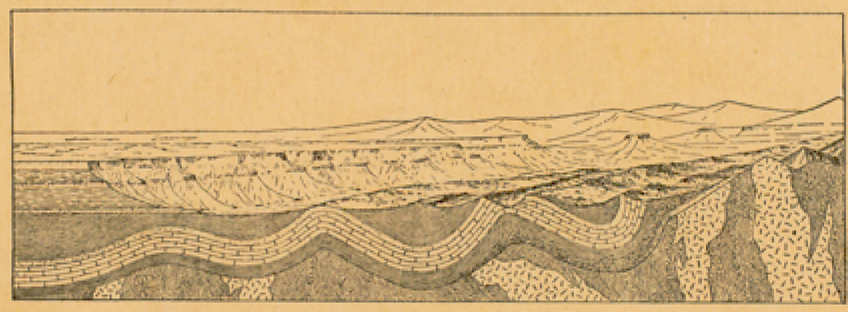

FIGURE 2.—Sketch showing a vertical section at the front and a landscape beyond.

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

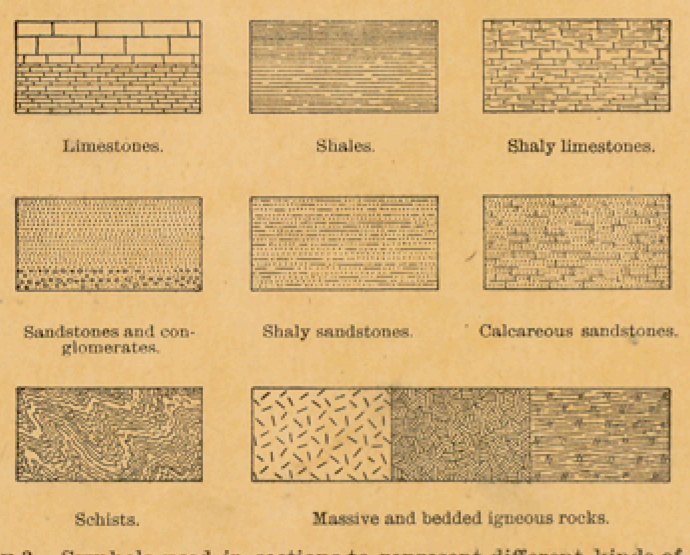

FIGURE 3.—Symbols used in sections to represent different kinds of rocks.

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

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

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

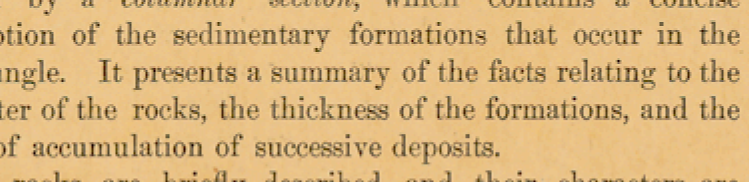

FIGURE 4.—Ideal sections of strata, showing (a) *normal* faults and (b) a *thrust* or *reverse* fault.

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

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

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

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

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

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

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

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

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

GEORGE OTIS SMITH,

May, 1909. *Director.*

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