DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, DIRECTOR

112

GEOLOGIC ATLAS OF THE UNITED STATES

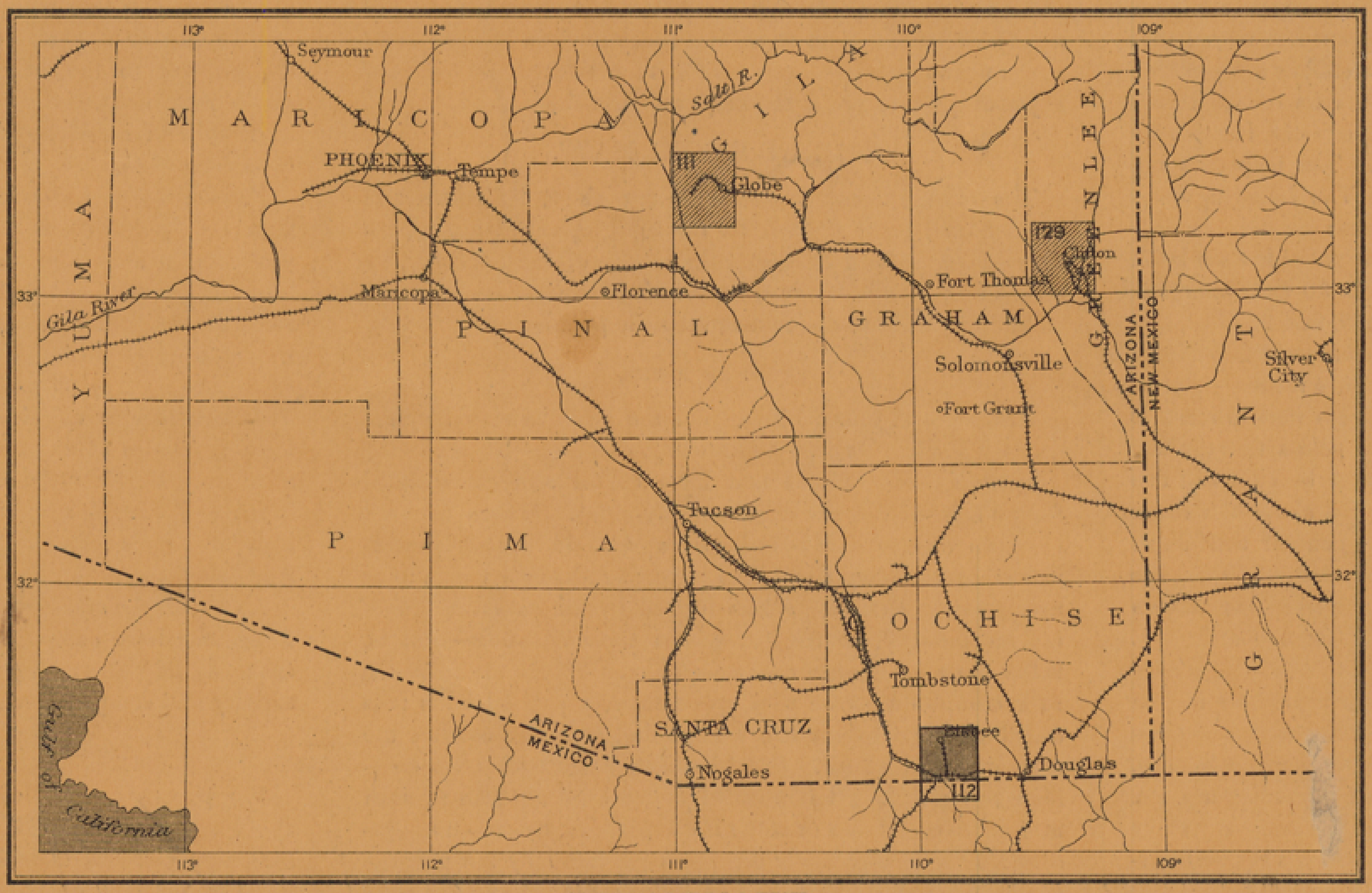
BISBEE FOLIO

ARIZONA

BY

F. L. RANSOME

INDEX MAP



SCALE: 40 MILES=1 INCH

BISBEE FOLIO

OTHER PUBLISHED FOLIOS LISTED ON BACK COVER

WASHINGTON, D. C.

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

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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 BISBEE QUADRANGLE.[1]

By Frederick Leslie Ransome.

INTRODUCTION.

PHYSIOGRAPHIC DIVISIONS OF ARIZONA.

The Territory of Arizona may be divided into three physiographic regions (see fig. 1). The first of these, occupying the northeastern portion of the Territory, is included within the Colorado Plateaus, that wonderful province which the writings of Powell, Gilbert, and Dutton have made classic ground in geology. This division, which within the boundaries of Arizona has an area of about 45,000 square miles, drains northward, through the Colorado Chiquito (Little Colorado), Rio Puerco, and smaller streams, into the Grand Canyon of the Colorado. Its southeastern limit traverses the Territory in a general southeasterly direction from the Grand Wash, near the eastern border of Nevada, to the New Mexico line, a few miles northeast of Clifton. This limit is not everywhere clearly defined. For about 240 miles, extending from the mouth of Diamond Creek on the Colorado River to the vicinity of Fort Apache, the edge of the plateau is marked, according to Gilbert in the Wheeler Survey reports, by the continuous line of the Aubrey Cliffs, which divide the waters of

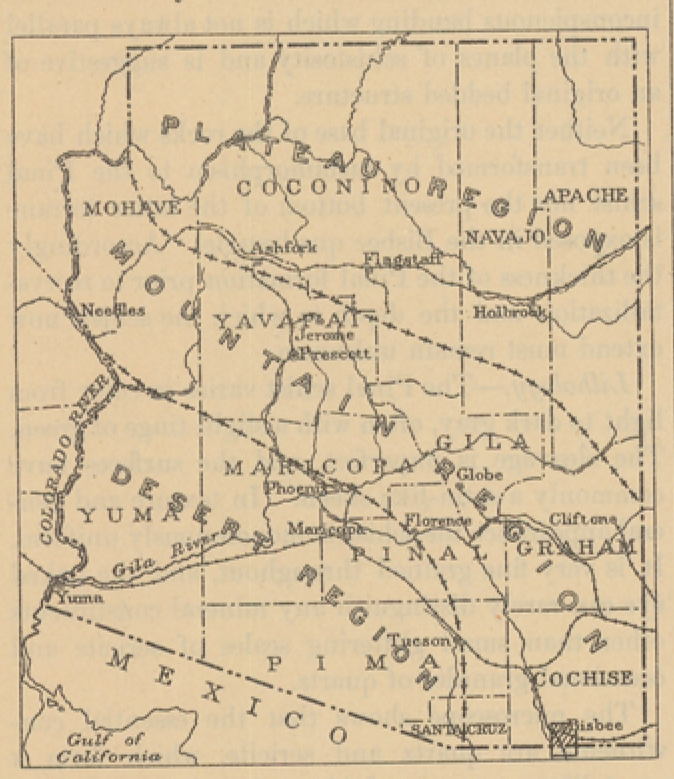


FIG. 1.—Map showing physiographic regions of Arizona.

the Colorado Chiquito from those of the Gila. These cliffs are well shown at the southwestern edge of the Mogollon Mesa, where they form an abrupt scarp from 1000 to 2000 feet in height, overlooking the Tonto basin and facing the Mazatzal and Ancha ranges. From Fort Apache eastward to the New Mexico line the plateau boundary is less distinct. Vast accumulations of volcanic rock have obscured the plateau surface and erosion has partly destroyed its continuity. The San Francisco, Mogollon, Blanca (White), and Escudillo mountains are described by Gilbert as volcanic masses resting upon the general plateau surface. Describing this surface Dutton, in his Tertiary History of the Grand Cañon District, says:

> Its strata are very nearly horizontal, and with the exception of Cataract Cañon and some of its tributaries it is not deeply scored. Low mesas, gently rolling and usually clad with an ample growth of pine, piñon, and cedar; broad and shallow valleys, yellow with sand or gray with sage, repeat themselves over the entire area. The altitude is greater than the plateaus north of the chasm except the Kaibab, being on an average not far from 7000 to 7500 feet. From such commanding points as give an overlook of this region one lonely butte is always visible and even conspicuous, by reason of its isolation. It stands about 20 miles south of the Kaibab division of the Grand Cañon and is named the Red Butte. It consists of Permian strata lying like a cameo upon the general platform of the Carboniferous beds. The nearest remnant of similar beds is many miles away. The butte owes its preservation to a mantle of basalt which came to the surface near the center of its summit. It is an important factor in the evidence upon which rest the deductions concerning the great erosion of this country.
>
> Fifty or sixty miles south of the river rise the San Francisco Mountains. They are all volcanoes, and four of them are of large dimensions. The largest, San Francisco Mountain, nearly 13,000 feet high, might be classed among the largest volcanic piles of the West. Around these four masses are scattered many cones, and the lavas which emanated from them have sheeted over a large area. The foundation upon which they are planted is still the same platform of level Carboniferous strata which stretches calmly and evenly from the base of the Vermilion Cliffs for more than 150 miles southward, patched over here and there with the lingering remnants of lower Permian strata and isolated sheets of basalt. South of the San Francisco Mountains the level Carboniferous platform extends for 20 or 30 miles, and at last ends abruptly in the Aubrey Cliffs, which face southward and southwestward, overlooking the sierra country of central Arizona.

It is the rolling, partly timbered surface of this great plateau, surmounted by isolated volcanic mountains, which surrounds the traveler as he journeys across the Territory from New Mexico, by way of Holbrook and Flagstaff, to Ash Fork on the Atchison, Topeka and Santa Fe Railroad.

The second physiographic division, which may be called the Mountain Region, adjoins the Plateau Region on the southwest, and is essentially a broad zone of short, nearly parallel ranges extending diagonally across the Territory from the southeast corner northwesterly to Colorado River. The width of this zone may be taken as from 70 to 150 miles, but, as will be later seen, its southwestern boundary is not susceptible of precise demarcation. It is characterized by numerous nearly parallel, short ranges, separated by valleys deeply filled with fluviatile and lacustrine deposits. The individual ranges, such as the Dragoon, Chiricahua, Pinalino, Caliuro, Santa Catalina, Tortilla, Pinal, Superstition, Ancha, and Mazatzal mountains, rarely exceed 50 miles in length or 8000 feet in altitude. Their general trend is nearly northwest and southeast, but near the Mexican border it 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 northwesterly belt of Arizona is described by Gilbert as continuous with the Basin Range system of Nevada and Utah, and is considered by him as exhibiting the same prevailing type of orographic structure. He states that his examinations "have demonstrated no anticlinal structures, except as minor features. The usual structure is monoclinal, demonstrably due to faulting in the Chiricahua and Pinal ranges, and presumably so in all the others." With this conclusion the observations embodied in the present folio accord.

As far as can be gathered from existing descriptions the greater number of the ranges consist mainly of Paleozoic sandstones or quartzites and limestones, resting with marked unconformity upon pre-Cambrian schists and granites. The extent to which this ancient basement composes the mass of a given range is dependent upon the elevation of the latter and the amount of subsequent degradation which it has undergone by erosion. The Paleozoic and pre-Cambrian rocks are cut by various eruptives and partly covered by flows of volcanic rock.

Adjoining the mountainous zone on the southwest is the third physiographic division, also characterized by numerous short mountain ranges of prevalent northwest-southeast trend. But in this region the ranges are separated by broad desert plains underlain by fluviatile and lacustrine deposits of late geological age, or by undulating granitic lowlands veneered with gravel or partly covered by flows of lava. This may be termed the Desert Region of Arizona. It can not be sharply distinguished, at least without further investigation in the field, from the Mountain Region, but the boundary between the two may provisionally be taken as a curved line extending from Nogales on the Mexican border past Tucson, Florence, and Phoenix, and thence northwestward to Needles, near the California line. The Mountain Region and the Desert Region are both included in the Basin Range system of Gilbert.

The main drainage of the Mountain and Desert regions is transverse to the trend of the ranges, through the Gila, Salt, and Williams rivers, into the Colorado River. The minor drainage is by streams, many of them intermittent in character, occupying in general the valleys between the parallel ranges.

LOCATION OF THE BISBEE QUADRANGLE.

The Bisbee quadrangle is in Cochise County, in the southeastern part of Arizona and within what has been termed the Mountain Region. It lies between the meridians 109° 45′ and 110° 00′ and the parallels 31° 30′ and 31° 20′, the latter being locally the Mexican boundary line. The area of the quadrangle is about 170 square miles, and includes the southeastern half of the Mule Mountains, one of the smaller of the isolated ranges characteristic of the Mountain Region of Arizona.

The Mule Mountains, while less markedly linear than the Dragoon, Huachuca, Chiricahua, and other neighboring ranges, have a general northwest-southeast trend. They may be considered as extending from the old mining town of Tombstone to the Mexican border, a distance of about 30 miles. On the northeast they are separated by the broad, flat floor of Sulphur Spring Valley from the Chiricahua Range, and on the southwest by the similar broad valley of the Rio San Pedro from the Huachuca Range.

The town of Bisbee, with an estimated population of about 6000, is crowded into a few narrow, confluent ravines near the heart of the range, 7½ miles north of the international boundary. On the east it is connected by the El Paso and Southwestern Railroad with the new town of Douglas, in Sulphur Spring Valley, and with Deming and El Paso; on the west, branches of the same road run to Naco, on the Mexican boundary, and to Benson, on the main line of the Southern Pacific Railroad. At Douglas connection is made with the Nacosari Railroad to Cos, and at Naco with the Cananea, Yaqui River and Pacific Railroad to Cananea, thus bringing the new smelting town of Douglas within reach of the important mines at Nacosari and Cananea in the State of Sonora.

TOPOGRAPHY.

MULE MOUNTAINS.

As the boundaries of the Bisbee quadrangle have been determined without regard to physiographic or geological unity, it is desirable that a brief general account of the topography of the Mule Mountains should precede the more detailed description of a smaller area.

Topographically the Mule Mountains are less imposing than the neighboring Huachuca and Chiricahua mountains, lacking both the striking linear plan and the bold serrate form of these ranges. They are a compact group of ridges and peaks, and, like other mountain masses in this part of Arizona, rise sharply above broad valley plains floored with Quaternary deposits. If the relatively low and rather scattered hills southeast of Tombstone be considered a part of the Mule Mountains, the length of the range is about 30 miles. Its maximum width, in the vicinity of Mule Pass, 2 miles northwest of Bisbee, is about 12 miles. The length of the range is thus about two and one-half times its breadth. Its trend is northwest and southeast. The greatest elevation, 7400 feet, is attained by Mount Ballard, one of the peaks of Escabrosa Ridge, 1½ miles southwest of Mule Pass and 2½ miles west of Bisbee. The general height of the range decreases both northwest and southeast of Mule Pass. About 5 miles northwest of the pass the road to Tombstone enters more open country. The hills become relatively low, and before Tombstone is reached are divided into semidetached clusters by broad embayments of Quaternary alluvium, continuous with that flooring San Pedro or Sulphur Spring valleys. Just southeast of Tombstone these island-like hills connect the main mass of the Mule Mountains with the southern end of the linear Dragoon Range, and form a low divide between Sulphur Spring and San Pedro valleys.

Five miles southeast of Mule Pass the width of the range contracts rather abruptly to about 5 miles, and this narrowed portion decreases in general altitude toward the Mexican border, where the range terminates in a low, broad pass through which the international boundary line runs from Sulphur Spring Valley to the valley of the San Pedro. The geological structure of the southeastern end of the Mule Mountains continues across this pass, however, and the Morita Hills in Mexico, just south of the boundary line, are made up of rocks similar to those composing the southern end of the Mule Mountains.

On their northeast side the Mule Mountains present a fairly straight front, their slopes rising with moderate steepness from the gently inclined detrital plain forming the southwestern part of Sulphur Spring Valley. The line separating the mountains from the San Pedro Valley on the southwest is much more sinuous and the mountain front is more variable in slope and height. Gently sloping plains continuous with the floor of the main valley extend, bay-like, into the mountain mass. The town of Naco lies in such an embayment, which in this case not only extends into the Mule Mountains, as Espinal Plain, but separates this range from the San Jose Mountains in Mexico, just southwest of Naco.

Within the Mule Mountains may be distinguished two topographic divisions, based upon geological structure and roughly separated by a northwest-southeast line passing through Bisbee, through Mule Pass, and down Tombstone Canyon. Northeast of this line the mountains are sculptured from comparatively soft Mesozoic beds striking approximately with the trend of the range and dipping at generally moderate angles toward Sulphur Spring Valley. The slopes of these hills are comparatively smooth, although the occurrence of a hard fossiliferous limestone in the middle of the generally arenaceous group has occasioned a conspicuous and persistent cliff of erosion.

Southwest of the divisional line Paleozoic and older rocks prevail. These are generally more resistant to erosion and more heterogeneous in character than the Mesozoic beds, and have a far more complicated structure. Their erosion has consequently produced a more rugged and less regular topography. These older rocks have their greatest development west of Bisbee, and it is here that the range is highest and broadest. With the gradual disappearance of the Paleozoic rocks to the northwest and southeast, the Mesozoic rocks make up an increasing part of the mountain mass and the general height of the range diminishes. Thus the low hills for some distance toward Tombstone and the insignificant ridges into which the range subsides at its southeast end are made up principally of these less durable Mesozoic beds.

The comparatively simple northeast front of the Mule Mountains conforms to the general strike of the Mesozoic strata. The more irregular southwest front is likewise conditioned by structure, but of a more complex character; for while the dominant structures of the Paleozoic rocks to a recognizable extent conform to the trend of the range, the minor and less uniform structures, resulting from transverse faulting, complex folding, and irregular intrusions, have deeply impressed their own character upon the topography.

With this preliminary survey of the topography of the Mule Mountains as a whole, attention may

[1] The descriptive text of the first edition of the Bisbee folio, issued in 1904, is here reproduced by photolithography without revision. It has been supplemented, however, by additional matter which the reader will find on pages 17 to 19.

now be given more particularly to the Bisbee quadrangle, which embraces practically the southeastern half of the range.

The two-fold topographic division of the Mule Mountains, just described, is well shown within the quadrangle itself. Northeast of a line drawn about half a mile northeast of Tombstone Canyon, Mule Pass, and Bisbee, and extending southeastward to Gold Hill, there is, broadly speaking, a monoclinal ridge composed of Mesozoic strata, with general northeasterly dip, resting upon pre-Cambrian schist and intrusive granite-porphyry. The back of this ridge is deeply furrowed by numerous consequent intermittent streams flowing northeastward into Sulphur Spring Valley. When considered in detail, however, the strata composing the ridge are found to be folded and to be cut by several faults.

Southwest of this dividing line are the Paleozoic and pre-Cambrian rocks. On the whole, the Paleozoic beds have a northwest-southeast strike, which finds topographic expression in Escabrosa Ridge and in the chain of hills extending past Black Gap to Gold Hill. On the southwest slope of Escabrosa Ridge numerous faults and dikes of porphyry, in general parallel with the strike, have cooperated in maintaining the dominant northwest-southeast trend of the main ridge. Inspection of the maps, however, shows that the complex deformation of this portion of the quadrangle has led to a much more irregular topography than that characterizing the Mesozoic terrane to the northeast.

Southeast of Gold Hill the general topographic division just described does not exist. The Paleozoic rocks are here for the most part buried beneath the Cretaceous beds, which extend farther to the southwest than elsewhere in the quadrangle.

SULPHUR SPRING VALLEY.

Probably the most striking topographical feature apparent in the map of the quadrangle is the sharp contrast between mountain and plain—a contrast which, while in no way exaggerated, is perhaps even more striking in a map than on the ground; for one who travels through the arid portions of New Mexico and Arizona usually sees the same feature again and again long before he reaches the Mule Mountains. In the eastern part of the quadrangle the floor of Sulphur Spring Valley, here rising gently toward the southwest from the valley axis, with a grade of less than 100 feet to the mile, ends abruptly at the Mule Mountains, whose northeast front rises with an average grade eight times that of the valley slopes.

A slight increase in the inclination of the plain is noticeable near the mountains, owing to the accumulation along their front of coarser fluviatile material in low, coalescing detrital fans. This increase, however, is not enough to detract materially from the abrupt change in slope, which corresponds in general with the boundary between the Quaternary wash and the older rocks. The difference in altitude between the lowest part of Sulphur Spring Valley included within the quadrangle and the highest point in the Mule Mountains is about 3300 feet.

ESPINAL PLAIN.

In the southwestern part of the quadrangle Espinal Plain, which surrounds the town of Naco and is really an embayment of the San Pedro Valley, exhibits a similar striking contrast to the mountains north of it. To the east of the plain the change is less marked, as the part of the Mule Mountains just east of Gold Gulch, composed of Mesozoic conglomerate, is well worn down by erosion. Espinal Plain is not entirely a constructional plain, but is in small part floored by Mesozoic and Paleozoic rocks that have been eroded to the general slope of the plain surface.

DRAINAGE OF THE AREA.

Two river systems compete for the drainage of the Bisbee quadrangle. One is the northward-flowing San Pedro, whose waters find their way through the Gila and Colorado rivers into the Gulf of California. The other is the southward-flowing Yaqui River, which also enters the Gulf of California after traversing the Mexican State of Sonora. The divide between these two drainage areas enters the quadrangle at boundary monument No. 91 and runs north across Espinal Plain to a low saddle about halfway between Black Gap and Gold Hill; thence it turns northwestward across the open basin just north of Black Gap, and coincides with the crest of Escabrosa Ridge as far as Mount Ballard. From this peak it swings northeastward across Mule Pass to the broad ridge known as Juniper Flat. The country lying northeast of this tortuous water-parting drains into Sulphur Spring Valley, and during the wet season such water as is not evaporated on the way reaches the Agua Prieta, a headwater tributary of the Yaqui River. The country southwest of the divide has a similar intermittent and partly underground drainage into the San Pedro.

CLIMATE AND VEGETATION.

The climate of Bisbee offers no marked exception to the prevailing aridity of central and southern Arizona. Owing to the altitude of the town, 5300 feet, a temperature of 100 degrees is rarely reached in summer. The winter temperature seldom falls below 15 degrees, and the annual mean is about 60.5 degrees. As shown by the reports of the United States Weather Bureau from 1891 to the end of 1900, the average annual precipitation is about 17 inches, so that the aridity, while pronounced, is not extreme. The hottest months are June and July. The greater part of the annual precipitation falls during July and August as heavy showers, which are often very local in extent and of short duration. Occasional showers of rain and flurries of snow may occur at other times during the year, but they are rarely sufficient to tint with green the brown landscape or to aid in the transportation of detritus from the mountain slopes into the valleys. The quadrangle contains no permanent streams and but few perennial springs.

Junipers and oaks of considerable size were formerly abundant in the quadrangle, particularly on Juniper Flat and Escabrosa Ridge, but with the demand for firewood these have disappeared. Such trees as still grow on some of the northern hill slopes are little more than bushes. Prior to 1893 oak trees stood in the streets of Bisbee and the neighboring hill slopes were dotted with shrubs, but this vegetation was destroyed soon after the introduction of the matte process in the Copper Queen smelter, by the resulting sulphurous fumes.

Once each year, just after the summer rains, the country awakes for a brief period from its long drought to a belated spring. Grasses wave over the hill slopes and gay-colored flowers nod among the rocks. But this change in the face of the country is as transient as it is beautiful, and the fresh verdure soon fades into the neutral tints of hopeless aridity.

PREVIOUS STUDIES IN THE AREA.

The first attempt to describe the geological environment of the Bisbee copper ores was that of Wendt, in 1887, which was followed thirteen years later by a more comprehensive account by Douglas. Both of these papers, however, touch on the geology and structure of the Mule Mountains in the briefest way, being concerned mainly with the ore bodies and with the process of ore extraction. Dumble's reconnaissance notes published in 1902, although necessarily fragmentary, are the first step toward any general knowledge of the broader geological features, and to him is due the first recorded recognition of the extensive Cretaceous deposits of the Bisbee region.

The papers just referred to, with two other works of a general nature, which have been drawn upon for historical data, are included in the following brief list of publications:

List of publications on the Bisbee district.

HINTON, R. J. The Handbook of Arizona. San Francisco and New York, 1878.

General description and early history of region about the Mule Mountains. Records the then recent discovery of ore in these mountains.

HAMILTON, PATRICK. The Resources of Arizona. First edition, Prescott, Ariz., 1881. Second edition, San Francisco, 1883. Third edition, San Francisco, 1884.

Contains notes of the early history of mining near Bisbee.

WENDT, ARTHUR F. The Copper Ores of the Southwest. Trans. Am. Inst. Min. Eng., vol. 15, 1887, pp. 25-77.

Sketches briefly the geological occurrence of the ores. Describes the latter as filling fissures and caves in Carboniferous limestone, and concludes that they were originally deposited as carbonates and oxides, and not derived from sulphides by oxidation practically in situ.

DOUGLAS, JAMES. The Copper Queen Mine. Trans. Am. Inst. Min. Eng., vol. 29, 1900, pp. 511-546.

Sketches the history of the mine and describes the character and geological occurrence of the ores. Discusses the origin of the ore bodies.

DUMBLE, E. T. Notes on the Geology of Southeastern Arizona. Trans. Am. Inst. Min. Eng., vol. 31, 1902, pp. 696-715.

Describes particularly the Cretaceous deposits in the Mule Mountains and names them the Bisbee beds. Estimates their total thickness at about 3000 feet. Notes the occurrence of Carboniferous limestone and suggests that Devonian is also represented. Correlates the quartzite (Bolsa quartzite) underlying the Paleozoic limestones with the quartzite of the Dragoon Mountains (Dragoon quartzite). Refers to it as pre-Devonian. Notes the occurrence of mica-schists, to which he assigns a thickness of 300 feet. States that they rest upon granite, although in some places an intrusive porphyry is said to intervene.

GENERAL GEOLOGY.

PRELIMINARY OUTLINE.

The fundamental rocks of the Bisbee quadrangle are crystalline schists of pre-Cambrian age, separated by a profound unconformity from the overlying Paleozoic beds. The latter comprise a basal Cambrian quartzite 430 feet in thickness, succeeded by over 4500 feet of limestones representing portions of Cambrian, Devonian, and Carboniferous time. The Ordovician and Silurian systems, so far as known, have no lithological representation in the quadrangle.

At the close of the Carboniferous period the rocks of the Bisbee quadrangle were deformed by faulting and folding and were cut by intrusions of granitic magma. The principal mineralization of the district probably dates from this time of revolutionary disturbance. The region as a whole was elevated above sea level and subjected to erosion until the beginning of the Cretaceous period.

During the Cretaceous the land again sank beneath the sea, and over 4500 feet of sandstones, shales, and limestone, representing the earlier part of this period, were accumulated.

Subsequent elevation brought these sediments above sea level and exposed them to erosion. The quadrangle contains no rocks of Tertiary age and there are no known facts from which to determine the exact date of the post-Cretaceous uplift. It was accompanied or followed by faulting and folding.

During the Quaternary and probably during a part of the Tertiary the higher parts of the Bisbee quadrangle have been undergoing erosion, their waste accumulating in the flat-floored valleys that surround the Mule Mountains.

DESCRIPTION OF THE ROCKS.

Pre-Cambrian Metamorphic Rocks.

PINAL SCHIST.

Name.—In the Globe folio, the name Pinal schist was applied to the fundamental crystalline metamorphic rocks of the Pinal Range. These were shown to be essentially quartz-muscovite- or quartz-sericite-schists derived from arenaceous sediments, and to be separated from the oldest Paleozoic rocks by a profound unconformity. The Pinal Range lies about 90 miles north of the Bisbee quadrangle, and no occurrence of Pinal schist has yet been identified within the intervening country. Nevertheless, the lithological similarity of the schists of the Pinal Range and of the Mule Mountains, and their identical relation to the great unconformity at the base of the Paleozoic, are considered to justify the application of the name Pinal schist to the fundamental schistose rocks of the Bisbee quadrangle.

Distribution and general structure.—The Pinal schist is the ancient crystalline foundation upon which rest all the Paleozoic and younger sediments of the region, and through which have broken the granite and porphyries exposed in various parts of the district. It is probable that it underlies the entire quadrangle, but for the most part it is buried beneath hundreds or thousands of feet of later rocks. At present it is exposed only in the northwest quarter of the quadrangle, where the beds which formerly covered it have been stripped off by erosion.

The largest area of Pinal schist, if interruptions due to intrusive bodies of porphyry be disregarded, is that which underlies the town of Bisbee. This area, which, so far as present exposures go, is divided by the porphyry mass of Sacramento Hill, extends southeastward from the town about 3 miles and finally disappears beneath the Cretaceous rocks in Mule Gulch. Northwest of Bisbee the area becomes much broader and the Pinal schist forms most of the slope between Tombstone Canyon and the crest of Escabrosa Ridge. It is the rock in which Brewery Gulch and Dubacher Canyon, north and east of Bisbee, have been excavated, and near the heads of these ravines it passes beneath the Glance conglomerate, which marks the base of the Cretaceous sediments. It is exposed also by the erosion of the overlying Cretaceous in the upper part of Soto Canyon, east of Juniper Flat.

Along Escabrosa Ridge, northwest of Mount Martin, the Pinal schist is well exposed, sometimes forming the crest of the ridge and sometimes capped by outliers of Paleozoic strata. It also extends down the southwest slope of the ridge, as in Moore and Bolsa canyons, but is there intersected by an elaborate network of dikes and faults.

The most southern exposures of the schist are in a few small fault blocks near the mouth of Escacado Canyon, $1\frac{1}{2}$ miles northwest of Don Luis.

In general the main exposed area of Pinal schist may be described as limited on the southwest partly by passage beneath the unconformably overlying Bolsa quartzite, but chiefly by faults and igneous intrusions, and as bounded on the northeast by the irregular line defining the base of the Cretaceous beds, under which the schist extends for an unknown distance as the eroded basement upon which these Mesozoic sediments were laid down.

The Pinal schist has a typical schistose structure. The planes of schistosity are usually more nearly vertical than horizontal, and are so contorted and so variable in dip and strike from point to point as to preclude, in the present stage of regional denudation, any unraveling of general pre-Cambrian structure. The dominant trend of the schistosity appears to be about NNE.-SSW., but wide departures from this direction are encountered on every hand. The schists sometimes exhibit an inconspicuous banding which is not always parallel with the planes of schistosity and is suggestive of an original bedded structure.

Neither the original base of the rocks which have been transformed by metamorphism to the Pinal schist nor the present bottom of the latter terrane is exposed in the Bisbee quadrangle. Accordingly the thickness of the Pinal formation prior to recrystallization and the depth to which the schists now extend must remain unknown.

Lithology.—The Pinal schist varies in color from light to dark gray, often with a slight tinge of green. The cleavage is imperfect, and the surfaces have commonly a satin-like sheen. In texture and general appearance the schist is monotonously uniform. It is very fine grained throughout, and the naked eye can rarely distinguish any mineral constituents other than small glittering scales of sericite and occasional granules of quartz.

The microscope shows that the essential constituents are quartz and sericite, which form a crystalline aggregate of minute interlocking grains, and tiny foliated wisps. The sericite shows a tendency toward arrangement in parallel bands and thereby gives to the rock its imperfectly fissile character. With these preponderant minerals are commonly associated a few small prisms of tourmaline up to a quarter of a millimeter in length, occasional red garnets of about the same diameter, a few nests or shreds of chlorite, small crystals of zircon, and granules of magnetite or ilmenite. An occasional grain of sodium-calcium feldspar, probably oligoclase, can be microscopically detected among the quartz grains which make up most of the rock.

Amphibole was not observed in any of the specimens studied, and biotite is certainly a rare constituent, although it was noted in a bleached and decomposed state in a single thin section.

Origin.—The general character of the schists in the Bisbee quadrangle indicates that they were at one time arkosic sands or silts. Their metamorphism has been more uniform than in the Pinal Mountains of the Globe district, without the development of any such coarsely crystalline phases as are there found. This difference is undoubtedly connected with the absence of pre-Cambrian granitic intrusives in the Mule Mountains and their abundance in the Pinal Range. Much of the metamorphism of the Pinal schist in the Globe quadrangle is due to the obvious contact action of large intrusive masses. While it can not be said that concealed bodies of intrusive rock have had no part in the recrystallization of the Pinal formation of the Mule Mountains, this process seems to be more nearly a simple case of what is known as regional metamorphism.

Age and correlation.—The crystalline Pinal schist which was probably originally a sedimentary rock but whose original structure has been nearly obliterated by metamorphism, underlies Cambrian beds in which the ordinary change from loose cross-bedded sands to hard sandstones or quartzites constitutes the only noticeable alteration. The Cambrian beds rest with a basal conglomerate upon the eroded edges of the contorted schists. The Pinal schist is therefore not only pre-Cambrian but is separated from the Cambrian strata by profound unconformity. This unconformity, considered in connection with the train of geological events implied by the complete metamorphism of Pinal schists prior to the deposition of the earliest Cambrian sediments of the region, presents no less vividly to the imagination "the long result of time" than do all of the up-piled beds of the Paleozoic. There can be no question that the Pinal schist is vastly older than the Cambrian sediments.

If, as is not improbable, the Pinal schist is the equivalent of the "Vishnu series" of Walcott in the Grand Canyon of the Colorado, then it is also much older than the supposed Algonkian rocks represented by the "Chuar and Unkar terranes," which in that great gorge are found to overlie the Vishnu schists with conspicuous unconformity. Furthermore, Powell and Walcott describe the "Grand Canon schists," or "Vishnu series," as in part metamorphosed sediments, and the Pinal schist of the Globe region was certainly derived from ancient sediments by metamorphism.

If, therefore, the original definition of the Algonkian as including all pre-Cambrian sedimentary rocks be accepted, the Pinal schists belong in that period, which must then be considered as embracing rocks above and below the most profound unconformity known in Arizona. In view of this fact, it seems best, in the absence of definite correlation, to refer to the Pinal schist simply as pre-Cambrian, leaving future investigation to determine whether the Algonkian is to be represented in Arizona by the Grand Canyon series, or by the Vishnu series, or by both of these series separated by an unconformity apparently as profound as any described in geological literature.

Paleozoic Sedimentary Rocks.

GENERAL STATEMENT.

The Paleozoic rocks of the Bisbee quadrangle are divisible into five formations. At the base, resting upon the Pinal schist, is the unfossiliferous Bolsa quartzite. Overlying the quartzite is the Abrigo limestone, carrying middle Cambrian fossils. Succeeding the Abrigo is the Martin limestone, of Devonian age, which in turn is overlain by the Carboniferous (Mississippian) Escabrosa limestone. The youngest of the Paleozoic formations is the Naco limestone, which overlies the Escabrosa and belongs in the Pennsylvanian series of the Carboniferous.

CAMBRIAN SYSTEM.

BOLSA QUARTZITE.

Name.—The name Dragoon quartzite has been applied by E. T. Dumble to some pre-Devonian arenaceous beds, about 400 feet in thickness, occurring in the Dragoon Mountains.

It is possible that the so-called Dragoon quartzites of the Dragoon and of the Mule mountains are, as Dumble supposed, stratigraphically the same, but this correlation can not be regarded as established. For this reason the name Dragoon quartzite has been abandoned as applied to the basal sedimentary formation of the Bisbee quadrangle and Bolsa quartzite adopted in its stead. The later designation is derived from Bolsa Canyon, on the southwest side of Escabrosa Ridge, where these beds are well exposed.

Distribution and general stratigraphy.—The principal exposures of the Bolsa quartzite are in Escabrosa Ridge, west of Bisbee. In the northeast corner of the quadrangle this formation is represented by small residual outliers resting here and there along the crest of the ridge upon the pre-Cambrian schists. These remnants of once continuous strata become larger toward the southeast, and near Bisbee the quartzite makes up a considerable part of Escabrosa Ridge. Owing to the prevalent faulting, however, the Bolsa quartzite is not found in extensive areas nor in continuous belts of more than a mile in length. About three quarters of a mile west of the center of town the quartzite, which has been quarried for silica, is well exposed as the basal formation of the faulted syncline of Paleozoic rocks, to be later described. Half a mile west of the quarry, and separated by a great fault from the syncline just referred to, is the most typical and instructive exposure of the Bolsa quartzite to be found in the quadrangle. The beds, with a total thickness of 430 feet, are continuously exposed in the line of strike for a distance of a little less than a mile along the northeast slope of Mount Martin. They rest with a very conspicuous unconformity upon the pre-Cambrian schists, and dip to the southwest at an angle of about 25 degrees. They are conformably overlain by the Abrigo (Cambrian) limestone, succeeded by the Martin (Devonian) and Escabrosa (Mississippian) limestones, the last named forming the summit of Mount Martin. As this section is a typical one not only for the Bolsa quartzite but for the overlying Paleozoic limestones, it will be frequently referred to in the following pages and may be conveniently designated the Mount Martin section.

Between Mount Martin and the western edge of the quadrangle are many small areas of the Bolsa quartzite bounded on one or more sides by faults.

As may be seen from the geological map, all the exposures of the Bolsa quartzite occur in the northwest quarter of the Bisbee quadrangle. The formation undoubtedly underlies other portions of the area studied, but is there buried beneath younger beds. The present distribution of the exposed areas is determined by deformation and erosion, not by original deposition.

Lithology.—The Bolsa quartzite is constant in its lithological character and is readily recognized wherever it occurs within the quadrangle.

The base of the formation is exposed at many places along Escabrosa Ridge. It is invariably marked by a bed of conglomerate from 6 inches to a foot in thickness, resting upon the eroded edges of the pre-Cambrian schists. Most of the pebbles of this basal conglomerate are composed of white vein quartz and are rarely over 3 inches in diameter. This conglomerate is overlain by hard pebbly grits in beds from 10 to 20 feet in thickness, the change from conglomerate to grit being as a rule not very definitely marked. The scattered pebbles in these thick-bedded grits are usually white quartz, but their matrix frequently contains abundant small fragments of pink feldspar mingled with the predominant quartz grains. Cross-bedding is often a conspicuous feature in the lower part of the formation. The pebbly grits in turn pass upward into thinner bedded, more vitreous, fine-grained quartzites showing no feldspathic material, which are conformably overlain by the Abrigo limestone.

Age and correlation.—As no fossils have been found in the Bolsa quartzite, its exact geological age is not directly determinable. It will presently be shown, however, that the Bolsa formation is conformably overlain by the Abrigo limestone, which contains a middle Cambrian fauna. It is thus, without much doubt, the stratigraphic equivalent of the Tonto sandstone of the Grand Canyon section, considered by Walcott as also included within the middle Cambrian, the lower Cambrian being there represented by the unconformity between the Tonto and the Grand Canyon series. It is possibly the equivalent of the lower part of the thicker and more varied Apache group of the Globe district in central Arizona, about 110 miles north-northwest of the Bisbee quadrangle, and also correlated provisionally in the Globe folio with the Tonto group.

In the Mule Mountains the absence of Algonkian beds equivalent to the Grand Canyon group renders the unconformity at the base of the middle Cambrian even more pronounced than in the Grand Canyon. At Bisbee the Bolsa quartzite rests directly upon the Pinal schist, which is regarded as probably the equivalent of the Vishnu schist of the Grand Canyon section, although further work in Arizona is necessary to establish this correlation.

ABRIGO LIMESTONE.

Name.—The Abrigo limestone is named from Abrigo Canyon, 3 miles southwest of Bisbee, where the beds composing the formation are well exposed.

Distribution and general stratigraphy.—Like the Bolsa quartzite, the Abrigo limestone occurs principally in the northwestern part of the quadrangle, although a few small areas are found within the attenuated belt of Paleozoic rocks extending southeastward past Gold Hill toward Glance Creek. The most satisfactory occurrence, and the only one in the quadrangle where the entire sequence of the beds from base to top may be studied in a single continuous exposure, is that of the Mount Martin section (see fig. 4), a mile and a half west of Bisbee.

As measured in this section the Abrigo limestone is 770 feet in thickness. It rests conformably upon the Bolsa quartzite and is overlain by the Martin limestone (Devonian). The beds strike nearly northwest-southeast, and dip southwest at an angle of 25 degrees.

Many smaller areas of the Abrigo formation occur along the crest of Escabrosa Ridge, commonly bounded on two or more sides by faults, or by dikes of granite-porphyry. The most extensive exposures, however, are found on the southwest slope of the ridge, where the Abrigo limestone underlies a practically continuous area about a mile in width and 4 miles in length, stretching northwest from Abrigo Canyon to about a mile beyond Moore Canyon. The boundaries of this area are in most cases faults or intrusive contacts. The prevailing strike of the beds is northwest-southeast, and they dip in general to the southwest.

As the Abrigo limestone is more readily eroded than the granite-porphyry, Bolsa quartzite, and younger Paleozoic limestones, the larger areas of this rock are found to be associated with topographic features of but relatively slight prominence. The area just described as stretching northwestward from Abrigo Canyon is characterized by gentle slopes, broad, open arroyos, and low ridges, in marked contrast with the more rugged topography of the main Escabrosa Ridge.

Lithology.—The Abrigo limestone is distinguished from the other calcareous formations of the local Paleozoic section by its prevailing thin bedding and particularly by a conspicuous laminated structure produced by alternation of thin, irregular sheets of chert with layers of gray limestone (see fig. 5). The layers of limestone may be 2 or 3 inches in thickness, while those of chert are usually less. This cherty lamination is eminently characteristic of the Abrigo limestone in the Mule Mountains and serves as a ready means of identifying the beds belonging to this formation within the various fault blocks into which the region is dissected. Chert also occurs in occasional irregular bunches in the Devonian and Carboniferous limestones of the Bisbee quadrangle, but never in the form of the thin, more or less anastomosing sheets peculiar to the Cambrian Abrigo limestone.

The beds are commonly from 1 to 2 feet in thickness. Their dominant color as seen in large exposures is dark greenish-yellow, whereas the prevailing tint of the overlying Martin limestone is dark gray, and that of the still higher Escabrosa and Naco limestones white or light gray.

In the typical Mount Martin section the Bolsa quartzite is immediately overlain by about 40 feet of thin-bedded, very cherty limestone, which breaks up, on weathering, into thin rusty plates. Above this occur a few beds of gray limestone, up to 2 feet in thickness, alternating with fissile, yellowish, calcareous shales and with laminated cherty beds such as have just been described. The upper 100 feet of the formation is made up of rather soft, sandy, thin-bedded, gray limestones, with one bed of harder gray limestone 6 feet in thickness about 40 feet from the top. The upper limit of the Abrigo formation is defined in the Mount Martin section by a bed of pure white quartzite about 8 feet thick.

This quartzite is a persistent stratum and is always found immediately underlying the Martin limestone, which carries Devonian fossils. Its thickness, however, is variable and it sometimes grades downward into the upper sandy limestones of the Abrigo formation. It apparently records the consummation of an increasing supply of sandy sediments during the later phases of the deposition of the Abrigo limestone, and contrasts with the more purely calcareous beds of the overlying Devonian formation.

The large area of Abrigo limestone stretching northwest from Abrigo Canyon exhibits the general lithological character of the Mount Martin section. In Abrigo Canyon, however, the soft sandy limestones below the white quartzite are represented by calcareous grits which are darker and harder than the corresponding beds farther north, and these grits, sometimes associated with hard, dark-gray, dolomitic beds containing abundant quartz grains, as just north of Don Luis, continue to characterize the upper part of the Abrigo limestone as far as the formation can be traced to the southeast. They are rather hard, thin-bedded, sandy limestones, usually dark gray in tint, and occasionally rusty on weathered surfaces. They frequently show cross-bedding, particularly just north of Don Luis.

Very fissile, greenish-yellow, calcareous shales, often showing casts of worm borings and glistening with minute scales of mica, are generally a characteristic feature of the lower half of the Abrigo formation where this part is exposed. Such beds usually form smooth topographic slopes and weather to fragments often superficially resembling those resulting from the disintegration of the pre-Cambrian schists.

Age and correlation.—The fossils collected from the Abrigo limestone, comprising trilobites, small lingulas, and pteropods of the genus *Hyolithes*, were submitted to Dr. Charles D. Walcott, who reported that they are middle Cambrian, indicating a fauna closely resembling that of the middle Cambrian of Texas.

DEVONIAN SYSTEM.

MARTIN LIMESTONE.

Name.—The Martin limestone is named from Mount Martin, on Escabrosa Ridge, where the moderately thick, usually dark-gray beds of this formation are typically developed and well exposed.

Distribution and general stratigraphy.—In the Mount Martin section the Martin limestone attains a thickness of 340 feet. The beds overlie the Abrigo (Cambrian) limestone and underlie the Escabrosa (Mississippian) limestone, both relations being those of apparent conformity.

Other small areas of the Martin limestone are involved in the faulted structure of Escabrosa Ridge, from the northwest corner of the quadrangle to Don Luis and thence southeastward past Black Gap and Gold Hill to Glance. The formation is typically developed north of Moore Canyon, being exposed from top to base at several localities. It is also well exposed in the vicinity of Abrigo Canyon, but the stratigraphic relations are here complicated by overthrust faulting.

The conspicuous turreted crag overlooking Main street in Bisbee, known as Castle Rock, is composed of Martin limestone. Extending southwestward from Castle Rock to Escacado Canyon and thence southeastward to Glance is a curved chain of small areas of this limestone, which, as will be more fully shown later, form part of a much faulted syncline. Although the areas are separated by faults, the beds dip and strike in conformity with the general synclinal structure. Those between Castle Rock and Escacado Canyon dip to the southeast, while those between Escacado Canyon and Glance dip to the northeast.

Owing to its medial position within the Paleozoic sequence and its comparative thinness, 300 to 350 feet, the Martin limestone is more generally distributed and is oftener present in its entirety than are the overlying or underlying beds. It is rarely topographically conspicuous, however, usually outcropping on slopes below cliffs of Escabrosa limestone and above lowlands floored with the Abrigo limestone.

Lithology.—The beds most characteristic of the Martin formation are dark-gray, hard, compact limestones which are generally well provided with fossils. Small brachiopods (*Atrypa reticularis* and *Spirifer hungerfordi*) of rounded outline are particularly abundant in some of the beds and give to the weathered surfaces of the limestone a nodular appearance, which in the Bisbee quadrangle is peculiar to the Martin formation. A few of the beds are richly provided with corals, some of which weather out as distinct and often beautifully silicified fossils, while others make rather ill-defined, white dendritic blotches in the dark limestone, producing an appearance that experience has shown to be a local criterion of some value in identifying small masses of the Martin limestone when they are faulted in among other beds.

Associated with the preponderant dark limestones are occasional beds of lighter hue, and sometimes calcareous shales of a decided pinkish tint. These shales, which flake and crumble on exposure, are well exposed in the saddle just northeast of Mount Martin, where they carry abundant characteristic Devonian fossils. They occur also in several of the other areas of the Martin limestone, particularly on the southwest slopes of Escabrosa Ridge, but owing to their softness are seldom conspicuous except where revealed by prospecting pits and tunnels. They belong in the lower half of the formation.

The upper limit of the Martin limestone is not always sharply defined. In general it corresponds with the decided change from the dark compact limestones characteristic of this formation to the nearly white granular limestones, made up largely of crinoid stems, which characterize the Escabrosa formation. The actual plane of division is, however, rarely visible owing to the tendency of the Escabrosa limestone to form cliffs and the consequent accumulation of talus over the contact. Even when no detritus conceals the relation of the two formations there may be an intermediate zone 10 to 20 feet in thickness which contains no characteristic fossils and which it is impossible to assign with confidence, on purely lithological grounds, to either the Martin or the Escabrosa limestone.

The beds of the Martin limestone are usually less than 4 feet in thickness. They are thicker, on the whole, than those of the underlying Abrigo limestone, but thinner than those of the overlying Escabrosa limestone, next to be described.

Age and correlation.—Several collections of fossils from the Martin limestone were submitted to Prof. Henry S. Williams, of Yale University. He reports that they represent a meso-Devonian fauna finding its nearest analogues in the Devonian faunas of Iowa and Russia. A few of the more common characteristic forms (see illustration sheet 2) are the brachiopods *Atrypa reticularis*, *Spirifer hungerfordi*, and *Schizophoria striatula*, and the corals *Pachyphyllum woodmani*, *Acervularia davidsoni*, and *Cladopora prolifica*.

CARBONIFEROUS SYSTEM.

ESCABROSA LIMESTONE.

Name.—The Escabrosa limestone takes its name from Escabrosa Ridge, where the thick white beds belonging to this formation are conspicuous.

Distribution and general stratigraphy.—The distribution of the Escabrosa limestone is practically that of the Martin limestone which underlies it. But its lighter hue, thicker beds, and greater power of resisting erosion makes it a much more marked feature in the landscape than any of the limestones yet described. The summit of Mount Martin, the prominent light-colored scarps visible from Bisbee along the northeast side of Escabrosa Ridge, and the bold cliffs which the same ridge presents toward Espinal Plain and Naco on the south are all due to this formation.

The most northern occurrence of the Escabrosa limestone is a small area 5 miles west-northwest of Bisbee, on the edge of the quadrangle, resting with apparent conformity and gentle westerly dip upon the Martin formation. Other areas north of Moore Canyon extend the distribution of the beds in a series of fault blocks westward beyond the bounds of the quadrangle, to the edge of the San Pedro Valley. Between Moore and Abrigo canyons the Escabrosa limestone has been removed by erosion. Nearly the whole thickness of the formation, however, is preserved on Mount Martin, and several faulted blocks of these beds occur southwest and south of this peak, within a radius of $2\frac{1}{2}$ miles.

The Escabrosa limestones is also exposed in Hendricks Gulch, just southwest of Bisbee, and, like the Martin limestone, extends in a curved belt, broken by many faults, southeastward past Gold Hill as far as Glance Creek.

The formation appears in most places to lie conformably above the Martin limestone, but the contact is not always well exposed and has in some places been modified by faulting. This faulting, chiefly along plains forming small angles with the bedding, is a particularly noticeable feature in the structure near Abrigo Canyon and will be fully described on later pages. The upper part of the Escabrosa passes without any stratigraphic break or marked lithological change into the overlying Naco limestone. These two formations were distinguished primarily upon paleontological evidence, and they have accordingly been mapped in different colors but with no definite dividing line except in the case of faults. There are, indeed, certain lithological differences between the Escabrosa limestone and the Naco limestone, as will be pointed out when the latter is described, but it is only after an intimate familiarity with the beds is gained that these lithological criteria can be utilized as a basis of separation. They would not in themselves have suggested the twofold division of the Carboniferous limestones here adopted.

The thickness of the Escabrosa limestone in the Bisbee quadrangle can not be determined with the same accuracy as that of the Devonian and Cambrian limestones. Although the overlying Naco limestone has been eroded from the summit of Mount Martin, there is good reason to conclude that the Escabrosa limestone is still present in this section in very nearly its original thickness, which measurements and calculations give as approximately 800 feet. Another section just west of Black Gap, where apparently the whole of the Escabrosa limestone is represented in conformable sequence between the Martin and Naco limestones, affords a thickness of a little more than 600 feet. A third section was measured $1\frac{3}{4}$ miles south of Bisbee, near the Whitetail mine, and intermediate in position between the two already referred to. This afforded a minimum thickness of 775 feet. It thus appears that the Escabrosa limestone has a maximum thickness of about 800 feet and probably thins out toward the southeast to about 600 feet. For general purposes 700 feet will be taken as the average thickness of the formation.

Lithology.—The characteristic rocks of the Escabrosa formation are rather thick-bedded, nearly white to dark gray, granular limestones, which close examination often shows to be made up very largely of fragments of crinoid stems. Near the base the beds are commonly 10 to 15 feet in thickness, but above the first hundred feet thicknesses of 1 to 5 feet are the rule, with occasional occurrences of more massive strata. The formation as a whole may be characterized as a pure nonmagnesian limestone, containing practically no arenaceous sediments and only occasional irregular bunches and nodules of chert, usually in its upper part.

Fossils are distributed through the formation, from the bottom to the top, but, with the exception of small scattered corals and the abundant fragments of crinoid stems, are rarely conspicuous and seldom appear on weathered surfaces of the limestone. As a rule they must be carefully sought for, with a liberal use of the hammer. The general appearance of the Escabrosa formation is nearly white or light-gray, but some dark-gray beds occur, particularly near the top.

NACO LIMESTONE.

Name.—The name Naco limestone is derived from the Naco Hills, situated near the western edge of the quadrangle, and composed of the moderately thick, nearly white beds belonging to this formation.

Distribution and general stratigraphy.—The Naco Hills, surrounded on three sides by the Quaternary wash of Espinal Plain and San Pedro Valley and cut off from the older Paleozoic rocks on the north by the Abrigo fault, are carved from the Naco limestone, and their steep southwest slopes afford exceptional opportunity for studying the lithological character of this formation. The broader stratigraphic relations of the beds are, however, not revealed in this relatively large but isolated exposure, where the only visible relation with the other Paleozoic rocks is that of faulting.

Between the Naco Hills and Bisbee are several smaller blocks of the Naco limestone, involved in the intricate web of faults that characterizes the structure of this portion of the quadrangle, particularly in the vicinity of Escacado Canyon.

The largest area of Naco limestone within the quadrangle, and by far the most important from an economic standpoint, is that which stretches southeastward from Bisbee to Gold Gulch and is thence continued by a series of smaller exposures extending past Glance to within a mile and a half of the Mexican boundary. The main area, between Bisbee and Gold Gulch, partly covered by the Cretaceous Glance conglomerate, constitutes the inner Paleozoic member of the faulted syncline which has been referred to several times and which will subsequently be shown to have a very important connection with the great copper deposits of the district. Although much disturbed by faulting, the beds generally conform to the dominant synclinal structure, dipping southeastward near Bisbee and then swinging around in a rather sharp curve until they dip to the northeast near Black Gap. The masses forming the summit of Gold Hill and the other areas to the southeast owe their positions to faults which have thrust them bodily over Cretaceous beds, as will be described in the section on geological structure.

The Naco limestone conformably overlies the Escabrosa limestone, as may be well seen at several points along Escabrosa Ridge southeast of Mount Martin, and particularly in the excellent exposures a mile due north of Don Luis (see fig. 3), where the rather thin beds immediately above and below the plane of division are continuously exposed for nearly a mile along a steep slope. The upper limit of the Naco formation is a rather irregular surface of erosion upon which the basal conglomerate of the Cretaceous Bisbee group was deposited. The original thickness of the formation is thus unknown, but it undoubtedly greatly exceeds that of any other member of the local Paleozoic section. Measured sections in the Naco Hills show that the formation as there exposed has a present thickness of at least 1500 feet and probably of as much as 2000 feet. To this there must be added an unknown thickness removed by erosion and an unexposed portion concealed by Quaternary deposits. Unless there are important faults which have escaped the careful examination given to the synclinal area of Naco limestone just south of Bisbee, 3000 feet is a very moderate estimate for the thickness of the Naco beds involved in this structure. Probably it is fairly safe to conclude that the original thickness of the Naco limestone was more than 3000 feet.

Lithology.—The Naco limestone, like the Escabrosa formation, is made up chiefly of light-colored beds which consist essentially of calcium carbonate. The beds range in thickness from a few inches to 10 feet, but are usually thinner than those of the Escabrosa limestone. They differ from the latter also in texture, the typical Naco limestone being compact and nearly aphanitic, ringing under the hammer, and breaking with a splintery fracture, whereas the Escabrosa limestone is usually more granular and crystalline and crumbles more readily when struck. There are, however, exceptions to this rule, dense aphanitic beds occurring rarely in the Escabrosa formation and granular crinoidal beds being not uncommon in the Naco limestone.

Fossils, particularly brachiopods, are much more abundant in the Naco than in the Escabrosa limestone, sometimes making up a considerable part of individual beds, and weathering out conspicuously on exposed surfaces.

While the greater part of the 3000 feet or more of the Naco formation is made up of fairly pure gray limestone, certain thin beds of a faint pink tint occur at several horizons and are often a useful means of distinguishing the Naco from the Escabrosa limestone. These pink beds, which, on weathering, usually show an inherent lamellar or shaly structure, are very fine grained and compact in texture. They effervesce freely with cold dilute acid and are evidently composed chiefly of calcium carbonate. Examination of natural surfaces with a lens, however, shows the presence of minute quartz grains and tiny flakes of mica. Typical exposures of these pink calcareous shales may be seen on top of Queen Hill, along the trail connecting the Lowell mine with the No. 2 shaft of the Lake Superior and Pittsburg mine, and in the Naco Hills a mile northeast of Naco Junction.

Chert is not uncommon in the Naco formation, occurring sometimes as irregular bunches and nodules in beds of otherwise pure limestone, and sometimes as the result of silicification of thin fossiliferous beds throughout their thickness. It is particularly abundant along and near zones of fissuring and faulting.

Age and correlation.—All of the fossils collected from the Escabrosa and Naco limestones were submitted to Mr. George H. Girty, who reports that three well-marked Carboniferous faunas are represented (see illustration sheet 2). One of these, characteristic of the Escabrosa limestone, is of Mississippian age; the other two, from the Naco limestone, are of Pennsylvanian age. The Mississippian fauna is the same as that which is widely distributed in the West, and has generally been recognized as that which characterizes the Waverly group of Ohio. A few characteristic forms are *Rhipidomella thiemei*, *Leptæna rhomboidalis*, *Chonetes loganensis*, *Spirifer centronatus*, *Spirifer peculiaris*, *Syringothyris carteri*, *Athyris lamellosa*, *Eumetria marcyi*, *Myalina keokuk* and *Phillipsia peroccidens*. This Bisbee fauna probably represents the earlier half of Mississippian time, including the Kinderhook and Osage divisions.

The earlier of the two Pennsylvanian faunas is largely composed of species which characterize the Pennsylvanian faunas of the Mississippi Valley.

The later of the two Pennsylvanian faunas comprises many species as yet undescribed. Very few of the species have exact representatives in the Mississippi Valley, and few, if any, are found in the earlier Pennsylvanian fauna of the Bisbee quadrangle. A few species are suggestive of the Aubrey limestone of the Grand Canyon section, while others suggest the Permo-Pennsylvanian of California. The whole fauna is closely related to that of the limestones of the Hueco Mountains in western Texas, and is very different from the so-called Permo-Pennsylvanian of the Mississippi Valley. Some of the characteristic Pennsylvanian forms from Bisbee are *Fusulina cylindrica*, *Chætetes milleporaceus*, *Derbya crassa*, *Productus semireticulatus*, *Productus inflatus* (?), *Productus nebraskensis*, *Spirifer cameratus*, *Seminula subtilita*, *Spiriferina kentuckyensis*, *Hustedia mormoni*.

The close relationship, pointed out by Mr. Girty, between the Carboniferous fauna of Bisbee and that of western Texas is particularly interesting in view of the fact that the Cambrian faunas of the two regions show a similar affinity. More than this, it will be shown later that the Cretaceous fauna of the Bisbee group finds its nearest analogue in portions of the Comanche series as developed in Texas.

RESUMÉ OF THE PALEOZOIC SECTION.

From the preceding descriptions it appears that Paleozoic time is represented in the Bisbee quadrangle by beds having a total thickness of a little over 5000 feet. Of these, the lower 430 feet are quartzites, while the remaining 4570 feet are so predominantly calcareous that they may be collectively designated limestones. The Pennsylvanian is represented by at least 3000 feet of strata (the Naco limestone), while only 340 feet (the Martin limestone) can be assigned to the Devonian. The Ordovician and the Silurian are wholly without stratigraphic representation, unless the unfossiliferous quartzite at the top of the Abrigo limestone belongs in one of these periods. No unconformity has been discovered to account for the absence of recognizable Ordovician and Silurian strata, but unless the quartzite mentioned is of such age and represents the whole of the time, the region was probably a land area during at least a part of the interval between the Cambrian and the Devonian.

The typical white crinoidal limestone of the Escabrosa formation is very nearly pure, containing over 99 per cent of calcium carbonate. The Naco, Martin, and Abrigo limestones are successively more siliceous and contain more alumina and iron oxides; but they consist essentially of calcium carbonate and the latter two are less impure than might be expected from their color and appearance. Although the Abrigo limestone locally exhibits dolomitic phases, it, like the other Paleozoic limestones of the quadrangle, is in the main practically free from magnesia.

Mesozoic Sedimentary Rocks.

GENERAL STATEMENT.

The Mesozoic era is represented in the Bisbee quadrangle by a thick accumulation of conglomerate, sandstone, shale, and limestone, which has been named the Bisbee group and is of Cretaceous age. It is probable that Triassic and Jurassic strata are absent.

CRETACEOUS SYSTEM (BISBEE GROUP).

NOMENCLATURE AND SUBDIVISIONS.

In 1902 Dumble described, under the name Bisbee beds, an assemblage of arenaceous and calcareous strata near Bisbee, assigning to them a thickness of about 3000 feet, and referring them on satisfactory paleontological evidence to the Cretaceous. In this folio Dumble's name has been retained for the Bisbee group, which has been divided into four formations. The lowest of these, the Glance conglomerate, derives its name from Glance, a station on the El Paso and Southwestern Railroad, near the Glance mine. The overlying Morita formation, chiefly sandstones and shales, is named from the Morita Hills, lying just south of the international boundary, between longitudes 109° 45′ and 109° 50′. The Mural limestone, overlying the Morita formation, is so called from Mural Hill, east of Bisbee. The topmost member of the group, the Cintura formation, composed of alternating sandstones and shales, derives its name from Cintura Hill, near the northern edge of the quadrangle. The local upper limit of the Cintura formation and of the Bisbee group is a surface of Quaternary erosion. The definition of the group is therefore left somewhat elastic as concerns its upper part, in the hope that future work in southeastern Arizona will discover the relation of the Bisbee group to possible stratigraphic representatives of upper Cretaceous or Tertiary time.

Beds belonging to this group are known to enter largely into the structure of the Mule Mountains north of the area here studied; they have been noted in great thickness by Dumble south of Rucker Pass in the Chiricahua Range; and they very probably occur in the San Jose Mountains southwest of Naco. The sequence and thickness of the various formations making up the group as it occurs in the Bisbee quadrangle are graphically shown in the accompanying generalized columnar section.

GENERAL DISTRIBUTION.

The rocks of the Bisbee group outcrop in a broad belt, of general northwest-southeast trend, occupying much of the northeastern and eastern portion of the quadrangle. From Juniper Flat to Gold Hill this belt is bounded on the southwest by the sinuous line defining the unconformable contact of the Glance conglomerate with the pre-Cretaceous rocks, while on the east the beds pass unconformably beneath the Quaternary detritus covering the floor of Sulphur Spring Valley. South of Gold Hill the Bisbee sediments are divided by overthrust faults into separate blocks, which together form a belt about 6 miles in width, bounded on the east, west, and in good part on the south by Quaternary deposits.

GLANCE CONGLOMERATE.

Distribution, thickness, and general stratigraphy.—The basal member of the Bisbee group is well exposed just north of Bisbee as a distinctly bedded, red-brown conglomerate, from 50 to 75 feet in total thickness, resting upon a pre-Cretaceous surface of erosion carved upon the Pinal schist. This old surface is, in this part of the quadrangle, a nearly even plain that has been tilted about 15 degrees to the east, and which, as it emerges from beneath the Glance conglomerate, is recognizable as a well-marked topographic bench formed by the tops of the schist ridges north of Bisbee and by the gently inclined surface of Juniper Flat (see fig. 10). The conglomerate continues northwestward, retaining a fairly constant thickness, to within a mile of the northern edge of the quadrangle, where it thins out rather suddenly and for a distance of about 1500 feet is wanting, the Morita formation resting directly upon the granite. The conglomerate comes in again, however, toward the north and continues beyond the bounds of the quadrangle. Toward the southeast the conglomerate, interrupted by some faulting and becoming rather thinner, extends to Mule Gulch, where it is offset to the west by a series of post-Cretaceous faults.

South of Mule Gulch a marked change occurs in the formation. Instead of resting as a smoothly spread and rather thin deposit upon a nearly plane surface, the Glance conglomerate becomes exceedingly variable in thickness and fills the hollows in a buried topography scarcely less diversified than that in the vicinity of Black Gap at the present day. North of the gap the conglomerate occupies an irregular basin. It probably attains a local thickness of nearly 300 feet in the deepest part of this depression, and must formerly have been considerably thicker. Hills of Paleozoic limestone project through the conglomerate at several points, notably a mile northeast of Black Gap, where there is excellent opportunity for studying the relation of the Glance formation to the irregular pre-Cretaceous surface upon which it lies (see fig. 9). A similar conglomerate-filled depression forms the head of Gold Gulch, the conglomerate in all probability attaining here a local thickness of over 200 feet.

This contrast between the pre-Cretaceous topography north and south of Mule Gulch is a very striking feature, the origin of which will be discussed in the section devoted to the geological history of the quadrangle.

Northwest of Gold Hill the conglomerate dips generally to the east or northeast at angles ranging from 10 to 20 degrees. At Gold Hill, however, the beds are overridden by an overthrust block of Paleozoic limestones and are locally turned up to a nearly vertical position in a compressed and slightly overturned anticline.

About $1\frac{1}{2}$ miles southeast of Gold Hill the belt of conglomerate thus far described is cut off by a fault.

The area of Glance conglomerate stretching southward from Gold Hill into Mexico presents by far the most extensive exposure of this formation within the quadrangle. Like the areas at the head of Gold Gulch and north of Black Gap, it probably rests upon an unevenly eroded surface of Paleozoic limestones, which in turn form part of the great fault block that has been thrust bodily northeastward over the belt of Glance conglomerate and Morita formation lying on the northeast side of the dislocation. Toward the southwest, near Johnson's and Armstrong's ranches, the conglomerate passes with southwesterly dip beneath the conformably overlying Martin formation. On the northeast the contact between the conglomerate and the Paleozoic limestones is seldom exposed. In some places there appears to have been faulting between the Cretaceous and older rocks, while elsewhere the conglomerate apparently lies undisturbed upon the slopes against which it was originally deposited. The thickness, of the conglomerate is undoubtedly much greater in this area than elsewhere in the quadrangle. At the Glance mine a shaft was sunk 500 feet before reaching the bottom of the conglomerate, and as the same rock with gentle easterly dip forms a hill just west of the mine that rises 400 feet above the collar of the shaft, the total thickness of the formation is probably at least 600 feet. As a whole the conglomerate beds of this area form a gently flexed anticline (see the structure sections) having a nearly northwest-southeast axis. The two narrow exposures of Naco limestone between Johnson's ranch and the Glance mine are plainly old eroded ridges forming part of the surface upon which the conglomerate was laid down, and now exposed by erosion along the crest of the low post-Cretaceous anticline.

Near the overthrust fault which is defined topographically by the open valley between Glance station and Christianson's ranch the beds of conglomerate have a local southwest dip and are in places nearly vertical. They thus form a narrow syncline along the northeast border of the main anticline.

The only other area of Glance conglomerate that requires particular mention is a small one (superficially divided in two by a strip of Quaternary material) occurring about a mile northeast of Glance station, on the edge of Sulphur Spring Valley. This, also, lies upon the back of an overthrust block of Paleozoic (Naco) limestone, which has been shoved, in this case from the east, over the Cretaceous (Mural) limestone.

Lithology.—The pebbles and fragments that make up the Glance conglomerate have been derived from the pre-Cretaceous rocks of the region and have, as a rule, undergone no considerable transportation. To a certain extent, therefore, the distribution of the derivative materials of the conglomerate corresponds with the areal disposition of the underlying rocks which supplied the conglomeratic detritus. It is thus rather difficult to characterize the formation as a whole, although its identification seldom presents any difficulty. The most constant features are fairly distinct bedding, imperfect rounding of the pebbles, considerable induration, and a prevalent reddish color, particularly of the matrix. The other and more variable lithological characters may best be exhibited by describing actual occurrences of the conglomerate and noting the changes that appear as the formation is followed across the quadrangle from its northern to its southern border.

At the northern edge of the quadrangle the Glance conglomerate rests upon granite and is composed of rather angular fragments of this rock mingled with bits of vein quartz. On Juniper Flat fragments of schist begin to be very abundant, and on the east side of Soto Canyon they make up by far the greater part of the conglomerate. With them, however, are associated occasional pebbles of granite, granite-porphyry, limestone, dark chert, and vein quartz. At the head of Brewery Gulch, just north of Bisbee, the Glance formation comprises several rather irregular beds of dark red-brown conglomerate containing lenses of red sandstone and shale. Imperfectly rounded pebbles of schist preponderate. These are occasionally as much as 8 inches in diameter, but are usually smaller, the average being perhaps 2 or 3 inches. They are embedded in a dark-red sandy matrix, evidently derived from the disintegration of Pinal schist. The coarser material predominates in the lower part of the formation, while the increasing proportion of sandstone and shale in the upper part produces the effect of a partial transition into the overlying Morita formation.

The conglomerate forming the area north of Black Gap and at the head of Gold Gulch is generally of a dull dark-red color and is made up principally of schist fragments, as may be well seen along the various roads running south from Bisbee and in the excellent exposures on the divide a mile northwest of Gold Hill. At the latter locality were observed several slightly waterworn blocks of the schist which were fully 18 inches across, and a few which measured 3 feet in diameter. As the rock underlying this mass of conglomerate is the Naco limestone, the schist fragments which compose the bulk of the material must have been derived from areas of Pinal schist lying immediately to the north and east, and now largely buried beneath the Cretaceous beds. Not all of the conglomerate, however, is of schist derivation, for wherever hills of limestone protrude through the Glance formation and along the southwestern border of the basin the lower part of the deposit is composed of blocks of limestone firmly cemented with the usual reddish matrix. These angular fragments and imperfectly rounded limestone pebbles were evidently derived from the immediately underlying Naco limestone. They lay upon the limestone hill slopes, or formed talus heaps against small cliffs, as may be seen a mile northeast of Black Gap, and after slight reworking by the waves of the Cretaceous sea were buried beneath the abundant schist detritus that was carried into the basin from the north and east.

The belt of conglomerate which passes from the head of Gold Gulch through the saddle northeast of Gold Hill and thence eastward toward Black Knob contains some beds of grit and shale associated with the usual coarser conglomerate. The pebbles of the latter are principally schist and granite (or granite-porphyry) with some limestone.

The low hills stretching southward from Gold Hill to the international boundary are carved from conglomerate similar in general appearance to that north of Black Gap. Pebbles of schist, quartzite, granite, granite-porphyry, and vein quartz were noted, and the fragments of schist in particular sometimes make up a considerable part of the upper beds, as in the vicinity of Johnson's ranch and in the lower part of Gold Gulch.

But near the Glance mine and along the line of the El Paso and Southwestern Railroad the formation is composed mainly of beds made up almost exclusively of pebbles of limestone embedded in a reddish matrix which effervesces freely with acids and is evidently also composed of detritus derived chiefly from limestones. Good exposures of these limestone conglomerates are found in the railroad cuts and along the sand-scoured rocky bed of Glance Creek. It can be seen that these limestone conglomerates sometimes alternate with beds of schist conglomerate like those north of Black Gap.

The calcareous pebbles of this area of the conglomerate have been derived mainly from the Carboniferous limestones, particularly the Naco limestone, which is known to underlie a portion of the beds. The schist fragments were undoubtedly supplied by the Pinal schist, but whether they came from the known areas north of Mule Gulch or from ancient exposures in the southern part of the quadrangle now concealed by Cretaceous or Quaternary deposits is not known. Similar uncertainty obtains in regard to the pebbles of quartzite and granite-porphyry. The Bolsa quartzite and the granite-porphyry intrusions of the northern half of the quadrangle could supply such materials, but it is not known whether the masses of these rocks now exposed were the actual sources of the conglomeratic material in the southern part of the quadrangle.

The small area of Glance conglomerate northeast of Glance station is composed almost exclusively of rather coarse fragments of Carboniferous limestone, sometimes containing fossils. These imperfectly rounded pebbles are firmly embedded in a compact, reddish, calcareous matrix of the same character as that cementing the conglomerates between Gold Hill and the Glance mine.

MORITA FORMATION.

Distribution, thickness, and general stratigraphy.—The Morita formation, consisting chiefly of alternating beds of reddish shale and tawny sandstone, is exposed within the Bisbee quadrangle in two main areas—one an irregular belt traversing the quadrangle almost diagonally from its northern edge to its southeast corner, the other a much shorter, parallel strip lying west of Gold Gulch and underlying Armstrong's ranch, 5 miles east of Naco.

In the former and larger area the beds dip generally east-northeast in the northern part of the quadrangle, at angles ranging from 15 to 20 degrees. The strata, however, are not merely tilted, but frequently exhibit slight undulatory folds with northeast-southwest axes. In the neighborhood of Mule Gulch the strike of the beds becomes nearly northwest and southeast. The dip is generally to the northeast, but varies from about 15 degrees in the lower beds near the Glance conglomerate to about 60 degrees in the higher beds close to the Mural limestone.

The hills between Gold Hill and Easter Sunday mine are carved from the Morita formation. Near the Gold Hill overthrust the beds are upturned until they are practically vertical. But the normal dip of 20 to 25 degrees to the northeast prevails along the main ridge and continues to within a short distance of the Easter Sunday mine, where the angle of dip again increases until an inclination of 55 degrees is attained near the base of the Mural limestone.

At about the line of this section the strike of the beds again swings into a nearly NNW.-SSE. direction, which is retained to the southern edge of the quadrangle. Northeasterly dips of from 20 to 35 degrees prevail in this portion of the area, except along its southwest border, where the beds are locally disturbed in the vicinity of the Gold Hill overthrust fault.

The beds of the second area of the Morita formation—that surrounding Armstrong's ranch—have the same general strike as those between the Glance mine and Christianson's ranch. Their dip, however, is southwesterly at an angle of about 15 degrees. They conformably overlie the Glance conglomerate of Gold Gulch and underlie the Mural limestone of the low hills 4 miles east of Naco. Were it not for the complication introduced by the Gold Hill overthrust, they might be considered simply as the southwestern limb of a low anticline of which the beds southeast of Glance form the northeastern limb.

The thickness of the Morita formation as measured in the excellent exposures north and east of Bisbee is 1800 feet.

Lithology.—The Morita formation comprises uniformly alternating beds of dull-red shales and red or tawny sandstones, with occasional layers of grit and lenses of impure limestone. Although some of the strata are 10 or 15 feet in thickness, the formation as a whole is characterized by beds of moderate thickness, usually less than 4 feet.

The general landscape tints are dull red or yellowish brown, dependent upon the local predominance of the red or tawny beds. As a rule the red color prevails near the base and the yellow tones in the upper part of the formation.

The red shales are finely arenaceous and not particularly fissile. In fact, when they have not been exposed to the weather they are tough, compact rocks with no distinct cleavage. The cementing material is calcite, as shown by the free effervescence of the shale in dilute acid. Little, light-gray, concretionary, calcareous nodules are a characteristic feature of the red shale. They are particularly conspicuous on weathered surfaces and might readily be mistaken at first glance for pebbles of limestone. In the upper part of the formation the red shales become still more calcareous. The gray nodular concretions increase in abundance, and occasional thin beds or lenses of compact gray limestone appear within the shales, into which they grade above and below. As a rule the limestone lenses are not fossiliferous, although in some of the sections exposed northeast of Bisbee and in the little hills southwest of Armstrong's ranch they contain molluscan fossils of the same types as those occurring near the base of the overlying Mural limestone.

The sandstones alternating with the shales frequently show cross-bedding, and range in color from reddish brown to buff or tawny. They are usually fairly hard, fine-grained rocks in which the original sand grains have been cemented by calcite. In the upper part of the formation, however, are occasionally hard tawny to buff-colored beds in which the cementing material is quartz. These might, therefore, properly be called quartzite. Microscopical examination of a representative specimen of the sandstone shows it to consist of incompletely rounded grains of quartz, frequently showing crystal enlargement by the growth of new quartz upon the worn particles, and a few fragments of plagioclase. The interstices between the detrital grains are filled with crystalline calcite.

About 1200 feet above the base of the Morita formation occurs a bed of reddish-brown grit from 10 to 15 feet in thickness, but otherwise there is no marked interruption in the monotonous repetition of sandstones and shales extending from the top of the Glance conglomerate to the bottom of the Mural limestone.

Between the Morita formation and the Mural limestone, next to be described, there exists no sharp natural boundary. The dominantly arenaceous Morita beds pass upward through transitional phases into the dominantly calcareous Mural limestone. The divisional plane chosen for descriptive purposes is that defined by the upper surface of a bed of hard buff sandstone or quartzite, which, as may be seen from the geological map, outcrops below the Mural limestone to the east of Bisbee in such a manner as to find topographic expression in a series of little bench-like spurs, easily recognized by anyone looking along the general line of contact of the two formations. Immediately overlying this sandstone is a bed of dark, impure limestone made up in considerable part of broken shells, chiefly *Ostrea*. The divisional plane marks practically the upper limit of the sandstones and red shales, although it does not absolutely define the lowest appearance of fossiliferous limestones.

MURAL LIMESTONE.

Distribution, thickness, and general stratigraphy.—As one approaches Bisbee through the southern passes, particularly when the noonday glare has softened into the shadows of evening and the beauty of the sculptured hills is compensation for their barrenness, he is confronted by a prominent light-gray cliff crowning Mural Hill and stretching like a rampart along the face of the ridge northeast of town. This cliff, giving scenic distinction to otherwise rather commonplace hills, is formed by a portion of the Mural limestone (see fig. 1). Below the cliff, which varies from 50 to 250 feet in height, is a smooth, steep slope, about 200 feet from top to bottom, and at the foot of this slope a line of projecting spurs marking the outcrop of the topmost bed of the Morita formation. The cliff and slope are genetically related and are the topographic expression of the resistance to erosion of certain thick, hard beds composing the upper part of the Mural limestone, and of the ready disintegration of some thin, impure limestone in its lower part.

If local concealment by Quaternary deposits and some irregularities due to faulting be disregarded, it may be said that the Mural limestone is exposed in a relatively narrow belt which, entering the quadrangle at about the middle point of its northern boundary, pursues a southerly course until it reaches the latitude of Bisbee; thence it sweeps southeastward to the edge of Sulphur Spring Valley, and, again curving southward, maintains a south-southeast course until it passes out of the southeast corner of the quadrangle into Mexico.

On the north the Mural limestone, like the beds of the Morita formation, dips generally to the northeast at angles ranging from 10 to 20 degrees. The breadth of the outcrop in the vicinity of Dixie Canyon is due to this low angle of dip, to the presence of some shallow folds with northwest-southeast axes, and to minor faulting. At the point where the beds turn southeast toward Mule Gulch the dip becomes steeper, and where the limestones are crossed by the road to Forrest's ranch they attain a maximum dip of 65 degrees to the northeast. Southeast of the Easter Sunday mine the dip decreases until it is from 20 to 30 degrees. The unusually steep dip of the Mural limestone near Mule Gulch is associated with dips nearly as great in the adjacent Morita and Cintura beds. The inclination of these beds rapidly diminishes, however, both to the northeast and to the southwest, away from the Mural limestone, the latter exhibiting the maximum effect of this local upturning of the strata.

A mile northeast of Glance station the Mural limestone is partly covered by a fault block of Naco limestone that has been thrust over it from the east.

In addition to the principal area just described, the quadrangle contains several smaller exposures of the Mural limestone. Such are the small hills rising out of the Quaternary deposits near the eastern edge of the quadrangle, opposite the mouth of Glance Canyon. The beds forming these hills dip to the southwest and constitute the western limb of an anticline, the other limb being partly represented by similar hills projecting above the Quaternary deposits farther east. Another small area is that near boundary monument 91, 4 miles east of Naco. The strata here conformably overlie the Morita beds of the Armstrong's ranch area and dip to the southwest. They continue southeastward into Mexico. The last area to which attention need be particularly directed lies a little less than a mile southeast of Gold Hill. It is a small block, bounded by faults. The interesting questions presented by the occurrence of a little isolated mass of Mural limestone at this place will be considered in the section devoted to geological structure.

Lithology.—Although mapped as a unit, the Mural limestone, with a thickness of 650 feet, is readily divisible into at least two stratigraphic members—a lower portion, about 300 feet in thickness, comprising thin-bedded impure limestones, and an upper portion, 350 feet thick, in which relatively thick-bedded and pure limestones predominate. The lower member is represented topographically by the smooth under-cliff slope. Its exposures are seldom conspicuous and show subdued greenish-yellow, dark-green, brownish, or gray tints. The top beds of the lower member are usually buff sandstones, which may have a total thickness of 25 feet. Below these are rather soft, thin beds of sandy limestone, sometimes grading into cross-bedded, highly calcareous sandstone, with occasional thicker beds of dark-gray shell limestone, composed almost entirely of oyster shells (*Ostrea*). Molluscan remains are plentiful in certain of these beds, although not always well preserved. The genera most commonly represented are *Ostrea, Turritella, Lunatia, Cyprina, Trigonia*, and in one highly fossiliferous bed exposed just northeast of monument 91, on the international boundary, well-preserved individuals of *Pecten stantoni* are abundant. Exceptionally favorable localities for making collections of representative fossils of the Bisbee group are found in the nearly isolated and faulted area of Mural limestone 2¼ miles northeast of Bisbee, on the slopes beneath the cliffs in the vicinity of Mural Hill, and on the northeast side of the little group of hills 4 miles east of Naco.

The upper member of the Mural formation, unlike the lower beds just described, outcrops prominently, usually forming a cliff. The strata range from gray to white, and thus contrast strikingly with the sober red and tawny tints of most of the sediments composing the Bisbee group. At the bottom, resting upon the buff sandstone at the top of the lower member, are two or three beds of hard gray limestone which constitute practically a single massive stratum from 40 to 60 feet in thickness. This is the cliff-making portion of the Mural limestone. Above it lie beds of similar lithological character but distinctly thinner, ranging usually from 6 to 10 feet in thickness.

The gray limestones are richly provided with fossils, but these do not weather out readily, and the tough, compact nature of the matrix renders their collection difficult. One or more species of *Ostrea*, in individuals up to 7 inches in length, are abundant, particularly in the very thick beds at the base of this upper member, while in the higher beds the little disk-like *Orbitolina texana* is very common and is associated with the so-called *Caprina occidentalis*, the large gasteropod *Lunatia pedernalis*, and a coral of the genus *Astrocœnia*. Casts were seen which suggested the occurrence of a large *Requienia*, but no distinct shells of this genus were found. Part of a well-preserved ammonite in the possession of Mr. W. G. McBride of Bisbee, said to have been picked up in Brewery Gulch, suggests that this form also may occur in some portion of the Mural limestone exposed at the head of that gulch.

The little hills near the eastern edge of the quadrangle north of Hay Flat are composed mainly of the hard limestones of the upper member of the formation. Some of the beds here contain abundant corals (*Astrocœnia* and another form not collected), "*Caprina*," and a number of little brachiopods (*Rhynchonella, Terebratella*, and *Terebratula*) not seen at any other locality in the quadrangle.

As a rule, the upper member of the Mural formation, consisting almost if not quite exclusively of gray limestone, is conformably overlain by a bed of rather vitreous buff quartzite. The contact between these two rocks has been chosen as the boundary between the Mural limestone and the Cintura formation. But as in the cases of the Mural limestone and the Morita formation, the division so made is somewhat arbitrary. Limestone strata from 3 to 5 feet in thickness continue to occur in alternation with sandstones and shales throughout the lower 100 to 150 feet of the Cintura formation, and occasionally contain *Turritella* and other fossils that are apparently identical with forms occurring in the Mural limestone.

CINTURA FORMATION.

Distribution, thickness, and general stratigraphy.—The occurrence of the sandstones and shales of the Cintura formation within the Bisbee quadrangle is limited to a single area, which lies along the edge of Sulphur Spring Valley and extends northward from the vicinity of Forrest's ranch past Cintura Hill and beyond the northern boundary of the quadrangle. The beds form a generally very shallow syncline which pitches northeastward under the Quaternary deposits of Sulphur Spring Valley, at an angle of about 20 degrees. Near Mule Gulch, along the contact with the Mural limestone, the Cintura strata at the rim of the generally slightly hollowed syncline are locally upturned until they attain a dip of 50 degrees, which, however, rapidly diminishes toward the north.

The total thickness of the beds belonging to the Cintura formation exposed in this syncline is at least 1800 feet. The original thickness of the formation is unknown, its present upper limit being an irregular surface determined by Quaternary erosion.

Lithology.—In general lithological character the Cintura formation is a repetition of the Morita formation. It is characterized by the same reddish, sometimes almost purplish shales, with gray nodular concretions, the same occasional bands of gray limestone, and the same tawny, buff or pinkish, cross-bedded sandstones with quartzitic phases. The stratigraphic arrangement of the beds, however, is different. Immediately overlying the Mural limestone there is usually a bed of buff quartzite from 10 to 15 feet in thickness. Then follow from 100 to 150 feet of red shales, thin-bedded sandstones, and arenaceous gray or greenish limestones. Some of the limestones contain fossils, particularly a *Turritella*, which is apparently identical with the form so abundant in the lower member of the Mural limestone. Upon these transitional beds repose red nodular shales with occasional strata of buff sandstone and very subordinate beds or lenses of impure, greenish, nodular limestone, the whole having a thickness of from 700 to 800 feet. The individual sandstone beds sometimes attain a thickness of 6 feet, but are greatly surpassed in volume by the shales. Overlying these dominantly shaly beds are 300 feet of flaggy, cross-bedded, gray and buff sandstones with occasional parting layers of red shale. These sandstones usually form a rough cliff or scarp along the hill slopes overlooking Mexican Canyon. They are succeeded in turn by about 600 feet of reddish nodular shales interbedded with flaggy cross-bedded sandstones. One of the latter beds, about 18 inches in thickness, occurring about 1600 feet above the base of the Cintura formation (or about 200 feet below the present top), has a pale-cream tint and by contact with the darker hue of the rest of the formation is conspicuous as a light band near some of the hilltops east of Grassy Hill.

AGE OF BISBEE GROUP.

The various collections of fossils made during the progress of the field work, chiefly from the Mural limestone, were submitted to Dr. T. W. Stanton, who reports that the fossiliferous horizon represented corresponds in large part with the Glen Rose beds of Texas and that possibly the upper portion is as high as the Edwards limestone; in other words, that they certainly belong to the Trinity division, and possibly in part to the Fredericksburg division of the Comanche series.

Mr. Stanton's report definitely assigns the Mural limestone to the lower Cretaceous or Comanche epoch. Direct paleontological evidence for as satisfactory a determination of the three other members of the Bisbee group is not obtainable. The conformable sequence of the beds, however, considered in connection with the lithological transitions between the various stratigraphic units, and the practical identity in character of the Morita and Cintura formations, below and above the fossiliferous Mural limestone, leave no room for any reasonable doubt of the Comanche age of the whole Bisbee group.

Quaternary Deposits.

Distribution.—Deposits referable to the Quaternary period cover fully half of the Bisbee quadrangle. They are not deeply channeled, and natural sections of any but the superficial portions of the material do not occur.

The Quaternary deposits occupy the main floors and embayments of the larger valleys, such as Sulphur Spring Valley and Espinal Plain, and rise in gentle slopes toward the Mule Mountains. Against these they terminate in a very irregular line, which is nearly everywhere rather indefinite owing to the insensible passage of the slightly transported materials of the valley deposit into the loose, stony detritus that cumbers the hill slopes.

Along the eastern front of the mountains the Quaternary of Sulphur Spring Valley buries the slopes of the older rocks up to an average altitude of about 4600 feet. The boundary between the Quaternary of Espinal Plain and the southern front of the Mule Mountains attains a greater elevation but is so irregular as to render a general description difficult. Its average elevation may be roughly given, however, as about 5250 feet, although in Escacado Canyon, northwest of Don Luis, characteristic Quaternary deposits extend to an elevation of 5650 feet.

Lithology.—Near the mountains the Quaternary deposits consist, as a rule, of rather coarse and imperfectly rounded stony detritus which has evidently been derived from the adjacent slopes and rarely exhibits distinct bedding. Along the western edge of Sulphur Spring Valley the fragments have been supplied chiefly from the harder sandstone beds of the Bisbee group. Along the northern border of Espinal Plain fragments of Paleozoic limestone greatly preponderate over those of any other rock, and are often found to be superficially consolidated into hard conglomerate through the addition of a white, travertine-like cement. Such cemented material is frequently not unlike certain phases of the Glance conglomerate, but may be distinguished by its white, travertine-like matrix, as contrasted with the reddish matrix of the older rock. The maximum depth to which this cementation extends is unknown, but the local depth is certainly in many places very slight. Prospecting pits less than six feet in depth frequently pass through the cemented crust into comparatively soft and loose material.

This calcareous matrix belongs to the class of deposits known in Mexico and southern Arizona as *caliche*.

Away from the mountains the Quaternary deposits become finer and exhibit more or less irregular cross-bedded stratification. The well west of Naco from which water is pumped to Bisbee by the Copper Queen Company is 118 feet deep and is apparently wholly in Quaternary material. For a distance of 100 feet from the surface this was so soft as to require timbering. Apparently no record was kept of the exact nature of the material passed through, but the dump shows that it was principally a partly consolidated reddish sand containing occasional small pebbles. Similar soft sandy beds, containing fragile fresh-water shells of the genus *Unio*, have been encountered in boring for a well at the new Copper Queen smelter near Douglas, in the middle of the Sulphur Spring Valley.

According to Mr. W. M. Adamson, superintendent of machinery at the reduction works, the material encountered in this well was as follows:

Record of well at Douglas.

	Feet.
Surface loam	15
Sand and gravel, containing abundant shells in its upper part, and affording 120 gallons of water per minute	22
Very white calcareous clay	15
Compact red clay	75
Sand, affording about 3 gallons of water per minute	1
Red clay	6
Very hard red clay	1
Red clay with considerable grit	36
Water-bearing sand and gravel	6
Total depth	177

At the above depth, the well yielded 245 gallons of water per minute, and as this was all that the pump could handle, sinking was for the time discontinued.

A second well, started by the same company near the one just described, had reached a depth of about 400 feet in April, 1903. At the last report received this well was all in unconsolidated material. At 120 feet a good flow of water was tapped, and at 355 feet, the drill, after penetrating a bed of compact clay, entered a thin layer of water-bearing gravel. The water from this stratum rose to within 3 feet of the surface.

Origin.—The Quaternary deposits of the Bisbee quadrangle consist of the waste or "wash" shed from the Mule Mountains (and, near Naco, from the San Jose Mountains also) into the surrounding valleys. Although the beds are undergoing some local dissection, they belong essentially to the present cycle of topographic development and are the work of streams similar in their mode of activity and in some cases nearly coincident in position with those of the present day. No physical break has been detected in this region between the early Quaternary (Pleistocene) and the late Quaternary (Recent) formations. Throughout the entire Quaternary period the streams have been engaged in sculpturing the mountains and distributing the detritus over the valleys as fluviatile deposits, which range from coarse, imperfectly rounded gravels near the mountain fronts to pebbly sands and even finer silts near the valley axes.

There is no evidence indicating that any part of the Bisbee quadrangle was covered by any considerable body of standing water during Quaternary time; but it seems highly probable that at least temporary lacustrine conditions prevailed in portions of the broader valleys, such as San Pedro or Sulphur Spring. The occurrence of fresh-water shells in the Quaternary deposits beneath Douglas indicates the former presence there of a lake, or at least of a perennial stream, neither of which could exist with the present scanty precipitation. It is therefore probable that the Quaternary has been marked by increasing aridity, and that such dissection of its deposits as has taken place in the

Bisbee.

Bisbee region is an expression of that fact rather than of differential changes of level.

Igneous Rocks.

GENERAL STATEMENT.

The eruptive or igneous rocks of the Bisbee quadrangle are for the most part intrusions of granitic magma, ranging in form from small dikes and sills to stocks of considerable size, and in texture from rhyolite to granite.

In addition to these are a few small dikes of monzonitic porphyry and occasional insignificant dikes of a decomposed greenish eruptive which was probably originally diabase.

GRANITE.

Definition. — Granite is a wholly crystalline, granular, eruptive rock, consisting essentially of orthoclase (or some other member of the group of alkalic feldspars), quartz, and usually muscovite, biotite, or amphibole, with small quantities of various accessory minerals, such as apatite, zircon, and magnetite or ilmenite. Chemically, the rock may contain from 70 to 78 per cent of silica, 11 to 16 per cent of alumina, rarely more than 4 per cent of the iron oxides, usually less than 1 per cent of magnesia, seldom over 3 per cent of lime, and commonly from 5 to 8 per cent of alkalies, the potash usually preponderating over the soda.

Occurrence and distribution.—The only granite found within the quadrangle is that composing the elongated intrusive stock which cuts the Pinal schist in the vicinity of Tombstone Canyon, northwest of Bisbee. The rock is well exposed both at Mule Pass and on Juniper Flat, and forms the bold cliffs overlooking from the northeast the road down Tombstone Canyon. Within the quadrangle, the stock has a length of about 5 miles and probably extends northwestward for an additional mile or so beyond the northern boundary. Its width is at least 2 miles, but the northeastern contact of the mass is partly concealed by overlapping Cretaceous beds.

Petrography.—The granite of Juniper Flat and of the cliffs northeast of Tombstone Canyon has a typical granitic texture, without any marked peripheral or contact modifications. The average diameter of the crystalline grains is about 7 millimeters. In color the rock is reddish-gray, with a suggestion of pink when viewed in large masses. The minerals visible with the unaided eye are a reddish-brown unstriated feldspar quartz, a white feldspar showing distinct polysynthetic twinning lamellæ, and a very little black mica in small flakes.

The microscope shows that the brown feldspar is microperthitic orthoclase, crowded with the usual minute dusty inclusions. This mineral, with quartz, a smaller amount of sodic oligoclase, and a little biotite, forms an allotriomorphic aggregate making up the greater part of the rock. The accessory minerals are tourmaline, muscovite, apatite, zircon, and magnetite or ilmenite. Of these, the tourmaline is of most interest. It occurs in nests of small prisms, the latter being frequently embedded in muscovite but penetrating also the quartz and orthoclase, showing that it is a primary constituent. The prisms show the characteristic strong absorption, rounded trigonal cross sections, and obtuse terminations characteristic of tourmaline.

A chemical analysis of the granite is given below under I, while an analysis of a similar granite from Norway is placed alongside under II, for comparison.

Analyses of granites, granite-porphyry, and rhyolite.

	I.	II.	III.	IV.
SiO_2	75.86	76.05	78.81	76.78
Al_2O_3	12.17	11.68	10.96	......
Fe_2O_3	.85	.34	1.18	......
FeO	.36	1.05	.08	......
MgO	none	.29	.14	......
CaO	.62	.42	none	trace
Na_2O	3.60	3.79	.26	.30
K_2O	5.04	5.09	8.50	9.28
H_2O-	.27	1.36	.48	......
H_2O+	.72		1.17	......
TiO_2	.21	.05	.13	......
ZrO_2	not det.	.42	not det.	......
CO_2	none	......	none	......
P_2O_5	trace	......	trace	......
F	......	trace	......	......
S	......	trace	......	......
MnO	none	trace	none	......
Li_2O	......	trace	......	......
	99.70	100.54	99.71	

I. Tourmaline-bearing alkali granite; intrusive stock in Pinal schist, 5 miles northwest of Bisbee, Arizona. George Steiger, analyst.

II. Alkali granite; Drammen, Norway. Rosenbusch, Gesteinslehre, 1898, p. 78.

III. Granite-porphyry; sill in Bolsa quartzite, 3¼ miles north of Naco Junction. George Steiger, analyst.

IV. Rhyolite (aporhyolite); probably volcanic neck, 2½ miles northeast of Naco Junction. George Steiger, analyist.

The rock is shown by the analysis to belong to the class known as alkali granites.

By calculation, the chemical analysis affords the following:

	Per cent.
Quartz	34.68
Orthoclase molecule	29.47
Albite molecule	30.39
Anorthite molecule	2.50
Biotite, tourmaline, zircon, magnetite, etc.	2.96
	100.00

Microscopical determinations indicate that the sodium-calcium feldspar present in the rock is oligoclase having an approximate composition of 4 molecules of albite to 1 of anorthite ($Ab_4 An_1$). The mineral composition of the granite may accordingly be given as:

	Per cent.
Quartz	34.68
Microperthitic orthoclase (Or_5Ab_2)	41.00
Oligoclase (Ab_4An_1)	21.36
Biotite, tourmaline, etc.	2.96
	100.00

The coarser phase of the granite to which the foregoing description particularly applies is characteristic of the western portion of the stock, in the vicinity of Cox's ranch. Finer grained varieties, however, also occur, particularly on Juniper Flat and near the basal boundary of the Cretaceous beds. The evidence obtainable in the field indicated that the difference between these fine-grained facies and the coarsely crystalline type selected for chemical analysis was textural only. Microscopical study, however, shows that there is a mineralogical and chemical difference as well. The fine-grained pink granite from the northern part of Juniper Flat consists chiefly of quartz and orthoclase, with very little oligoclase, even less biotite, and, as far as known, no tourmaline.

The dominant minerals form an allotriomorphic aggregate, with a tendency on the part of the quartz to poikilitically inclose the orthoclase. In mineralogical composition and texture, therefore, the rock belongs with those aplitic granites for which the name *alaskite* has been proposed.

In chemical composition the fine-grained granite just described corresponds more nearly than the coarser variety analyzed to the granite-porphyries next to be considered, in which a similar mineralogical association is also connected with a marked preponderance of the potash molecule over that of soda (see analysis I). Although there can be little doubt of the essential unity of the Juniper Flat granitic stock, and although additional analyses would probably show close agreement as regards silica, alumina, iron oxides, lime, magnesia, and total alkalies, yet the mass evidently exhibits considerable variation as regards the relative proportions of potash and soda, and it is accordingly unsafe to assume that the analysis given under I is representative of the intrusion as a whole. There is good reason to suspect that the tourmaline-bearing granite analyzed contains less potash and more soda than the average rock of the stock.

GRANITE-PORPHYRY.

Definition.—Granite-porphyry is a wholly crystalline eruptive rock having the same chemical and mineralogical composition as granite but distinguished from the latter by a porphyritic instead of granular texture. That is, the quartz and feldspar occur as sharply bounded crystals or phenocrysts embedded in a distinctly finer grained matrix or groundmass. This groundmass may be, and in the Bisbee quadrangle usually is, aphanitic, or so fine grained as to show no crystalline texture to the unaided eye.

The granite-porphyries are divided by no definite line from the rhyolites, in some of which the groundmass, prevented by rapid cooling from assuming a wholly crystalline texture, solidified in part as volcanic glass. Both of these textural modifications of the granitic magma occur within the Bisbee quadrangle, but as they are of the same general geological age and are derived from the same magma, their separate mapping would serve no useful purpose, and the rhyolite is accordingly included with the predominant granite-porphyry.

Occurrence and distribution.—Granite-porphyry occurs chiefly in the northwestern part of the quadrangle, in the form of dikes and irregular intrusive masses cutting all of the formations from the Pinal schist to the Naco limestone, and less commonly as small sills intercalated between the beds of Bolsa quartzite. The rock is readily recognized by its usual pinkish or occasional buff tint, by its speckled appearance, due to the contrast of the porphyritic crystals of quartz and feldspar with the compact reddish groundmass, by its erratic occurrence within the limestones, quartzite, and schist, and by its clearly intrusive character.

Numerous small dikes of granite-porphyry occur within the pre-Cambrian schists between Bisbee and Juniper Flat. For the most part these dikes have no observable connection with the granite mass of Juniper Flat. One of them, however, cuts the latter a third of a mile southeast of Mule Pass and is accordingly younger than the granite.

Similar dikes are found traversing the schists of Tombstone Canyon, on the southwest side of the granite stock, particularly near Brown's ranch in the extreme northwest corner of the quadrangle. While the relation of these dikes to the granite is not always clearly shown, they are in some cases undoubtedly direct offshoots from the latter, as may be well seen just north of Brown's ranch.

It is on the southwestern slope of Escabrosa Ridge, however, that the granite-porphyry dikes attain their most interesting development. They have a general northwest-southeast trend, and are most abundant within a belt about a mile wide stretching northwestward from the vicinity of Don Luis to the western edge of the quadrangle. Within this zone the dikes, ranging in width from a foot to half a mile, branch and cross, forming an intrusive network of great complexity. Many of the broader intrusions shown on the geological map are so crowded with masses of schist, quartzite, or limestone, as to be in reality complexes of many dikes, for which simplified representation is demanded by the scale of the map.

As a rule the dikes occupy fault fractures, along many of which it is evident that there was considerable displacement before the fissure was finally sealed by the intrusion and solidification of the granite-porphyry magma. Such a dislocation is well shown about 2 miles south of Brown's ranch, near the edge of the quadrangle, where the Escabrosa limestone on the northwest side of the main dike has been dropped 500 feet below the base of the Bolsa quartzite on the northeast side of the dike-filled fissure, indicating a throw of more than 2000 feet. Farther to the southeast the total throw has been distributed among the many branches composing the dike zone, but the aggregate displacement must be nearly or quite as great. These fissures are not always occupied by dikes for their whole lengths. It is not uncommon to find a dike becoming narrower and finally disappearing while the fault fissure can still be readily followed. An excellent example of this may be seen near the head of Abrigo Canyon.

Although some of the dikes on Escabrosa Ridge are nearly vertical, most of them dip steeply to the northeast. Consequently the displacement along their fissures corresponds in the greater number of cases to reversed faulting.

Occasionally, the dikes as they passed upward from the Pinal schist into the Bolsa quartzite, took advantage of the bedding planes of the latter to expand in the form of irregular sills, as may be seen in Bolsa Canyon and between Abrigo and Moore canyons.

That the dikes of Escabrosa Ridge were not all intruded at precisely the same time is proved by a few instances in which one dike clearly cuts others. Rhyolitic dikes have been observed cutting those of the more abundant granite-porphyry type, while in other cases the relation is reversed.

Although many of the granite-porphyry dikes exhibit no selvage modifications, others pass near their walls into rhyolitic facies showing flow banding.

One of the most important masses of granite-porphyry, on account of its relation to the ore bodies of the district, is that forming Sacramento Hill, just southeast of Bisbee. This is a stock which, although of irregular outline and partly concealed on the east by Cretaceous beds, may be described as about a mile in diameter. Like most of the porphyry intrusions of the quadrangle, it is closely related to a fault, but instead of following the fissure as a narrow dike, the magma has invaded the rocks on both sides of the fracture and formed a rudely cylindrical, intrusive plug. On the northeast this plug or stock cuts the Pinal schist; on the southwest it cuts the Naco limestone and at greater depths, in all probability, the Escabrosa and older formations.

A much smaller plug-like mass occurs 2½ miles northeast of Naco Junction, forming a little conical hill, which owing to its shape and to the contrast of its dark-brown color with the surrounding limestones, is a conspicuous feature as seen from Espinal Plain. The rock composing the upper part of this hill is of much darker hue than the usual granite-porphyry of the quadrangle and has a pronounced vertical fluidal structure trending nearly north and south. It is more properly classed as a rhyolite than a granite-porphyry. On the north side of the hill, poorly exposed and partly concealed by a talus of massive rhyolite derived from the top of the hill, is a rhyolitic breccia, which has the general appearance of a volcanic agglomerate. Unfortunately the relations of the rhyolite and rhyolite breccia to each other and to the surrounding limestones are concealed by superficial detritus in this region of usually unrivalled exposures. But the form of the rhyolite mass, its vertical flow structure, and its association with an agglomerate-like rhyolitic breccia suggest that it is probably a small volcanic neck or plug through which rhyolitic lava ascended to a pre-Cretaceous surface.

About a mile northeast of Naco Junction is a small mass of white rhyolite intrusive in Naco limestone. The rock is remarkable for a very regular and pronounced flow banding which stands nearly vertical and trends with the longer axis of the intrusion. This lamination is so pronounced as to give the eruptive rock much the appearance of a white schist or shale.

Petrography.—The granite-porphyry, as it occurs in most of the dikes of Escabrosa Ridge, is a pinkish or reddish rock having a decidedly speckled appearance, which usually serves to distinguish it at a glance from the other rocks of the quadrangle. It contains corroded or idiomorphic phenocrysts of quartz up to a centimeter in diameter, and generally smaller or less conspicuous phenocrysts of flesh-tinted orthoclase, embedded in a reddish groundmass that is nearly or quite aphanitic. Biotite in small scales is sometimes present, but as a rule quartz and orthoclase are the only minerals recognizable by the unaided eye.

There can be little doubt that the reddish color of the porphyry, although characteristic of the freshest rock obtainable at the surface, is a result of incipient weathering, for specimens obtained from deep mine workings, away from oxidizing or mineralizing action, are light gray or pale green.

Under the microscope the dominant phenocrysts are found to be quartz, showing the usual embayed outlines, and orthoclase, often rendered semi-opaque by minute ferritic inclusions. Much less abundant are crystals of sodic oligoclase, usually more or less altered to kaolin, and an occasional scale of bleached biotite. In the more coarsely crystalline rock of the larger dikes the groundmass shows both microgranitic and micropegmatitic textures. The micropegmatite usually envelopes the phenocrysts and is commonly divided into somewhat irregular radial segments of different optical orientation. At a distance from the phenocrysts the groundmass is made up of quartz, orthoclase and muscovite in a fine microgranitic aggregate. In the less coarsely crystalline rocks of the small dikes and near the walls of the larger dikes the groundmass is often a minutely and rather obscurely crystalline aggregate of quartz and orthoclase in little micropegmatitic granules less than 0.1 mm. in diameter. Such porphyries are not to be sharply distinguished from those of rhyolitic habit (aporhyolites) in which the minutely crystalline felsitic groundmass has resulted from devitrification of a glassy base subsequent to the solidification of the rock.

A chemical analysis of a representative specimen of the granite-porphyry is given under III, on page 7. It will be seen that it differs from the analyzed specimen of the Juniper Flat granite in the great preponderance of potash over soda. In this respect it probably corresponds closely with the fine-grained granite described on page 7.

By calculation the following conventional composition is obtained from the chemical analysis:

	Per cent.
Quartz	42.78
Orthoclase molecule	50.04
Albite molecule	2.10
Hematite, magnetite, water, etc	5.08
	100.00

As no albite is visible in thin section under the microscope the albite molecule is probably combined with the orthoclase molecule in the mineral orthoclase. The rock thus consists of 42.78 per cent of quartz and 52.14 per cent of orthoclase, with 1.65 per cent of water and 3.43 per cent of iron oxides, zircon, and indeterminate accessory minerals.

The rock with conspicuous flow banding forming the little hill 2½ miles northeast of Naco Junction shows in hand specimens minute phenocrysts of quartz and pink orthoclase in an aphanitic reddish-gray groundmass, within which may occasionally be seen little cavities lined with projecting crystals of quartz.

Under the microscope the texture is found to be very similar to that of the finer-grained granite-porphyries. Phenocrysts of quartz and orthoclase lie in a holocrystalline quartz-orthoclase groundmass. The crystallization of this groundmass is finely and obscurely granular, with patchy, shadowy extinctions between crossed nicols and occasional minute micropegmatitic intergrowths. It is such a texture as is known to result from the devitrification of an originally partly glassy groundmass, and in view of the pronounced fluxion structure of the rock mass this origin seems sufficiently probable to justify the classification of the rock as a rhyolite (or more strictly aporhyolite) rather than a granite-porphyry. But, as already pointed out, this distinction is unimportant in this region, where the rocks here called granite-porphyry are connected by direct transitions with devitrified rhyolites.

A partial chemical analysis of the above-described rhyolite is given under IV on page 7, and a comparison of this analysis with that of the granite-porphyry under III shows that both are products of the same magma.

The small intrusive mass a mile northeast of Naco Junction, already referred to, is a devitrified rhyolite in which the original flow structure, as seen under the microscope, has not been wholly obliterated by the subsequent crystallization of the glassy groundmass.

The important intrusive mass of Sacramento Hill was probably originally a granite-porphyry of the type common along Escabrosa Ridge. But it has been greatly altered in a manner that will be described when the mineralization of the region is discussed.

CONTACT METAMORPHISM.

If the ore bodies and their possible relation to contact metamorphism be disregarded, it may be said that the effect of the intrusion of the granite-porphyry into the limestones has not been conspicuous, and that in the case of many of the smaller dikes it is inappreciable. In Uncle Sam Gulch, just above the old mine of the same name, the Naco limestone is cut by an irregular dike of granite-porphyry. The contact between the two rocks is well exposed in a prospect pit, and the limestone preserves its usual color and compact texture up to the actual junction with the intrusive rock. In other words, it exhibits to the naked eye no apparent metamorphism. A thin section of the limestone at the contact, shows, however, that it is nearly one-third altered into a granular aggregate of quartz which forms an irregular web inclosing residual kernels of calcite.

In the vicinity of Sacramento Hill, the only place where a large body of granite-porphyry comes into contact with the limestones, these show considerable alteration, which, however, is to a large extent shared by the porphyry itself. As seen in surface exposures the principal change in the limestone has consisted in the replacement of the calcium carbonate by granular aggregates of quartz containing chlorite and pyrite. The chlorite tends to form little ellipsoidal nests, and when the rock is exposed to the weather the chlorite is removed, the pyrite is oxidized, and the originally light-colored limestone becomes a rusty, cavernous, siliceous rock looking superficially not unlike a weathered amygdaloidal lava. Rock of this character is abundant in the vicinity of the Gardner shaft and on the ridge extending from that shaft toward the ice factory.

The crest of this ridge corresponds roughly with the outer limit of the notably metamorphosed zone as visible on the surface. The boundary between altered and unaltered limestone is, however, extremely irregular and often indefinite. Certain beds retain nearly their original texture and composition close up to the porphyry, while others are obviously altered for long distances from the intrusive contact.

The Pinal schist in the vicinity of the porphyry of Sacramento Hill has lost its schistose structure and become a fine-granular aggregate of quartz and sericite containing abundant disseminated pyrite.

The porphyry itself exhibits throughout much of its mass a similar alteration, of which the extreme product, exemplified in the dump of the Copper King mine, is a fine-granular aggregate of quartz, sericite, and pyrite, indistinguishable from certain altered forms of the schist. Less altered phases reveal traces of the original porphyritic texture, but the microscope shows that the quartz phenocrysts have recrystallized as granular aggregates, and that the former feldspar phenocrysts are now mixtures of quartz and sericite.

The nature of the metamorphic processes that have been active in the vicinity of the intrusive mass of Sacramento Hill will be considered at greater length in the discussion of metasomatic processes connected with ore deposition.

AGE OF GRANITIC INTRUSIONS.

As the granite and granite-porphyry have supplied pebbles to the Glance conglomerate and nowhere cut the beds of the Bisbee group they are evidently pre-Cretaceous. Many of the granite-porphyry dikes and the stock of Sacramento Hill are intrusive into the Naco limestone and are therefore clearly post-Carboniferous. Although the granitic stock of Juniper Flat is in contact with no rocks younger than the pre-Cambrian Pinal schist, yet from the close connection of this granite with the granite-porphyry, it is fair to conclude that all of the forms assumed by the granitic magma belong to one general period of intrusion, and are accordingly post-Carboniferous and pre-Cretaceous. The period of eruptive activity, however, extended over a sufficient length of time to allow the solidification of the granite and of some of the granite-porphyry dikes before they were cut by later intrusions of the same magma.

OTHER ERUPTIVE ROCKS.

At a few places within the quadrangle occur small dikes of a gray porphyritic rock cutting the Cretaceous beds and therefore younger than the granite-porphyry just described. The best exposed dike of this class occurs at the Glance mine, cutting Glance conglomerate. It is less than 50 feet wide and runs nearly north and south through a little saddle just south of the mine. This dike is composed of a light-gray rock that contains small phenocrysts of white feldspar and biotite and superficially resembles a mica-diorite-porphyry. The microscope shows phenocrysts of oligoclase partly altered to calcite, of some mineral (pyroxene?) now altered to aggregates of calcite, quartz, limonite, and other secondary products, and of biotite, all lying in a groundmass composed mainly of orthoclase, which is crowded with minute inclusions and extinguishes in shadowy patches between crossed nicols. The rock is too much altered to repay thorough investigation but is probably a monzonite-porhyry, approaching a syenite-porphyry in composition.

A decomposed greenish intrusive is occasionally seen in small dikes in the Paleozoic rocks southwest of Bisbee. These masses are of no structural importance and are too small to map. Thin sections show complete alteration to aggregates of chlorite, quartz, calcite, sericite, and other secondary products, while such vestiges of original texture as remain suggest that the rocks were formerly fine-grained diabases.

GEOLOGICAL STRUCTURE.

Introductory Statement.

Up to this point the rocks of the quadrangle have been considered chiefly as objects of description. They have been divided into natural assemblages or groups, and these groups subdivided into geological units. Finally the present distribution, form, and lithology of each unit have been described, and some conclusions reached as to age and origin.

All this, however, is preliminary. The rocks are merely the materials from which geological forces have fashioned a complex structure that will require further labor for its elucidation and comprehension.

In the production of this rocky fabric, faulting, folding, and igneous intrusion have cooperated, often so intimately that it becomes impossible to consider the part played by any one of these dynamic processes without referring to the others. The structure of the quadrangle, however, is preeminently characterized by faults, and to these some preliminary attention will now be given.

Faults.

DISTRIBUTION.

The visible faults of the Bisbee quadrangle are most abundant within an irregular, northwest-southeast zone that lies between Bisbee and Don Luis. This belt of dislocation is partly bounded on the northeast by the great Dividend fault, which passes under Dividend Flat in the town of Bisbee and brings the Paleozoic rocks on the southwest against pre-Cambrian schist on the northeast. The southwestern limit of the belt is similarly defined by another important dislocation which passes about 2½ miles northeast of Naco Junction and may be called the Abrigo fault, since it is followed for a part of its course by the canyon of that name. Where it crosses the western boundary of the quadrangle the faulted tract has a width of about 4 miles, while between Bisbee and Don Luis it is about 2½ miles wide. At Glance the zone is about 1½ miles wide, while southeast of that point it is represented by a single fault—the continuation of what will presently be described as the Gold Hill overthrust. It is probable that in this southeastern portion of the quadrangle much intricate faulting of the Paleozoic beds is concealed by the Cretaceous formations, and consequently the faults which are visible at the surface and to which description is necessarily confined may constitute but part of a belt of faulted structure as wide as or wider than that west of Bisbee.

It will be noted that the tract thus characterized by abundant faults is practically coincident with the present areal distribution of the Paleozoic rocks exclusive of the comparatively unfaulted Pennsylvanian limestone of the Naco Hills.

The only other important faults are a few that cut the Cretaceous beds northeast of Bisbee, and although these are of comparatively moderate displacement they receive conspicuous expression on the geological map of the quadrangle from the manner in which they offset the gently inclined beds of the Mural limestone.

EXPRESSION IN TOPOGRAPHY.

The topographic expression of faults may be considered as of two general kinds, distinguished as *primitive* and *erosional*, the latter being further susceptible of elaborate analysis into many subtypes. In the primitive expression of a fault, the upheaved block forms a ridge or hill while the downthrown block floors a valley, the top of the ridge and the bottom of the valley representing the displaced portions of the surface as it existed before faulting occurred. Obviously, ideal primitive expression can be found only in connection with very recent faults or in regions so extremely arid that erosion has been able to make but slight progress. According to Russell's descriptions it obtains in that part of the Great Basin which is included in southern Oregon. In somewhat less ideal sharpness it is probably exemplified in other regions of the Great Basin, as in those ranges which led Gilbert, in the course of the Wheeler Survey, to the recognition of the well-known and much discussed Basin Range type of orographic structure. As the normal progress of erosion must soon soften the primitive expression of a fault, and in time must greatly modify and perhaps finally obliterate or reverse it, there is clearly no sharp distinction in nature between the evanescent condition of ideal primitive expression and the manifold stages of erosional modification. Consequently it is often difficult or impossible to determine whether the topographic expression of a given fault should be considered as essentially primitive or as erosional. Thousands of feet of overlying beds may have been removed, and yet differences in elevation in the present topography, as determined by some hard stratum in the dislocated formations, may continue to topographically register the original displacement of the fault.

In the erosional expression of faulting in topography, on the other hand, the displacement is not directly recorded by differences in elevation of the present surface. The fault in the typical case has become a mere element of internal structure, introducing (just as do folds, intrusive masses, and variations in the lithological character of beds) factors of structural diversity which are neither overlooked nor exaggerated in the impartial work of erosion. The topographic accentuation or subordination of the fault bears no necessary relation to the amount or character of its displacement, but is the accurate expression of the importance of the dislocation as one of many factors determining that heterogeneity of material which in most regions of erosion is the essential condition of topographic variety.

In the Bisbee quadrangle the topographic expression of most of the faults is of a maturely erosional type, such as is well exemplified in the Dividend and Abrigo faults.

When the Dividend dislocation occurred, the Pinal schist near Bisbee was surmounted by Paleozoic beds at least 5000 feet in total thickness—the continuation of the strata now preserved in the downthrown block on the southwest side of the fault. Unless the movement along the fissure was so slow as not to outstrip denudation, the now-vanished beds were uplifted as a mountain ridge overlooking the downfaulted tract to the southwest. But these mountains have since succumbed to erosion, and the limestone hills of the depressed block look down upon the upheaved and denuded schists, on which a few tiny remnants of Bolsa quartzite remain as witnesses of the former presence of the Paleozoic series.

The Abrigo fault, which brings the Naco limestone against the Bolsa quartzite on the western edge of the quadrangle, corresponds to a throw of at least 3000 feet. But of this great actual deformation of an older topographic surface the present topography retains no trace.

Many other illustrations of the erosional expression of faults might be drawn from the tract of faulted Paleozoic rocks west of Bisbee, but individual citation is hardly necessary, since the total disappearance of the primitive topographic expression of the faults may be readily verified by reference to the geological map and structure sections.

As regards the faults cutting the Cretaceous beds northeast of Bisbee, the case is not so patent. The principal dislocation is here effected by a nearly vertical fissure which passes through the saddle at the head of Mexican Canyon and has elevated the beds on the southeast about 500 feet relative to those on the northwest. This fault is very evident to an observer looking up toward the head of Mexican Canyon from the conglomerate-filled basin north of Black Gap, since it interrupts the conspicuous white band of Mural limestone, and as this limestone determines the outline of the ridge in this neighborhood, the displacement by the fault finds corresponding expression in the topography.

This then, taken by itself, is an example of one of those indeterminate cases already referred to, in which the expression of the fault may be either essentially primitive or erosional. It is probable, however, that the Bisbee quadrangle has been considerably eroded since this faulting occurred, so that the expression of the dislocation is erosional and that its superficial resemblance to the primitive type is due to the control maintained over erosion by the resistant beds of the Mural limestone. This view is confirmed when study is made of the opposed Gold Hill and Glance overthrust faults and it is seen that the relation of the present topography to the faults is such as to clearly demonstrate a subsequent origin for the topography.

It may be concluded, then, notwithstanding the present aridity of climate and the many points of geological resemblance between this part of Arizona and the Great Basin, where the primitive topographic expression of faults has been described by careful observers, that no trace of such primitive relationship is extant in the Bisbee quadrangle. The faults of the latter region are probably all much older than those which have been appealed to in explanation of the main topographic features of the typical Basin Ranges.

By looking a little more closely into the manner in which the faults of the Bisbee quadrangle have influenced erosion, considerable diversity may be found, as would be expected when faults constitute but one factor in a complex process. As a rule the structurally important faults are rather inconspicuous at the surface, in view of the usual excellence of the rock exposures in this region. They rarely show any appreciable silicification and are not accompanied by the resistant siliceous breccias which are so characteristic a feature of the faulting of the Globe quadrangle, where similar rocks are involved. Instead of outcropping more or less boldly above the surface, as in that region, the comparatively unindurated fault breccias of the Bisbee quadrangle are commonly elements of weakness and as such tend to find topographic expression as saddles, ravines, or valleys. For example, the Dividend fault has determined in part the course of Mule Gulch. The Abrigo fault is taken advantage of by Abrigo Arroyo for a distance of about half a mile, and near the western edge of the quadrangle determines a saddle between quartzite hills on the north and limestone hills on the south. The positions of Black Gap and the saddle at the head of Mexican Canyon are due to erosion along lines of weakness resulting from faulting. The course of the Gold Hill overthrust is marked by a curved line of ravines and saddles and by the straight open valley extending from Glance to Christianson's ranch.

Along a few of the fault planes cliffs have been developed by erosion. These are occasionally 300 or 400 feet in height, and the best examples occur on the east side of Escacado Canyon about $1\frac{1}{2}$ miles northwest of Don Luis. These bold white cliffs, which are visible from any part of the broad Espinal Plain, are composed of Carboniferous limestones which have been slightly downfaulted against Devonian and Cambrian beds.

Very frequently it is found that faults of much structural importance and with throws of several hundred feet have been impotent to impress their presence upon the topography, whose local development was in such instances controlled by other structural elements.

As will be later shown, many fault-fissures in the Bisbee quadrangle have been filled by dikes of granite-porphyry. So far as the dike persists such a fault can be followed with comparative ease. Other faults in the Paleozoic rocks may be accurately traced for long distances by one who looks carefully for evidence of fracturing and crushing and who has gained sufficient familiarity with the distinctive features of the local Paleozoic formations to recognize the particular abrupt lithological changes which are characteristic of faulted structure. But when the faults traverse the Carboniferous limestones, as they do southwest of Bisbee, their recognition demands close observation and patience. Even with good exposures it is not always possible in limestones to distinguish an important fault from an insignificant fissure—indeed the brecciation, silicification, or mineralization may be far more pronounced in the case of the latter. In the Bisbee quadrangle, the great thickness and uniformity of the Naco limestone and the lithological identity of certain of its beds with those of the Escabrosa limestone make the working out of the faulted structure a laborious process, entailing the unremitting collection of the never-too-abundant fossils in order to check, step by step, the structural interpretations by the evidence of paleontology.

The obscurity of many of the faults in the limestones is well illustrated by the structurally and economically important Czar fault, which traverses the northwestern slope of Queen Hill, separating the Naco limestone of the mass of the hill from the Escabrosa limestone of Hendricks Gulch. It has a throw of probably more than 500 feet and crosses a steep hillside upon which apparently every bed of limestone is exposed to view from the hotel in Bisbee. Yet so slightly does it affect the appearance of the bare, fume-swept hill that daily familiarity with the slope gives no hint of dislocation to one unaware of its existence.

TRENDS AND DIPS.

The dominant faults of the Bisbee quadrangle range in trend from northwest to west-northwest. Such are the Dividend, Abrigo, and Gold Hill faults, the conspicuous dislocation near the Bisbee West mine (hereafter referred to as the Bisbee West fault), and most of the dike-filled faults along the southwest face of Escabrosa Ridge. Distinctly subordinate to the northwesterly fractures, but of much structural importance, are a number of faults with northeasterly trend. Some of the more prominent of these occur within an irregular zone of faulting that stretches southwestward from Bisbee across Escacado Canyon and past the Bisbee West mine. One of the most interesting members of this belt of cross faults may be traced almost continuously from the vicinity of the quartzite quarry west of Bisbee to a point half a mile northwest of the Bisbee West mine—a distance of 2 miles. As there will be frequent occasion to refer to this important dislocation, it may conveniently be called the Quarry fault. On the northeast the Quarry fault apparently ends at the Dividend fault, while on the southeast it may terminate at the Bisbee West fault, although a tongue of Quaternary material unfortunately conceals the junction of the two fractures. As a rule the northeast faults in the Escacado zone are less persistent than the dominant northwest faults and frequently terminate at the latter. There are, however, several short northwest faults which end against northeast faults, so that direction and persistency are not invariably related.

A northeast fault of considerable economic importance traverses the northwest slope of Queen Hill and has been called the Czar fault. Others of similar trend occur in Uncle Sam and Silver Bear gulches and still another dislocates the Paleozoic formations at Black Gap.

The faults cutting the Cretaceous beds northeast of Bisbee are also to be classed with those of northeastern trend.

In addition to the fissures of generally northwestern or northeastern trend, the quadrangle, as is to be expected, presents several examples of faults which do not conform to either of the principal directions. For example, Queen Hill is cut by a north-south fault, while a nearly east-west fault passes just south of the Cole shaft of the Lake Superior and Pittsburg mine. Such dislocations are structurally very subordinate and are a necessary accompaniment of the general fissuring of the quadrangle in two main directions.

CHARACTER OF DISLOCATION.

Faults that are not vertical admit of a twofold classification based upon the relative movement of their walls. Those along which the hanging wall has slipped down (or the foot wall risen) are known as normal faults, while those in which the hanging wall has risen (or the foot wall gone down) are known as reversed, thrust, or overthrust faults. In the case of vertical faults, the foregoing distinction vanishes, and the more nearly a fault approaches the vertical position, the more difficult it may become to determine by surface exposures the character of the dislocation.

Both of the foregoing classes are represented in the Bisbee quadrangle. Faults of normal type are clearly exemplified by the Abrigo fault, by several of the fissures along the southwest slope of Escabrosa Ridge, particularly those not occupied by dikes, by the Quarry fault, the Bisbee West fault, most of the faults in the vicinity of Escacado Canyon, most of those lying between Bisbee and Don Luis, and by the faults in the Bisbee group northeast of Mule Gulch.

Faults of the overthrust type are remarkably well shown in the southeastern part of the quadrangle, where limestones ranging in age from the Cambrian to the Carboniferous have been thrust from opposite directions over the Cretaceous formations by the Gold Hill and Glance faults. These, as will be fully shown in the following pages, are typical examples of this always impressive form of dislocation, in which older rocks have been thrust for considerable distances up gently inclined planes of fracture until they conspicuously overlie very much younger beds. Other cases of overthrust occur in the vicinity of Abrigo Canyon about a mile west of the Bisbee West mine. Here the Escabrosa limestone rests discordantly upon the Martin and Abrigo limestones with an undulating but on the whole nearly horizontal contact which is apparently the result of faulting. If so it represents a slightly inclined overthrust of unknown extent and direction.

The dike-seamed southwest face of Escabrosa Ridge presents several instances of reversed faults of a special kind. They are fissures now occupied by dikes of granite-porphyry, apparently intruded during the faulting. Such contemporaneous faulting and intrusion may conveniently be referred to as intrusion faulting, and the results of the action as intrusion faults. The best examples of this structure are to be found close to the western boundary of the quadrangle, about halfway between Moores Canyon and Brown's ranch, where two dikes may be seen cutting through the Abrigo, Martin, and Escabrosa limestones and displacing the beds by reversed throws of 75 and 150 feet. As most of the dikes along Escabrosa Ridge dip to the northeast, and as the general result of the faulting with which they are associated has been to depress the country on the southwest relatively to that on the northeast, the examples cited, although of very moderate throw, may be taken as typical of the intrusion faulting of the southwest slope of Escabrosa Ridge.

There still remain those faults for the classification of which the obtainable data are insufficient. Of these the most important, and the only one that need here be mentioned, is the Dividend fault. In spite of the extensive underground work accomplished in its vicinity this fault is not well exposed and the direction of its dip is unknown. It is apparently nearly vertical, and as it is known that the southwest wall has gone down or the northeast wall up, the determination of the particular class of faults to which it belongs is perhaps a merely academic matter.

As a rule only the relative movement of faults can be ascertained. We can very rarely determine, for instance, in a given normal fault whether the hanging wall actually moved down, or the foot wall really moved up, or whether both walls moved in opposite directions. With this clearly understood once for all, to avoid circumlocution, the hanging wall of a normal fault will usually be described in the following pages as dropped or downthrown and the hanging wall of a reversed fault as upheaved or overthrust.

AGE OF THE FAULTING.

The faults of the Bisbee quadrangle may be grouped as follows: (1) those of post-Pennsylvanian but pre-Cretaceous age, (2) those of post-Cretaceous but pre-Quaternary age, and (3) those which are post-Pennsylvanian and pre-Quaternary, but which can not be assigned with certainty to either of the two preceding groups.

To the first group belong the intrusion faults and the fissures so directly connected with these as to preclude the idea of difference in age. Such are the Dividend fault, the Quarry fault, the Bisbee West fault, and most of the faults on the southwest slope of Escabrosa Ridge. The nearly horizontal overthrust west of the Bisbee West mine probably belongs here, although there is reason to believe that it was formed a little earlier than the nearly vertical faults in its vicinity. The Black Gap fault certainly belongs in this group, as it dislocates the Pennsylvanian Naco limestone but not the unconformably overlying Cretaceous Glance conglomerate.

To the second group are assignable the faults cutting the beds of the Bisbee group. Such are the nearly vertical faults northeast of Bisbee, several small displacements in Mule Gulch southeast of town, the Gold Hill overthrust with its associated complex minor faulting as manifested southeast of Gold Hill, and the Glance overthrust. Accompanying this post-Cretaceous faulting there was very likely some revival of movement along the Dividend and other faults whose initial displacements dated from pre-Cretaceous time.

To the third group belong a few faults in the Paleozoic terrane southwest of Bisbee, which are not so clearly related to the granite-porphyry intrusions as to establish conclusively their pre-Cretaceous age. The most prominent example of these is the Abrigo fault. Although the age of these faults can not be directly ascertained, there is nevertheless strong probability that they are of the same age, at least so far as their initial displacements are concerned, as the faults of the first group. Their general similarity, as regards trend, dip, and character of dislocation, to faults known to belong to this group and their lack of relation by the known post-Cretaceous faults afford a reasonable basis for deciding that the faults placed in the first and third groups are all post-Pennsylvanian and pre-Cretaceous in age, and that but two general periods of faulting were concerned in the structure of the Bisbee quadrangle.

With this preliminary outline of the nature and expression of the principal dynamic process concerned in the structure of the quadrangle, we may pass at once to the consideration of the whole geological fabric, introducing into this general discussion such further details in connection with the faults and such reference to folds and igneous intrusions as may be required.

General Structural Analysis.

DIVISIONS OF QUADRANGLE BASED ON STRUCTURE.

Clearness of treatment requires us for the present to strip from a somewhat complex structure those various details with which Nature embellishes her handiwork, and to compress essentials into the artificial simplicity of a diagram. In the fault diagram sheet the quadrangle has been roughly divided into several structural blocks or tracts. On the northeast and southwest are the broadly spread Quaternary deposits of Sulphur Spring Valley and Espinal Plain, which effectually conceal the underlying rocks in these quarters. Between Bisbee and Sulphur Spring Valley, stretching from the top to the bottom of the diagram, is the main Cretaceous tract, occupied by the rocks of the Bisbee group—broad at the north but constricted in the south by the Gold Hill and Glance overthrusts. Here blocks consisting in their lower part of Paleozoic strata but bearing Cretaceous beds on their backs have been thrust toward each other from nearly opposite directions through and over the Cretaceous beds.

Extending from the northwest corner of the diagram past Bisbee is outlined an area of Pinal schist representing the largest exposure in the quadrangle of the ancient pre-Cambrian foundation of the region. It is shown as cut by the granite stock of Juniper Flat and by the smaller granite-porphyry stock of Sacramento Hill. The latter is indicated as of later origin than the Dividend fault.

South of the pre-Cambrian schist area is a triangular area of Paleozoic beds characterized by a gentle southwesterly dip. The relation of these beds to the schists north of them is that of unconformable deposition.

The schists, the intrusive masses, and the triangular area of Paleozoic beds are all included in a single structural unit, which has been distinguished in the diagram as the Bisbee block.

On the southwest the Bisbee block is separated diagrammatically by a simple line, representative of the complex zone of faults and dikes along Escabrosa Ridge, from an area of Paleozoic rocks possessing a general southwesterly dip. This has been called the Escabrosa block and with reference to the Bisbee block is downfaulted.

Southwest of the Escabrosa block, separated from it by the Abrigo fault, is the Naco block of gently folded Pennsylvanian limestone. With reference to the block northeast of it this mass represents a further important downthrow to the southwest.

The remaining area of Paleozoic rocks distinguished in the diagram is that designated the Copper Queen block, lying south of the Dividend fault and extending eastward to the Gold Hill fault. Structurally this is a fragment of a syncline. Its relation to the Bisbee block is that of a downfaulted mass. Its relation to the Escabrosa block is that of an upheaved mass. Its relation to the Gold Hill block is that of the underlying mass over which the latter has been partly shoved.

Comparison of the diagram with the geological map at this stage of the discussion will not only aid in comprehension of the latter but will give some idea of the intricate mass of structural detail which must now be adjusted to the bare framework of a diagrammatic conception.

BISBEE BLOCK.

The Bisbee block is bounded on the southwest and southeast by faults. On the northeast it is overlapped by the Cretaceous beds comprising the Bisbee group, and on the northwest extends beyond the limits of the quadrangle. It consists fundamentally of crumpled crystalline schists (Pinal schists) partly overlain by Paleozoic formations and cut by granitic intrusives. Structurally it is the highest of the several simple blocks into which the quadrangle has been divided, all the others having been relatively downfaulted. It is thus the block which in the present stage of regional erosion best exhibits the crystalline pre-Paleozoic foundation upon which the stratified rocks of the quadrangle have been piled.

Of the pre-Paleozoic structure which must once have belonged to the rocks now known as the Pinal schist nothing is directly discoverable. The bedded sediments from which the schists were likely derived by metamorphism were probably much folded and perhaps considerably faulted; but metamorphic recrystallization has obliterated the direct record of these processes. The present lamination of the Pinal schist is on the whole nearly vertical and the dominant strike is a little north of east; but the dip and strike of this cleavage are extremely variable, and the rock is too uniform to reveal, in so limited an area of exposure, any clue to the character of the pre-Paleozoic deformation.

The granite mass of Juniper Flat and the smaller granite-porphyry body of Sacramento Hill, both of which are important structural elements of the Bisbee block, have the typically irregular forms of intrusive stocks. The comparatively simple southwest boundary of the Juniper Flat stock and its approximate parallelism with the dominant dikes and faults of Escabrosa Ridge indicate that the intrusion took place along a northwest-southeast fault or fault zone. The evident relation of the Sacramento Hill mass to the Dividend fault shows that here, also, intrusion was facilitated by faulting. Something more than simple faulting, however, is necessary to explain the irregular invasion of the schists and Paleozoic rocks by the granitic magma. There is no evidence that the latter fused and assimilated the invaded rocks in the vicinity of the contact. It must therefore be concluded that the magma made place for itself either by forcing the encircling rocks aside or upward, or by the process of block engulfment. So far as available evidence goes, either or both of these processes may have been operative in the case of the Bisbee intrusions.

In that portion of Escabrosa Ridge which is surmounted by Mounts Martin and Ballard, and which corresponds to the triangular area indicated in the diagram between the Quarry fault and the Escabrosa zone of faults, is preserved a section of the Paleozoic rocks which is complete very nearly to the top of the Escabrosa limestone and rests unconformably upon the crystalline basement of the Pinal schist. These beds dip generally to the southwest at an angle of about 25 degrees, but southwest of Mounts Martin and Ballard, where they are cut off by the faults of the Escabrosa zone, they become horizontal or dip slightly to the northeast. They thus constitute a fragment of the northeast half of a gentle syncline having a northwest-southeast axis and a southeasterly pitch. Outlying remnants of Bolsa quartzite, formerly parts of this syncline, occur perched along the crest of Escabrosa Ridge for some distance beyond the western boundary of the quadrangle, showing that the present crest of the ridge northwest of Mount Ballard corresponds approximately to the bottom of this structural trough and to the old Paleozoic surface of erosion. This same ancient surface can be identified on the northeast side of Mule Gulch by a few outlying remnants of the Bolsa quartzite—one on the hilltop just north of Bisbee and four at lower altitudes east of the Sacramento Hill porphyry mass. These remnants were formerly connected, probably through an intervening anticline, with the Mount Martin syncline, and their present positions indicate that the Dividend fault terminates on the west at its junction with the Quarry fault. In other words, that part of the Copper Queen block between the Dividend and Quarry faults may be likened to the first wedge-shaped slice cut from a circular cake. This conclusion is supported by the absence of any evidence to show that either of these important faults continues into the Pinal schist beyond their meeting point.

The distribution of these outlying remnants of Bolsa quartzite is further significant as showing that the Cretaceous beds north and east of Bisbee were laid down upon an erosion surface that was locally very nearly coincident with the pre-Cambrian peneplain (see also page 12).

When the fragmentary Mount Martin syncline is further examined it is seen to be dissected by numerous faults. The most important of these is one of northeasterly trend which crosses Escabrosa Ridge about halfway between Mount Martin and Mount Ballard. This is a normal fault which drops the beds on its northeast side about 250 feet.

ESCABROSA BLOCK.

This complex structural division is bounded on the northeast by the Escabrosa zone of faults and dikes, and on the southwest by the Abrigo fault. On the northwest it extends beyond the bounds of the quadrangle and on the southeast it passes beneath the Quaternary of Espinal Plain. In its broadest structural aspect it may be imagined a wide step upon which one mounts from the Naco block and thence ascends to the Bisbee block. The rock most extensively exposed upon the surface of this block is the Abrigo limestone. The general dip of these beds is southwesterly, but they are usually gently folded, the axes of the folds striking northwest and southeast. In the vicinity of faults and dikes the Abrigo beds often show local departures from the prevalent strike and dip, and near the Escabrosa fault-and-dike zone the beds pass as a rule through rapidly increasing steep southwesterly dips into a nearly vertical attitude.

The other formations exposed in this block are the Pinal schist along the northeastern margin, the Bolsa quartzite, and the Martin, Escabrosa, and Naco limestones, all constituting a mosaic of minor fault-blocks, diversified by dikes and sills of granite-porphyry.

The Escabrosa zone of faults and dikes is far from being the simple line of dislocation indicated in the diagram. It is a complex belt of branching and reticulating dikes and faults. The net result of the faulting along this zone has been to drop the Escabrosa block with reference to the Bisbee block. The total throw can not be exactly determined. It is over 2000 but probably less than 2500 feet. Northwest of Abrigo Canyon the dislocation has been effected mainly by intrusion faults of the reversed type. Southeast of Abrigo Canyon, however, the greater part of the displacement occurs along the Bisbee West fault, which is normal in type. The faults of the Escabrosa zone are occasionally opposed in throw. For example, the Mount Martin syncline is cut off, half a mile southwest of the summit of the peak, by an intrusion fault which has dropped the beds to the northeast of it, thus counteracting in part the prevalent southwest downthrow of the zone as a whole.

Just north of Abrigo Canyon the Escabrosa block is transversely divided by a nearly north-east-southwest fault with downthrow to the southeast. The throw of the fault is probably nowhere more than 500 feet, but it is sufficient to bring the Escabrosa limestone in contact with Abrigo beds. Inclosed between this fault, the Bisbee West fault, the Abrigo fault, and some minor faults to the southeast is a block a little over $1\frac{1}{2}$ square miles in area in which are exposed the Abrigo, Martin, and Escabrosa limestones. The Martin limestone overlies the Abrigo formation in its usual conformable position, but the Escabrosa limestone, as may be seen from the map, rests unconformably upon both the Martin and Abrigo limestones. Such a relation may result either from erosional unconformity or from faulting. If from the former, then it implies post-Devonian deformation and erosion of such intensity as may fairly be considered incompatible with the apparent conformity that elsewhere in the quadrangle prevails between the Devonian and Mississippian beds. The hypothesis of a fault is further supported by the noticeable and unusual brecciation of the superincumbent Escabrosa beds in the immediate vicinity of Abrigo Canyon, and the development of much secondary chert along what appear to have been nearly horizontal planes of movement in the limestones above the supposed main fault. Although the contact between the Escabrosa limestone and the underlying Martin and Abrigo beds is usually concealed by a talus of limestone and cherty breccia, its immediate vicinity is usually marked by indubitable evidence of disturbance and frequently by an abundance of silicified limestone breccia. The only point where the contact is clearly exposed is in the western angle of the little fault block, close to the Abrigo fault, in that part of its course coincident with Abrigo Canyon. Here the shattered Escabrosa limestone may be seen resting discordantly above the Martin limestone and separated from the latter by a foot or more of breccia consisting of limestone fragments in a triturated reddish matrix. It is concluded from the foregoing evidence that the Escabrosa limestone in the vicinity of Abrigo Canyon has been thrust by a nearly horizontal fault over the Martin and Abrigo formations. This movement evidently took place before the nearly vertical faults now inclosing the block in which it is recorded were formed. The continuation of this overthrust beyond the fault block in which the observed phenomena connected with it are now isolated has been removed by erosion or carried down below the present surface by later faulting. The direction and original extent of the overthrust are accordingly unknown.

NACO BLOCK.

This unit, lying on the southwest or downthrown side of the Abrigo fault, is structurally the most simple of the divisions into which the quadrangle has been diagrammatically divided. Its exposed portion consists of Naco limestone cut by two small masses of rhyolite. The beds have the form of a gently arched anticline pitching at an angle of 10 to 15 degrees to the north, but becoming nearly horizontal near the Abrigo fault. Upon this general anticline are superposed slight minor corrugations with various axial trends. The Abrigo fault, which bounds the block on the north, is a simple dislocation with a southerly dip of about 75 degrees. The throw is normal and amounts to rather more than 2000 feet. The fault is well exposed in Abrigo Canyon, where it is associated with a breccia of crushed limestone.

COPPER QUEEN BLOCK.

Economically, this is by far the most important structural division of the quadrangle, as within it occur all of the productive copper deposits known in the Mule Mountains. On the northeast it is bounded by the Dividend fault, the granite-porphyry stock of Sacramento Hill, and, superficially, by the overlapping Cretaceous beds of the Bisbee group. On the northwest it is cut off by the Quarry fault. On the southwest it is limited by the Bisbee West fault of the Escabrosa zone and is partly overlapped by Quaternary deposits. On the southeast it disappears beneath the Gold Hill overthrust.

In its broader structural aspect the Copper Queen block is a fragment of a canoe-shaped syncline having a nearly northwest-southeast axis that pitches southeastward. The northeastern limb of this syncline, cut off by the Dividend fault and relatively upheaved, has been removed by pre-Cretaceous erosion. In the down-dropped Copper Queen block is preserved the northwestern end of the southwestern half of the original synclinal canoe.

In this structure are represented all of the pre-Cretaceous rocks of the quadrangle. At the bottom is the Pinal schist, bent downward into a basin by the forces which produced the syncline. This basin is lined by the Bolsa quartzite. Above the quartzite in successive layers, lie the Abrigo, Martin, Escabrosa, and Naco limestones, the latter filling up the central part of the depression to the present surface of erosion. Finally, the Sacramento Hill stock is an eruptive mass that has broken up through the schists and the overlying Paleozoic beds on the line of the Dividend fault, which is nearly coincident with the synclinal axis.

In spite of the complexity introduced by faulting, the syncline is distinctly recognizable in the accompanying geological maps. The thick axial core of Naco limestone extends southeast of Bisbee along the south side of Mule Gulch. This is inclosed on the west and south by successive faulted bands which, beginning at the Dividend fault west of Bisbee and sweeping in a strong curve around the pitching end of the syncline toward Gold Hill, represent the outcrops of the Escabrosa, Martin, Abrigo, and Bolsa formations conforming in general strike and dip to the synclinal structure. Lastly, in the southwest corner of the Copper Queen block, about a mile and a half northwest of Don Luis, the fundamental Pinal schist is exposed in a few small fault blocks.

When the Copper Queen block is more closely scrutinized it appears that the syncline constituting its dominant feature may be distinguished from a minor structural division of the block occupying the triangular area including and lying west of Escacado Canyon and inclosed between the Quarry and the Bisbee West faults. This area is characterized by many vertical or normal faults, some of which have throws of over 1000 feet. It corresponds to a downthrown block with reference to the Bisbee block and to the synclinal part of the Copper Queen block. Owing, however, to its internal faulted structure the amount of this relative downthrow is variable. It is slight in the southern part of the triangular area, where Cambrian and pre-Cambrian rocks prevail, but is very much greater in the northern part, where Pennsylvanian limestone composes most of the surface. This minor structural division may be considered as a marginal portion of the Copper Queen block, from which it became detached and fault-shattered in the general dislocation of the quadrangle at the close of the Carboniferous; or it may be regarded as one or more structural units of equivalent rank, although inferior in size, to the larger structural divisions recognized in the accompanying diagram.

Where faults are as numerous as in the Bisbee quadrangle, descriptive reference to each feature is out of the question. Although, owing to their important relation to economic problems, the dislocations of the Copper Queen syncline will be described somewhat fully, yet for many of the details of structure the geological maps and sections must be left to speak for themselves.

The greater part of Queen Hill, including the summit and southeastern slope, is composed of beds of Naco limestone. Instead of dipping to the southeast, as they should were they strictly conformable to the general synclinal structure, these particular beds constitute a little local syncline with northwest-southeast axis, as may be seen upon viewing Queen Hill from the north or from the vicinity of Sacramento Hill. This structure, however, is very local and passes by change of dip, in the vicinity of Uncle Sam Gulch, into that of the main syncline. North and west of Queen Hill are several faults that complicate the general structure of the Copper Queen syncline. The lower part of Hendricks Gulch, including the old open cut of the Copper Queen mine, are in Escabrosa limestone. Instead, however, of passing conformably beneath the Naco limestone of Queen Hill, the Escabrosa is separated from the latter by the Czar fault. This dislocation has dropped the Naco limestone for a distance of over 500 feet, so that it abuts against the Escabrosa limestone, which stratigraphically belongs below it. The head of Hendricks Gulch is in a block of Naco limestone which has been faulted down into the Escabrosa. One of the faults bounding this block continues north-northeastward to the Dividend fault near Castle Rock and effects a conspicuous displacement of the Escabrosa and Martin limestones. Between this north-northwest fracture and the Quarry fault are other important dislocations which drop Martin and Escabrosa beds of the Copper Queen syncline against the stratigraphically lower Abrigo limestone. The general effect of these faults is to locally increase the southeasterly pitch of the main syncline.

The beds of Martin limestone, from which are carved the picturesque turrets of Castle Rock, in the western part of Bisbee, are apparently in their normal stratigraphic position beneath the Escabrosa beds of Hendricks Gulch, but the contact is not exposed and the two formations may be separated by a fault.

In Uncle Sam Gulch, south of Queen Hill, erosion has cut through the Naco formation and exposed a triangular area of the underlying Escabrosa limestone in its normal stratigraphic position. Higher up the gulch, above the Uncle Sam mine, are two small areas of Martin limestone, showing that erosion has in places cut through to the Devonian member of the syncline. At the highest point on the ridge between Uncle Sam Gulch and Escacado Canyon the Naco limestone rests with southeasterly dip conformably upon the Escabrosa. There are many faults between this point and the hill north of the Whitetail mine, most of which drop the beds on their northwest sides and thus tend to diminish the southeasterly pitch of the Copper Queen syncline. Faulting of this kind has enabled erosion to expose the top of the Escabrosa limestone in two small areas in Silver Bear Gulch. Had there been no faulting the dip of the beds would have carried the Escabrosa much deeper in this part of the syncline.

In the vicinity of the Whitetail mine the formations making up the syncline are exposed in fairly regular succession from the Pinal schist on the southwest to the Naco limestone that on the northeast forms the upper part of the triangular hill upon which is a bench mark at an elevation of 6320 feet. On the southwest slope of this hill the Naco limestone lies in undisturbed conformity upon the Escabrosa. But there has been faulting between the latter and the Martin formation. The exact nature of the movement is somewhat obscure, but the Escabrosa formation seems to have slipped down along a surface of dislocation that nowhere departs greatly from the bedding planes. A movement of the same kind has occurred between the Martin and the Abrigo limestones at the Whitetail mine.

North of Don Luis, in the vicinity of the Cole shaft of the Lake Superior and Pittsburg mine, the syncline is modified by a group of faults of various trends, and a normal dislocation, probably of over 1000 feet throw, occurs between Black Gap and the pass through which the railroad runs from Don Luis to Bisbee. Although this fault is conspicuously apparent on the south side of the ridge, which it crosses, its northwestward course through the Naco limestone is rather obscure, and it has not been traced beyond the point where it is covered by Quaternary deposits. It may join one of the faults mapped in the vicinity of the Cole shaft, the two ending at the junction as do the Quarry and Dividend faults.

East of the fault just noted the beds composing the Copper Queen syncline, except for a moderate displacement at Black Gap, retain their normal synclinal structure up to the point where the structure disappears beneath the Gold Hill overthrust. These beds do not exhibit the changes in strike and dip that are characteristic of the curved, northwest-pitching bow of the synclinal canoe, but constitute part of the straight side.

GOLD HILL BLOCK.

This structural unit is bounded on the north and east by the Gold Hill overthrust fault. On the west it passes beneath Quaternary deposits and on the south extends into Mexico. Superficially it is composed for the most part of Cretaceous beds arched into an anticline with northwest-southeast axis. These beds lie upon a Paleozoic and perhaps in places upon a pre-Paleozoic foundation, which is exposed along the northeastern edge of the block. The block rests, at least in part, upon Cretaceous beds. It owes its position to faulting. The entire block has been thrust from the southwest up a gently inclined, undulating fault fracture for a distance that can not be accurately determined but is thought to be at least 2 miles.

Before the mechanics of the fault are discussed the evidence for its existence will be briefly presented. The contact between the Paleozoic rocks and the Cretaceous rocks lying to the north and east is so related to the topography as to indicate that the older rocks overlie the younger rocks. A view of Gold Hill from the northwest strongly reinforces this suggestion (see fig. 11). A view of the hill from the southeast is scarcely less striking, and the same relation is apparent to one looking northwest from Glance station. Close examination confirms the hypothesis suggested alike by distant views and by the areal distribution of the rocks with reference to the topography. Wherever the contact between the Paleozoic and Cretaceous rocks is exposed the former are found to overlie the latter and to be separated from them by a zone of fracturing and brecciation. On the northwest side of Gold Hill a tunnel has been run from Gold Gulch into the hill. The tunnel is entirely in Glance conglomerate and its face is apparently nearly vertically under the outcrop of the fault on the hillside above. The fault itself has not been reached, but the conglomerate near the face of the tunnel is greatly sheared and crushed. The approximate line of the fault can be readily followed along the north slope of Gold Hill, where it has a rather steep dip to the south and is accompanied by much crushing and disturbance of the underlying conglomerate and overlying Escabrosa and Naco limestones. In the saddle northeast of the hill, the Glance conglomerate has been squeezed between the upthrust limestone and the mass of Cretaceous beds northeast of it into a closely compressed local anticline. On the southeast side of the hill the thrust fault is exposed in some prospects and exhibits a local southwesterly dip of 50 degrees. The Cretaceous beds upon which the overthrust Paleozoic rocks rest are much disturbed in the immediate vicinity of the fault. They are crushed and sheared and in some places metamorphosed to a much crumpled, greenish sericitic schist, very similar in appearance to some of the vastly older Pinal schist.

We may pass for the moment the very complicated corner just southeast of Gold Hill and continue to follow the course of the main overthrust. This swings through a saddle half a mile southwest of Black Knob and thence down past Glance station. While it is not always clearly exposed, the tracing of its approximate course presents no difficulty, owing to the signal discordance in lithology and structure of the rocks it separates and the visible signs of disturbance that accompany it. South of Glance the fault comes to the surface along the bottom of the open valley that extends southward past the Glance mine, and is not very well exposed. The dip is to the southwest as usual but its amount is unknown. It is probably about 40 degrees. It is noteworthy that throughout its course the Gold Hill fault actually outcrops with a somewhat steeper dip than might be expected from the general character of the overthrust. It is probable that this dip becomes less beneath the mass of the block and that its steepness near the present exposures of the fault is local and due to causes that will be later pointed out.

A return may now be made to the faults southeast of Gold Hill, already mentioned. These features are not well exposed as a whole, and the complicated structure to which they give rise may be variously interpreted. The explanation most in harmony with the facts obtained in the course of a minute investigation of this particular area is briefly as follows: The offsetting of the Gold Hill overthrust and the cutting out of the Glance conglomerate southeast of Gold Hill are due to nearly east-west normal fault with southerly dip. This fault is younger than the overthrust. About a mile southeast of Gold Hill is a little mass of Mural limestone inclosed by faults. It occurs with small fault blocks of the Martin and Morita formations in the axis of the Cretaceous syncline, where normally only Glance conglomerate would be expected. It apparently extends beneath the Martin limestone and is a part of the Gold Hill overthrust block. The only conclusion possible is that it was derived from the overridden and buried southwest limb of the Cretaceous anticline and was formerly part of the beds in that limb corresponding to those now exposed in the northeast limb in the vicinity of Black Knob. If the anticline was originally fairly symmetrical this little block of Mural limestone must have been shoved by the Gold Hill overthrust for a distance of at least 2 miles from the southwest. It thus affords an approximate measure of the minimum amount of overthrust.

The mechanical conditions under which the Gold Hill overthrust was initiated can not be satisfactorily determined. As the Paleozoic strata are involved, the forces concerned were by no means superficial, and it is unsafe to conclude that the locus and character of the faulting were determined by any pre-existing structure in the Cretaceous beds. The most that can be said is that the overthrust was effected by strong compression acting along northeast and southwest lines. There is reason to believe that the hanging wall of the fault has been thrust over the foot wall for a distance of at least 2 miles, but nothing can be learned of the antecedent structural conditions that determined the fracture.

As movement along the fault continued the Paleozoic rocks of the hanging wall were thrust forward and upward until they pressed against the Cretaceous beds northeast of Gold Hill and squeezed them into a closely compressed anticline in the immediate vicinity of the fault. The effect of the thrust appears also to have been recorded, at a distance from the fault, in the change of strike and upturning of the Mural limestone near the Easter Sunday mine. It is probable that the overthrust Paleozoic beds never extended much farther to the northeast than the present outcrop of the fissure. The steep dip of the fault where actually exposed and the nature of the local folding and squeezing of the Cretaceous beds in its vicinity are phenomena to be expected along the plowing front of a rigid overthrust mass rather than in those portions of the foot wall which have been greatly overridden.

GLANCE BLOCK.

This is a well-defined overthrust mass that emerges from beneath the Quaternary deposits of Sulphur Spring Valley and rests upon the Mural limestone northeast of Glance station. The block consists of Naco limestone in nearly horizontal beds, unconformably overlain by Glance conglomerate. It has been thrust from the east over the Mural limestone by a fault that is parallel to the bedding of the latter. The outcrop of this fault plane is marked by a slight topographic bench and the presence of a distinct fault breccia. The dip of the fault is about 25 degrees to the east.

Owing to the covering of Quaternary deposits the geological structure that gave rise to this dislocation and the horizontal extent of the overthrust can not be determined. It was evidently effected by forces operating along nearly east-west lines. It is likely that the Naco limestone of this block was ordinarily thrust forward until it met the Naco beds of the Gold Hill block advancing from the southwest. The meeting of these resistant masses probably formed a competent arch over the Morita beds of Black Knob and put a stop to the nearly opposite movements of the two overthrust blocks.

CRETACEOUS TRACT.

This, the largest of the several areal units into which the quadrangle has been diagrammatically divided, is not, like the others, a definite structural block.

On the north it is an area within which the pre-Cretaceous structure is hidden by the overlying beds of the Bisbee group, with their gentle folds and moderate normal faults. Its western boundary is here the sinuous eroded edge of the Glance conglomerate, which rests with low northeasterly dip upon granite, schist, and limestone and conceals the northeastern extensions of the Bisbee and Copper Queen blocks. Its eastern boundary is the similarly overlapping but less indented edge of the Quaternary deposits.

On the south the Cretaceous tract appears as a narrow strip superficially constricted by the opposed Gold Hill and Glance overthrusts and overlapped on the east by the Quaternary deposits of Sulphur Spring Valley.

The outline of the tract is thus conditioned by erosion, by Quaternary overlap, and by low angle overthrusts. Its internal structure has already been briefly described.

Summary of Structure.

In the development of the geological structure of the Bisbee quadrangle faulting has been the dominant factor. Folding, while it has produced important results, has been a less conspicuous process.

A large number of the faults are of post-Pennsylvanian but pre-Cretaceous age, a lesser number are post-Cretaceous but pre-Quaternary, while some can not be definitely classified with either of these groups, although known to be post-Pennsylvanian and pre-Quaternary. The pre-Cretaceous faults are the more numerous and important. They are for the most part nearly vertical and include both normal and reversed types. There is, however, at least one flat thrust fault that is referable to this pre-Cretaceous group. The trends of the more important of these earlier faults range from north-west to west-northwest. These dominant faults are associated, however, with a number of minor faults having northeasterly trend.

The most prominent post-Cretaceous dislocations are thrust faults of northwesterly trend, which have shoved Paleozoic beds over Cretaceous beds. Less conspicuous are normal faults of northeasterly trend.

None of the faults in the area find primitive expression in the topography. The present surface is the work of erosion acting upon a geological fabric whose heterogeneity is only in part due to faulting.

Amid the innumerable blocks into which the pre-Quaternary rocks of the Bisbee quadrangle have been divided by this complex dislocation, it is possible by the elimination of detail to recognize certain dominant structural units. These are (1) the Bisbee block, (2) the Escabrosa block, (3) the Naco block, (4) the Copper Queen block, (5) the Gold Hill block, (6) the Glance block, and (7) the Cretaceous tract.

Broadly considered, the Bisbee, Escabrosa, Naco, and Copper Queen blocks are essentially masses of pre-Cretaceous rocks bounded wholly or in part by faults of the earlier period. In detail, however, they are themselves dissected by minor faults, and their boundaries are in some cases broad and complex fault zones instead of simple dislocations.

With reference to the Bisbee block, the Escabrosa block has been dropped from 2000 to 2500 feet, while with reference to the latter block the Naco block has also been dropped about the same amount. Structurally, therefore, these three blocks constitute gigantic steps rising from the southwest to the northeast.

The Copper Queen block, comprising a fragment of a canoe-shaped syncline of Paleozoic beds, is downthrown with reference to the Bisbee block, but less so than is the Escabrosa block. Economically this block is the most important structural division of the quadrangle, as within it occur all of the known important deposits of copper ore.

Within each of these blocks the beds are folded. The axes of the folds usually have northwesterly trends, although there is much local irregularity, complicated by minor faulting.

The Gold Hill and Glance blocks are essentially masses of Paleozoic and younger beds which have been thrust toward each other, from the southwest and east respectively, over the beds of the Cretaceous Bisbee group.

The Cretaceous tract is less a definite fault block than an area of relatively little disturbance as compared with the other structural units of the quadrangle.

GEOLOGICAL HISTORY.

Major Divisions.

The geological history of the Bisbee quadrangle is divisible into three grand eons—(1) that of pre-Cambrian sedimentation, deformation, and metamorphism, (2) that of pre-Cambrian erosion, and (3) that embracing the Paleozoic, Mesozoic and later eras.

Pre-Paleozoic Sedimentation and Deformation.

The dim, timeworn record of the oldest eon is found in the Pinal schist. It has been shown that this formation probably consisted originally of sediments. It follows that these were derived from still more ancient rocks and were deposited in a pre-Cambrian sea. Long before Cambrian time these sediments were altered to crumpled crystalline schists and were therefore presumably deeply buried beneath other rocks and intensely folded and compressed. As a result of such folding they were probably elevated as an extensive mountain mass.

Pre-Paleozoic Erosion.

During the second eon, which may not have been sharply marked off from the preceding one, this mountainous land was eroded.

It perhaps underwent many vicissitudes during this interval, involving oscillations in level and accumulations of fresh sediments which were only to be again stripped away by erosion. All that is recorded, however, is a vast interval of erosion during which mountains were brought low and rocks bearing the stamp of deep-seated metamorphic processes were exposed at the surface of a nearly level plain of erosion.

Paleozoic and Later History.

PALEOZOIC SEDIMENTATION.

With the opening of Cambrian time this plain sank beneath the sea. The waves, as the shore line encroached upon the land, rounded the fragments, chiefly of vein quartz, that lay upon the subsiding land surface, added to them such coarse material as they produced by direct attack upon the schists, and spread the detritus evenly over the sea bottom as the basal conglomerate of the Bolsa quartzite. As the shore advanced inland the quartzite was deposited as sand above the conglomerate in the deeper water of the outer littoral zone, to a thickness of 430 feet.

Then a change took place. Either there was an increased subsidence which carried this part of the sea bottom beyond the reach of littoral currents having sufficient power to transport sand, or the nearest land mass still remaining above water no longer supplied arenaceous sediments. The Bolsa formation was succeeded by the siliceous calcareous muds of the Abrigo formation, 770 feet in thickness. Here, for the first time in this region, marine life made its appearance, for in the impure, cherty Abrigo limestones are inclosed pteropods, abundant fragments of trilobites, and small *Lingula*-like brachiopods. An incursion of white quartz-sand, now consolidated as the upper bed of the Abrigo formation, marked the close of Cambrian sedimentation. Probably at no time during this period was the local sea bottom depressed to a very great depth, and it appears to have been only occasionally cut off entirely from the finer terrigenous silts.

Neither the Ordovician nor the Silurian period, so far as known, has left any record in the Bisbee quadrangle, the fossiliferous beds of the middle Cambrian Abrigo limestone being succeeded with no visible stratigraphic interruption by the Martin limestone, carrying abundant characteristic Devonian fossils. In spite of the apparent conformity, however, the absence of the Ordovician and Silurian can be satisfactorily accounted for only by supposing that an interval of erosion separates the Cambrian and Devonian formations—that is, there is an actual although locally imperceptible unconformity. Any other explanation meets with insuperable obstacles. The existence of such an unconformity is indicated by the similar conditions described by Walcott in the Grand Canyon of the Colorado, about 350 miles northwest of Bisbee, where Ordovician and Silurian beds are absent and the Devonian is separated by an erosional unconformity from the underlying Cambrian Tonto group. It must be noted, however, on the other hand, that Lindgren (Clifton report, in preparation) has described the Ordovician of the Clifton district, about 100 miles a little east of north from the Mule Mountains, as overlain conformably by the Devonian. But the presence of Ordovician beds at Clifton, even if conformably beneath the Devonian, is evidence for rather than against pre-Devonian erosion at Bisbee, where such beds are lacking. It is one of many facts tending to show that the earlier Paleozoic sedimentation of Arizona was accompanied by great diversity of local conditions.

Whatever may have been the conditions during the Ordovian and Silurian, in the Devonian period the quadrangle was covered by an open sea of moderate depth, in which flourished abundant marine organisms that contributed their calcareous parts to form the Martin limestone. That there was still a land mass rising above the Devonian sea at no great distance from the tract of deposition now under consideration is shown by the occasional occurrence of shales within the Martin formation.

Walcott has shown that in the Grand Canyon region there was an interval of erosion between the Devonian and the Carboniferous periods. The evidence available in the Bisbee quadrangle is not decisive on this point. The most that can be said is that there is apparent conformity between the Martin and Escabrosa limestones. The latter formation, consisting chiefly of pure granular limestone made up very largely of the fragments of crinoids, records probably the deepest water that ever covered the Bisbee region. So far as known no land-derived sediments found their way into this part of the Mississippian sea.

The most careful examination of many excellent natural sections has failed to discover any evidence of unconformity between the Escabrosa and Naco limestones. It is concluded that the deposition of limestone continued without interruption from the Mississippian to the Pennsylvanian epoch. The depth of the water probably gradually decreased as a consequence of the steady accumulation of thousands of feet of calcareous material. It is probable, too, that there was a general elevation of the sea bottom or of a not very distant land mass, for fine terrigenous sediments are occasionally found intercalated between the beds of the Naco limestone, as they are in the Martin formation.

POST-CARBONIFEROUS DEFORMATION AND EROSION.

With the close of the Carboniferous period the long era of Paleozoic sedimentation, during which deposits had piled up to a thickness of over 5000 feet, or approximately a mile, came to an end. Orogenic forces became dominant and the region of the Bisbee quadrangle was elevated above sea level. To this elevation, faulting, folding, and igneous intrusions all contributed.

The beds appear to have been first rather gently folded by forces acting in a northeast-southwest direction. There was some overthrust faulting, as is shown by the sliding of the Escabrosa over the Martin and Abrigo limestones in the vicinity of Abrigo Canyon. This was closely followed by the nearly vertical normal faults and the reversed intrusion faults which constitute the salient features of the pre-Cretaceous structure. The intrusion of the Juniper Flat and Sacramento Hill stocks accompanied or immediately followed this general faulting.

MESOZOIC SEDIMENTATION.

During Triassic and Jurassic time the mountainous country elevated by the post-Carboniferous deformation was subjected to erosion. If any sediments were deposited within the quadrangle during these periods they were removed prior no the opening of the Cretaceous and have left to trace of their former presence. Erosion had stripped most of the Paleozoic beds from the elevated fault block northeast of the Dividend fault and reduced the quadrangle as a whole to a moderately hilly region when the Cretaceous period was introduced by a general subsidence during which the Glance conglomerate was laid down as a coarse littoral deposit along a marine shore line that rapidly encroached upon the land. The comparative rapidity of the submergence is shown by the variable size and very incomplete rounding of the pebbles. These were evidently subjected for a brief time only to the wear of the waves and were then buried beneath the fine gravels, sands, and muds of the Morita formation. Further evidence that the subsidence was, locally at least, a geologically rapid movement is found in the hilly topography that underlies a considerable part of the Glance formation. The pre-Cretaceous surface sank beneath the waves before the latter could reduce its inequalities by planation or do more than slightly rework the stony detritus that littered its slopes and lay in its hollows.

The final result of the deposition of the Glance conglomerate was to level up the pre-Cretaceous topography, which must have exhibited differences in elevation amounting to at least 600 feet, to a smooth sea bottom upon which were afterwards accumulated the regular beds of the Morita formation. The filling necessary to effect this leveling was, however, as has already been pointed out, much greater in the southern half than in the northern half of the quadrangle, and some explanation of the abrupt change which occurs along the line of Mule Gulch is necessary to fully elucidate the manner in which deposition proceeded.

If the Cretaceous beds could be restored to their original nearly horizontal position and then entirely removed, we should see exposed the old surface upon which they were laid down. In the northern part of the quadrangle this surface would be a nearly level plain of erosion floored with Pinal schist, granite, and granite-porphyry. In the vicinity of the present Mule Gulch the plain would terminate, and one standing upon its edge would overlook to the south a lower country diversified by hills of light-hued Paleozoic limestones. What geological events, it may be asked, resulted in this association of elevated plain and hilly lowland? Was the plain formed prior to the submergence by ordinary subaerial erosion at a generally lower level than the neighboring limestone hills, and was it subsequently elevated with reference to the latter, by faulting? Or was it cut during the subsidence by the combined attack of rain, streams, and waves upon the highest portion of the land mass and the last to be covered by the sea?

Reference to the geological map of the quadrangle shows that the line of abrupt change between the comparatively thin uniform layer of conglomerate on the north and the locally thick and variable conglomerate on the south coincides with a line of faulting which brings the Naco limestone against small remnants of the Bolsa quartzite resting upon the Pinal schist, and which is the easterly continuation of the great Dividend fault that passes through the town of Bisbee. It is probable, therefore, that this fault had a direct influence upon the development of the pre-Cretaceous topography. As is elsewhere shown (p. 9), the main displacement along this fissure was accomplished before the intrusion of the porphyry and consequently before the Cretaceous submergence; but there has also been a revival of movement along the fault since the Glance conglomerate was deposited, as may be seen from the offsetting of the latter formation along Mule Gulch.

It seems probable, in the light of all the known facts, that the deposition of the Glance conglomerate was preceded and conditioned by the following train of events: After the main dislocation of the Dividend fault, subaerial erosion continued to degrade the region until nearly all of the Paleozoic rocks had been stripped from the up-faulted northeast half of the quadrangle and the pre-Cambrian schists, with their included granitic intrusives, had been laid bare as a broad and topographically simple ridge whose upper surface was nowhere greatly above or below the surface of the denuded Cambrian peneplain upon which the Bolsa quartzite had been deposited. The southeastern half of the quadrangle, on the other hand, with its intricate structure of downfaulted Paleozoic beds, was carved into a complex hilly topography that stood as a whole somewhat lower than the schistose terrane to the northeast. The region was then rapidly submerged until the schists and granite of the northeastern part of the quadrangle alone stood above the sea. During this subsidence the calcareous conglomerates of the Glance formation accumulated over the uneven surface of the Paleozoic rocks. Possibly, also, renewed movement along the Dividend fault may have somewhat accentuated the physiographic boundary between the northeastern and southwestern parts of the quadrangle. There was probably at this stage a retardation of the general subsidence, while the waves and streams attacked the still projecting schist mass and gradually reduced it to sea level, the material derived from its degradation helping to level up the hollows in the region that was carried down in the more rapid sinking, and finally accumulating as a relatively thin deposit over the last land to become sea bottom. With the entire submergence of the region embraced in the quadrangle the deposition of the Glance conglomerate came to an end, and was followed by the accumulation, upon a gradually sinking sea bottom, of 1800 feet of sands and muds composing the Morita formation. This is a shallow-water deposit and records conditions intermediate between those under which the littoral Glance conglomerate was formed and those represented by the Mural limestone. The actual source of the Morita sediments is unknown. It is evident that the Pinal schist contributed detritus to the basal beds, but as it is probable that all of the schists within the limits of the quadrangle were covered by the Glance conglomerate before any considerable part of the Morita beds was laid down, the land mass that furnished the sands and muds must have lain outside of the area under investigation. The main shore line probably lay to the west of the Mule Mountains.

After the greater part of the Morita sands and silts had accumulated in a sea that was apparently poorly provided with animal life, there was a change in the character of the sediments. They became more calcareous and gradually passed into the impure limestones, often crowded with marine shells, that make up the lower member of the Mural limestone. These fossiliferous calcareous muds were in turn succeeded by the fairly pure limestone beds of the upper member of the Mural formation, indicative of a moderately deep sea containing abundant animal life. The 650 feet of Mural limestone, however, mark an episode in a general accumulation of sands and silts, as is shown by the return in the Cintura formation to conditions of deposition similar to those which prevailed during the laying down of the Morita formation.

The formations from the Glance to the Cintura inclusive were deposited in the early Cretaceous (Comanche epoch), which accordingly is represented by nearly 5000 feet of sediments. How much more material was deposited during later Cretaceous and Tertiary time is unknown.

POST-CRETACEOUS DEFORMATION AND EROSION.

Since the deposition of the Cintura formation the rocks of the quadrangle have been deformed by folding and faulting and subjected to erosion. The exact sequence of these events is not revealed. The latest faults, for example, are certainly older than much of the erosion, but the quadrangle may also have been actively eroded long before this faulting.

The first event subsequent to Comanche sedimentation recorded in the structure of the quadrangle was a general tilting to the northeast at an angle of 15 or 20 degrees. This movement was probably connected with regional elevation that converted the sea bottom of early Cretaceous time into dry land. The northeasterly tilting, which appears to have affected the whole of the Mule Mountain mass, may have resulted from a gentle anticlinal arching of the Cretaceous beds and their underlying Paleozoic and pre-Paleozoic basement. If so the Mule Mountains are part of the northeast limb of a broad anticline whose southwestern limb must have extended over the region now occupied by the San Pedro Valley and has been either downfaulted or cut away by erosion. Another possible explanation is that the Mule Mountains constitute a tilted fault block whose weathered escarpment overlooks the downthrown tract of San Pedro Valley. The verification of either of these principal hypotheses involves, however, more than the study of a single quadrangle. From the fact that the Cretaceous beds of the Bisbee quadrangle exhibit minor northwest-southeast folds, the hypothesis that the post-Cretaceous northeasterly tilting is a result of a broad anticlinal structure is for the present regarded as having the greater probability.

As a result of this differential elevation the beds of the Bisbee group stood highest in the southwestern part of the quadrangle. With the progress of erosion these upraised beds were first carried away and more and more of the pre-Cretaceous basement was exposed, until at the present day the Cretaceous beds have been stripped from the greater part of the southwestern half of the quadrangular area. This denudation, however, has not gone on without interruption. At some stage during its progress occurred post-Cretaceous faulting of two distinct kinds—normal faults of moderate throw, exemplified by the Mexican Canyon fault, and extensive overthrusts produced by forces operating along nearly east-west lines and resulting in the structure of the Gold Hill and Glance blocks.

During late Cretaceous and Tertiary time the Bisbee quadrangle was probably a land area undergoing erosion. No formations referable to these periods are known within the quadrangle. It is possible that some of the unconsolidated material penetrated by deep wells in Sulphur Spring Valley may be Tertiary, but there is as yet no evidence justifying the separating of these deposits from the overlying Quaternary accumulations.

QUATERNARY EROSION AND DEPOSITION.

The record of Quaternary time is one of uninterrupted erosion. During this period the present topography was carved. Under the more humid conditions that probably prevailed in the Pleistocene epoch, much of the material stripped from the Mule Mountains was carried down to the sea. But with the increasing dessication of later Pleistocene and Recent time the bulk of the detritus has accumulated in the neighboring Sulphur Spring and San Pedro valleys.

ECONOMIC GEOLOGY.[1]

INTRODUCTION.

HISTORY OF MINING DEVELOPMENT.

Prior to 1880 Bisbee was an unimportant lead camp, a single furnace being then in operation upon the cerussite mined from the Hendricks claim, close to town. The copper ore of the Copper Queen mine was discovered early in this year, and was profitably exploited until 1884. This ore was free from sulphur and averaged 23 per cent copper. It was treated in two 36-inch furnaces, which, in spite of their small size and the use of wood as fuel, were able to turn out about 500,000 pounds of copper per month. In 1882 the men composing the present Copper Queen Company bought the Atlanta claim, near the original discovery, and began prospecting. In 1884 the Copper Queen ore body, which had been worked for 300 feet down an incline, was exhausted. The outlook was gloomy and work was almost abandoned when a second ore body was simultaneously discovered from the original Copper Queen incline and from the Atlanta workings. In order to avoid legal complications the two companies combined as the Copper Queen Consolidated Mining Company, which gradually absorbed the neighboring properties by purchase. In 1886 the old smelting plant became inadequate and was rebuilt. Greater economy was necessary, as the average tenor of the ore had fallen to about 8 per cent and the price of copper had also notably declined.

Shortly after 1890 the completely oxidized ores showed signs of failing, but in 1893 the works were remodeled by the introduction of converters, and sulphide and oxide ores have since that time been successfully worked together by the matte process. The introduction of these converters was due to Dr. James Douglas and marked the beginning of a new epoch in the smelting of copper ores in Arizona.

Up to the end of 1902 practically all the copper from Bisbee was the product of the connected group of mines owned by the Copper Queen Company. Recently, however, extensive ore bodies have been opened up in the Calumet and Arizona mine, and in the latter part of December, 1902, this company was turning out from 30 to 40 tons of copper a day from its new smelter at Douglas.

MINES.

The Bisbee quadrangle contains two large productive copper mines—the Copper Queen and the Calumet and Arizona. The former comprises a maze of workings connecting with the surface through the Czar, Holbrook, Spray, and Gardner shafts. The area exploited covers nearly half a square mile, while the vertical range of exploration is about 950 feet. The Calumet and Arizona mine adjoins the Copper Queen on the south and is worked through the Mag shaft, 1200 feet in depth.

Other mines which were being operated in 1902, and which, although not then productive, contain some copper ore, are the Lowell, 1120 feet deep, and the Cole shaft of the Lake Superior and Pittsburg Company, about 1000 feet in depth. The Calumet and Pittsburg, 950 feet deep, the Bisbee West mine, 700 feet deep, and Glance mine, 500 feet deep, are active prospects which up to the close of the year 1902 had not found ore in paying quantities. The Easter Sunday, although a small mine, is of exceptional interest as the only producer of gold ore in the quadrangle.

PRODUCTION.

The total production of the Copper Queen mine from the beginning of operations to the end of 1902 was about 378,047,210 pounds of copper.

If 2,000,000 pounds be added to the above total as the roughly estimated product of mines other than those of the Copper Queen group there is obtained a total output for the Bisbee quadrangle, to the close of 1902, of 380,047,210 pounds of copper.

COPPER ORES.

GENERAL CHARACTER OF MINERALIZATION.

The Bisbee quadrangle owes its economic importance exclusively to the occurrence within it of ores of copper. The unimportant deposit of lead carbonate in Hendricks Gulch, the first discovery in the district, is still worked in a small way, and the Easter Sunday mine has supplied a siliceous gold ore that is used in the Copper Queen smelter for converter lining, or ganister. But these, so far as known, are the only ores in the quadrangle that are commercially exploited for other metals than copper. In comparison with the copper deposits the known occurrences of other ores are economically insignificant.

For a district that has produced nearly 400,000,000 pounds of copper, the Bisbee quadrangle, in spite of the general bareness of its rocky slopes, exhibits little superficial evidence of its mineral wealth. The porphyry mass of Sacramento Hill and the schists that partly inclose it southeast of Bisbee show considerable alteration and contain abundant disseminated pyrite, which by oxidation colors the rocks with a rusty stain, but so far as known no deposits of value occur wholly within these rocks. Along the Dividend fault in Bisbee are outcrops of dark, rusty masses composed principally of limonite. Similar ferruginous ledges occur in Hendricks Gulch, on Queen Hill, and in the limestone south of Bisbee. Experience has shown that such limonitic croppings, although rarely containing appreciable quantities of copper-bearing minerals, are nevertheless frequently associated with an underlying ore body. They mark loci of fracturing and mineralization in the limestone. They evidently result from the oxidation of pyrite. The less soluble iron oxide and some silica remain near the surface, while such copper as was originally present has been carried down by percolating solutions and redeposited at lower levels. These bodies of limonite, when not too siliceous, are the best surface indication of ore that the district affords, although it by no means follows that there is always ore beneath them. Many of the most important ore bodies, on the other hand, would have remained undiscovered were superficial phenomena alone relied upon to suggest exploration. Although the rocks of the quadrangle are seamed with faults and dikes none of the workable copper deposits occur as lodes or fissure veins. With a few exceptions they are irregular replacements of limestone. Originally pyritic, containing probably subordinate amounts of chalcopyrite, they owe their present value to secondary concentrations effected by processes of sulphide enrichment and oxidation.

DISTRIBUTION OF THE ORE BODIES.

The principal bodies of copper ore thus far exploited in the quadrangle are contained within an irregular area that is approximately a quarter of a square mile in extent. This area begins at the north in the heart of the town of Bisbee and extends southward for three quarters of a mile. It lies west and northwest of Sacramento Hill and for the most part between the Czar and Calumet and Arizona (Irish Mag) shafts.

Outside of this limited area, no large bodies of copper ore have yet been discovered, although more or less ore is known to occur in the Lowell, Uncle Sam, Whitetail, Wade Hampton, and other mines and prospects.

MINERALOGY OF THE ORES.

ORE MINERALS.

Native copper.—Copper in the native state was not an uncommon constituent of the lower portions of the great oxidized ore bodies that were worked a few years ago in the Copper Queen mine. According to Dr. Douglas it was abundant just above the third level at the bottom of the great ore body southwest of the Czar shaft, where it occurred sometimes in masses weighing several hundred pounds. Native copper is now, however, rather rare in this mine, but is abundant in the Calumet and Arizona mine, particularly on the 950- and 1050-foot levels. It is usually closely associated with cuprite and occurs as a rule in proximity to sulphide ores. On the 950-foot level, about 400 feet southeast of the shaft, the bulk of the ore of a large rich stope consists of crystalline cuprite bound together into a tough mass by an irregular web of native copper. With the cuprite and copper are associated some limonite and other earthy oxides and a little fibrous malachite, chiefly in vugs.

On the 1050-foot level of this mine, native copper is abundant as tough spongy aggregates of small crystals, sometimes encrusting chalcocite and sometimes enveloped in ferruginous clay or earthy oxide ores. It also occurs in thin layers along fissures in clayey oxidized ground as small loose crystals up to 2 or 3 millimeters in diameter, which show the usual modified cubes and octahedra embedded in a soft, earthy mixture of cuprite, limonite, and kaolin.

Pyrite.—Although not, strictly speaking, an ore, pyrite is here included with the ore minerals on account of its intimate chemical, physical, and genetic relationship to them. It is the most abundant and widespread sulphide in the district, and the one of which all the ore bodies, however, varied may be their present constitution, originally in greater part consisted.

In the form of small crystalline grains disseminated through masses of altered rock, pyrite is abundant in the intrusive porphyry mass of Sacramento Hill and in the adjacent schists which partly inclose that mass on the east. Associated with the great bodies of copper ore disposed about the porphyry mass in the limestone south of Bisbee, pyrite occurs in large quantity. In the upper levels of the mines, where oxidation has been active, it is sometimes found in isolated masses inclosed in envelopes of chalcocite and oxidized ore. In the lower levels it forms extensive bodies which pass somewhat gradually into altered limestone in which the pyrite occurs disseminated in small grains, usually of rather irregular outline, and in little bunches and stringers. Of these pyritic bodies only those portions that contain chalcopyrite or chalcocite have proved workable.

Microscopical examination of thin sections shows that the pyrite disseminated through the limestone is nearly always associated with tremolite, diopside, garnet, or vesuvianite. In some cases the calcite of the limestone has been entirely replaced by silicates and pyrite, with usually more or less quartz; in other cases, the silicates are lacking and the limestone has been altered to a mass of quartz and pyrite. The pyrite is contemporaneous with these minerals, and is intergrown with them.

Chalcopyrite.—So far as observed, in the Bisbee quadrangle this mineral occurs only in massive form, never in distinct crystals. It is apparently confined to the limestones. Unlike the pyrite it is rarely found in a disseminated condition, but when present at all is likely to be accompanied by pyrite and to constitute fairly solid masses of ore. An excellent example of such an occurrence may be seen in a body of chalcopyrite ore on the seventh level of the Spray mine. As an ore-forming mineral, however, it is much less common in the present workings of the Bisbee mines than chalcocite and the various oxidized ores.

Sphalerite.—Sphalerite, or zinc blende, is of rare occurrence in the Bisbee quadrangle. It occurs occasionally in little specks, with pyrite and chalcopyrite, in metamorphic limestone.

Chalcocite.—This mineral, familiarly known as copper glance or "glance," is the most important sulphide occurring in the Bisbee quadrangle, since nearly all of the bodies of workable sulphide ore owe their value to its presence. So far as observed it occurs only in massive form, distinct crystals being nowhere seen. It is sometimes firm and compact in texture, but is often rather soft, and occasionally has almost a sooty character. Much of the sulphide ore occurs as friable, granular pyrite, each grain being coated with chalcocite.

In the Copper Queen group of mines, chalcocite is found at various depths but never far from oxidized ore. Its most characteristic place of occurrence is in the irregular zones of rich sulphide ore that usually intervene between masses of lean pyrite and oxidized ores containing cuprite, native copper and carbonates.

In the Calumet and Arizona mine chalcocite is found associated with cuprite, limonite, malachite, and brochantite (a basic sulphate of copper). As in the Copper Queen mine, it frequently occurs as a dull, cryptocrystalline coating on pyrite.

In the Lowell mine, chalcocite occurs in a soft, black earthy condition, with partly oxidized pyrite, and also in a more compact form associated with pyrite, native copper, and malachite.

Outside of the larger mines chalcocite is found irregularly but widely distributed through the large area of Glance conglomerate that stretches from

[1] For a fuller account of the Bisbee ore deposits than can be compassed in the brief outline of a folio text, from which details and discussion are purposely excluded, the reader is referred to a report on the geology and ore deposits of the Bisbee quadrangle, published as Professional Paper No. 21 of this Survey.

Gold Hill southward to the international boundary. The mineral occurs in minute reticulating veinlets, often microscopic in size, and in little rounded bunches, rarely over half an inch in diameter, usually inclosed within a thin envelope of malachite. The chalcocite is usually accompanied by the development of a secondary quartz in veinlets and small vugs. Both chalcocite and quartz have in part filled minute fissures in the conglomerate, but have also in part replaced some of the finer interstitial calcareous matrix by which the pebbles are held together.

The mass of conglomerate forming the hill just west of the Glance mine exhibits well the scattered mineralization just described. The occurrence of this chalcocite in the Glance conglomerate has led to extensive prospecting, which has not, however, revealed workable ore bodies.

About 1000 feet northwest of the No. 3 shaft of the Lake Superior and Pittsburg Company chalcocite altering to malachite occurs in a little vein in Martin limestone. This is the only observed instance in the quadrangle of the occurrence of the mineral in a fissure vein.

Malachite.—The familiar green carbonate of copper is found in greater or less quantity wherever copper ores are undergoing oxidation. In the older workings of the Copper Queen mine this mineral was abundant, occurring in large and beautiful masses with azurite and calcite in caves in the limestone. The walls of these caverns were covered with velvety moss-green malachite and sparkled with the blue crystals of azurite, while from the roofs hung translucent stalactitic draperies of calcite, delicately banded and tinted with the salts of copper. But the caves have been stripped of their treasures and either filled with waste or allowed to collapse. They are things of the past, and museum specimens, of which perhaps the finest collection is that in the American Museum of Natural History in New York, can but feebly suggest their former splendor.

The malachite occurred in the form of mammillary incrustations, which, while often of considerable thickness, were of fibrous texture and not adapted to the ornamental purposes to which the well-known Russian malachite has long been applied.

In the present workings of the Copper Queen mine, malachite is not very abundant. It occurs usually in little nests and bunches in soft limonitic ore containing earthy cuprite. The presence of little green specks of malachite in such ores is generally indicative of a high tenor in copper.

The Calumet and Arizona mine exhibits similar occurrences, but the mineral is here found also in vugs within masses of crystalline cuprite and native copper.

In both the Copper Queen and Calumet and Arizona mines the malachite is frequently associated with small amounts of brochantite, a mineral easily mistaken for the green carbonate, and with chrysocolla. Nowhere at the present time does it constitute more than a very small portion of the ore.

Azurite.—The blue carbonate of copper, while formerly fairly abundant and occurring in large crystalline slabs in the oxidized ores in the Copper Queen mine, is now seldom found, except in occasional little bunches in the earthy ferruginous ores of the thoroughly oxidized zones.

Chrysocolla.—The hydrous silicate of copper, like malachite, azurite, and brochantite, is a minor constituent of the Bisbee copper ores, and seems never to have been very abundant. It was noted in the Calumet and Arizona mine, where it forms thin concentric shells about kernels of crystalline cuprite, native copper, and brochantite, and is enveloped in turn by malachite and calcite. Intimately associated with the chrysocolla is a lustrous, brittle, pitch-black substance which Koenig has recently described as a new mineral species and named melanochalcite.

Melanochalcite.—This is described by Koenig as forming a thin envelope about kernels of cuprite and inclosed in turn by chrysocolla. It is black, with a pitchy luster, and apparently amorphous. According to Koenig's chemical analyses, it is a silico-carbonate of copper having the formula $Cu_2(SiC)O_4.Cu(OH)_2$.

Material identical with that described by Koenig was obtained from the same locality, namely, the 850-foot level of the Calumet and Arizona mine. It occurs as thin shells about nuclei consisting of crystalline cuprite, native copper, and brochantite.

Aurichalcite.—This mineral, a basic carbonate of zinc and copper, has been reported from the Copper Queen mine, but none was seen in 1902.

Brochantite.—This green, orthorhombic, basic sulphate of copper is not abundant in the Bisbee quadrangle, but has been noted in small amounts, often associated with malachite, for which, upon superficial examination, it might readily be mistaken.

As a rule it is recognizable in the Bisbee ores only by the microscopical examination of thin sections. Its most characteristic occurrence is in the form of little nests and irregular veinlets in the cuprite of the Copper Queen and Calumet and Arizona mines.

Brochantite is not sufficiently abundant to form an important constituent of the Bisbee ores, and its occurrence in the district has not been previously recorded.

Cuprite.—The red oxide of copper is an abundant and important constituent of the Bisbee ore bodies. It occurs sometimes in an impure earthy condition, mixed with limonite and ferruginous clays; sometimes in crystalline masses, associated with native copper. The latter occurrence is particularly characteristic of the deeper oxidized zones in the vicinity of chalcocite and other sulphides.

In the present workings of the Copper Queen mine the bulk of the cuprite occurs in the earthy condition, mixed with limonite, pure crystalline masses of any size being comparatively rare. In the Calumet and Arizona mine, however, new stopes have been opened in ore bodies containing cuprite in large crystalline masses, usually associated with native copper, and in beautiful druses of ruby-red isometric crystals, usually in the form of simple cubes or of cubes modified by the octahedron and dodecahedron.

Tenorite.—The crystalline form of the black oxide of copper was not observed in the course of the present investigation. The earthy variety, however, commonly known as melaconite, occurs in some of the soft, clayey ores, usually mixed with the black oxide of manganese in the form of a light, sooty powder. Ore of this character containing about 5 per cent of copper was observed in the Lowell mine. In the Calumet and Arizona mine, about 800 feet below the surface, there is in the limestone a natural cavern whose damp walls are covered with a black, moss-like botryoidal growth. This material is apparently still being deposited, for the fragile stems of the dendritic efflorescence break off by their own weight when they reach a length of over half an inch and the floor of the cavern is deeply covered with a fluffy carpet of this black material. Inspection of the walls shows that this is composed of alternating, irregularly overlapping layers of the black efflorescence with druses of calcite. Chemical tests of the black material show that it is a mixture of the oxides of copper and manganese, probably melaconite and bog-manganese, or wad.

Koenig, in 1891, described some small black crystals from the Copper Queen mine and concluded that they were essentially a mixture of cupric and cuprous oxides and were tetragonal in crystal form. He decided that they represented a distinct mineral species, for which he proposed the name *paramelaconite.*

Footeite.—This mineral, a deep blue chlorhydrate of copper, occurring in minute monoclinic prisms implanted with paramelaconite on limonite, was first described and named by Koenig, from a specimen said to have come from the Copper Queen mine. Footeite is evidently of rare occurrence in the Bisbee mines and was not seen in 1902.

GANGUE MINERALS.

Of the various minerals associated with the ores, *calcite,* in its role of principal constituent of the limestone in which the important ore bodies occur, is the most abundant. It is seldom, however, that the mineral forms so large a part of the altered limestone in the immediate vicinity of the ore as it does of the unchanged rock in which mineralization has not been active. As will presently be shown, it has been largely, in the process of mineralization, replaced by pyrite, amphibole, pyroxene, garnet, chlorite, quartz, vesuvianite, and other minerals.

In the form of stalactites, often beautifully colored with salts of copper, and in showy crystalline masses, calcite was abundant in the bodies of oxidized ore worked in early days in the Copper Queen mine, and is still encountered to some extent within the oxidized zones. It is rarely, however, a conspicuous gangue mineral in the ores now exploited.

The unoxidized pyritic ores, particularly those too poor for working, are intimately associated with several minerals, chiefly silicates of calcium, magnesium, and aluminum in varying proportions, which so far as observed occur only in crystals of microscopic size. Their identification accordingly depends upon the microscopical investigation of thin sections. Of these probably the most common is the calcium-magnesium amphibole *tremolite,* usually occurring in aggregates of minute radiating prisms, which under the microscope show the characteristic cross sections, cleavage, and optical properties of this mineral. Nearly or quite as abundant, and usually accompanying the tremolite, is a colorless pyroxene which occurs in microscopic grains, as a rule less than a tenth of a millimeter in diameter, rarely showing sharp crystal outlines, but exhibiting a distinct tendency to the development of stout prismatic form. This mineral has the optical properties of *diopside.* Although neither tremolite nor diopside, so far as observed, occur in the Bisbee quadrangle in crystals large enough to be seen with the naked eye, their presence in the altered mineralized limestone can generally be recognized by a faint greenish tint in the rock, joined with a certain compactness of texture unlike that found in any of the unaltered limestones. Most of the limestone encountered in the Spray workings from the fourth level down, and in the Calumet and Arizona mine from the 850-foot level down, exhibits this development of tremolite and diopside, and all gradations may be studied, from limestones consisting almost exclusively of calcium carbonate to those in which all of the carbonic anhydride has been replaced by silica.

A colorless garnet, probably the calcium-aluminum garnet *grossularite,* occurs in some of the altered limestone associated with tremolite and diopside. As seen under the microscope in thin section, it occurs in imperfect crystals of rounded outline, often poikilitically inclosing other constituents of the rock. It is seldom perfectly isotropic but usually exhibits an indistinct and irregular birefringence—a not uncommon phenomenon for grossularite. This mineral, associated with tremolite, diopside, and calcite, was particularly noted in the altered limestone from the new station on the 1150-foot level of the Calumet and Arizona mine (the deepest point reached in the underground exploration of the district) and on the fifth level of the Holbrook, northeast of the shaft. It is probably fairly abundant throughout the compact, greenish, pyritized limestones in the deeper levels of the Copper Queen, Calumet and Arizona, and Lowell mines.

In several thin sections of the altered limestones from the Copper Queen and Calumet mines there was noticed, in addition to the minerals already enumerated, small colorless prisms, having an index of refraction about equal to garnet but with a birefringence somewhat lower than quartz. The few cross sections found are square or octagonal and remain dark between crossed nicols. The mineral extinguishes parallel with the prism, and the prismatic axis corresponds with the direction of greatest elasticity. The mineral is probably *vesuvianite,* a basic calcium-aluminum silicate of somewhat uncertain formula.

The metasilicate of calcium, *wollastonite,* was looked for in the altered limestones but was not detected in any of the thin sections, although the silicates described are those with which it is often associated.

Quartz varies greatly in abundance in different portions of the ore-bearing ground. A few small veinlets of quartz, carrying pyrite, were observed in the altered limestone on the 950-foot level of the Calumet and Arizona mine, but vein quartz is exceptional in connection with the cupriferous ore bodies. The mineral, where it occurs at all, usually has the form of fine-grained aggregates that have replaced the calcium carbonate of the limestone or the feldspars of the granite-porphyry. Small amounts of quartz may usually be found as a microscopic constituent, associated with tremolite, diopside, garnet, and pyrite, of the altered limestones of the locally prevalent type. Near the porphyry mass of Sacramento Hill quartz is more abundant than elsewhere. Much of the rock in the vicinity of the Gardner shaft, for example, originally limestone, now consists essentially of a finely crystalline granular aggregate of quartz with varying amounts of pyrite and chlorite. The bottom of the shaft, in 1902, was in such material. Quartz of the same fine-grained granular character, associated with pyrite, sericite, and kaolin, also makes up much of the altered and mineralized granite-porphyry of Sacramento Hill.

Most of the soft, earthy oxidized ores mined in the Copper Queen and the Calumet and Arizona mines are accompanied by and more or less intimately mingled with *limonite* and clays of various colors. The limonite sometimes occurs in stalactitic or botryoidal form, but in the present workings is more often earthy, and mixed with ore or clay.

The clay is sometimes white, sometimes pink or greenish-gray, but more often it is yellow or reddish, from the presence of limonite. A snow-white, waxy variety, beautifully diversified by little veinlets of light-green malachite, was collected on the second level of the Copper Queen mine, about 250 feet south of the Holbrook shaft, and was subjected to chemical examination as representative of the purest form in which these clay-like secondary products occur. According to Dr. W. F. Hillebrand the material contains no carbon dioxide and no magnesia. It suffers a loss of 22.8 per cent of silica on ignition, and the residue consists chiefly of silica and alumina. It is thus probably nearly pure *kaolinite,* although too minutely crystalline to reveal any distinct structure under the microscope. This white kaolinite, which occurs in bunches and streaks in earthy limonite and ore, is usually associated with bright-red and pale-green varieties, the former owing its color to oxide of iron and the latter to some salt of copper.

These clays, in varying purity, together with soft earthy limonite, constitute the most abundant and characteristic gangue materials of the thoroughly oxidized ores.

PARAGENESIS OF THE ORE AND GANGUE MINERALS.

By paragenesis is meant the association of the various ore and gangue minerals with special reference to the order and mode of their formation. It is not, however, implied in the definition that the minerals were formed in any rigid, unalterable sequence or that the development of any one mineral was a synchronous process in different ore bodies, or was peculiar to any particular division of geological time.

Among the metallic sulphides of the Bisbee copper deposits, pyrite was undoubtedly one of the first to form. Whether small quantities of chalcopyrite and minute amounts of sphalerite were deposited at the same time as the primary pyrite, is a moot question. Although some of the chalcopyrite is certainly later than the bulk of the pyrite, yet the contemporaneous formation with the latter of more or less disseminated chalcopyrite is by no means disproved or improbable. The association of most of the pyrite with amphibole, pyroxene, garnet, and vesuvianite is such as to demonstrate their essentially contemporaneous development in the limestone. To the same general epoch of mineralization belongs also the formation of most of the quartz and chlorite associated with the ores. In the development of the ore and gangue minerals, there is thus distinguishable an early stage characterized by the practically simultaneous appearance of pyrite, tremolite, diopside, grossularite, vesuvianite, chlorite, quartz, and perhaps also of chalcopyrite and sphalerite.

That at least some of the chalcopyrite is of more recent origin than pyrite is shown by the occurrence of chalcopyrite as an envelope about grains of pyrite and as veinlets in the latter mineral.

Such sphalerite as was observed in the Bisbee quadrangle was always closely associated with chalcopyrite and was probably formed at the same time as the latter mineral.

Chalcocite is undoubtedly the most recently formed sulphide mineral occurring in the Bisbee ore bodies, and has resulted from the action upon other sulphides, chiefly pyrite, of solutions moving generally downward from the zone of oxidation.

Of the minerals of the oxidized zone cuprite and native copper are apparently among the first to develop, since they occur usually near the bottom of the oxidized ore, in proximity to the sulphides. The direct alteration of chalcocite into native copper is exhibited by specimens from the Calumet and Arizona mine. These show very irregular kernels of compact chalcocite encrusted with a spongy aggregate of small, sparkling crystals of native copper, associated with a little earthy cuprite. The copper is not strictly confined to the exterior of the chalcocite kernels but penetrates these for varying distances up to about half an inch in the form of little vugs and indefinite stringers.

As a rule cuprite has formed just after the native copper with which it is immediately associated, but the sequence is by no means always clearly shown. In the Calumet and Arizona mine native copper occurs in branching crystalline masses beautifully encrusted with crystals of cuprite. The cuprite is in such cases obviously the younger mineral. At other places in the same mine the two minerals are found so intimately associated that it is difficult to determine which was the first to form. The copper constitutes a metallic mesh or sponge which is filled with crystalline cuprite. Although some of the copper may have formed slightly in advance of some of the cuprite, both minerals were probably crystallizing at the same time.

Brochantite has been found only in close association with cuprite and appears to have been formed shortly after that mineral. Melanochalcite and chrysocolla are also characteristic of the deeper portion of the oxidized zone. The sequence of formation as shown in specimens from the Calumet and Arizona mine was: native copper, cuprite, brochantite, melanochalcite, chrysocolla, malachite, and calcite.

In general the formation of limonite appears to have accompanied or closely followed that of cuprite and to have continued for some time after, so that it is also intimately associated with the occurrence of malachite and azurite.

The azurite on the whole belongs to a later stage of the general oxidation than the malachite. But there is much overlapping in the occurrence of these two carbonates.

Tenorite is usually associated with wad, or "bog manganese," in the upper part of the zone of oxidation.

MODE OF OCCURRENCE OF THE ORES.

FORM AND DIMENSIONS OF THE ORE BODIES.

The Bisbee copper ores, as exploited in the Copper Queen, Calumet and Arizona, and Lowell mines, occur for the most part very irregularly as large masses in the Escabrosa and Naco limestones. The horizontal dimensions of these ore bodies are usually much greater than the vertical. They are rudely tabular or lenticular in form, and lie generally parallel to the bedding planes of the inclosing limestones. Definite walls are exceptional. As a rule the oxidized ore passes gradually and irregularly on its peripheries into so-called "ledge matter," consisting chiefly of soft limonitic clays, which in turn grade into more or less altered limestone. The unoxidized sulphide ores may exhibit a peripheral transition either to oxidized ores or to metamorphosed limestone impregnated with pyrite.

On any single horizontal plane the dimensions of the ore masses rarely exceed 150 by 200 feet, but series of connected stopes indicate that in general plan these figures may be considerably exceeded. Thus the stopes northeast of the Holbrook shaft in the Copper Queen mine indicate the existence of a practically continuous body of ore and "ledge matter" about 800 feet in length and 600 feet in width. On the other hand, the actual maximum thickness of the ore bodies hitherto extensively worked rarely exceeds 125 feet.

RELATIONS TO THE BEDDING OF THE LIMESTONES.

The statement that these very irregular tabular or lenticular masses of ore lie parallel with the bedding planes of the inclosing limestones is the simplest expression of a general relation and requires some qualification when the ore bodies are studied in detail. It is then found that the original structure of the limestone in the vicinity of the ore is very much obscured by metamorphism, if it is not entirely obliterated by the extensive formation of ferruginous clay resulting from the oxidation and decomposition of the ores and country rock. Furthermore, the ore sometimes cuts across the bedding of the limestones for considerable distances, as will be shown later.

Owing to the extensive alteration of the limestones in the vicinity of the ore bodies, observations on dip and strike of the beds can be made in but a small part of the extensive underground workings of the Copper Queen mine. Such observations as were recorded indicate a general southeasterly dip of less than 20 degrees, but there is much diversity, and the beds were evidently subjected to considerable local disturbance prior to the deposition of the ore. At the old Queen incline, which follows the bedding, the dip is about 40 degrees and is toward the south. This steep and unusual local dip apparently accounts for the exceptional attitude of the original Queen ore body, a roughly cylindrical mass 60 feet in diameter and 400 feet in length, inclined at an angle of 30 or 40 degrees from the horizon.

This single ore body, according to Douglas, yielded about 80,000 tons of ore and 20,000,000 pounds of copper.

Between the Queen incline and the Holbrook shaft and southwest of the Czar shaft the usual gentle southeasterly dip seems on the whole to prevail, although opportunities for satisfactory observation are rare. The very important ore bodies occurring in this part of the Copper Queen mine have been found on the whole to be nearly horizontal. As a rule very few traces of original bedding are discoverable in the much altered, mineralized, and decomposed material occurring within 500 feet of the probable position of the Dividend fault.

In the Spray workings the general dip of the limestones appears to be toward the southeast at an angle of about 15 degrees. The ore bodies correspond roughly to this gentle inclination.

In the Calumet and Arizona mine the limestones maintain their general southeasterly dip, but are on the whole more steeply inclined than in the adjoining Copper Queen workings, the average dip being about 35 degrees. Stoping had not gone far enough in 1902 to demonstrate the approximate shape of the large ore bodies. There is little doubt, however, but that they are of the same general character as those worked from the Spray shaft, although more noticeably inclined in conformity to the increased dip of the inclosing beds.

The development of the Lowell mine is as yet insufficient to throw much light on the shape and extent of the ore bodies. They are evidently of irregular form, but lie with their two greater dimensions parallel to the bedding planes of the limestone, which here have an easterly dip of from 35 to 45 degrees. These ore bodies are undoubtedly of the same general type as those found in the Copper Queen and Calumet and Arizona mines.

RELATIONS TO STRUCTURES OTHER THAN BEDDING.

Bedding planes are not the only elements of geological structure that have influenced the deposition of ore. In the deeper workings of the principal mines, particularly of the Calumet and Arizona, there is a well-marked and significant tendency of the original pyritic impregnations to concentrate along minor zones of fissuring and shearing in the generally mineralized limestone. That tendency, clearly shown on a small scale usually below and at a little distance from the main ore bodies, is not merely a minor phenomenon, but illustrates in miniature what has taken place on a much larger scale in connection with the great ore masses. In the case of the latter, however, the important part played by fissures in ore deposition is to a considerable extent obliterated by later changes wrought in ore and country rock by general oxidation and secondary concentrations. The horizontal distribution of the important ore bodies is related to certain structures that are nearly vertical. These are the Czar and Dividend faults and the main limestone-porphyry contact. The ore bodies on the whole constitute a broad belt, about 900 feet in width, which beginning (so far as present explorations show) at a point about 2000 feet southwest of the Czar shaft, continues northeastward, chiefly along the southeast side of the Czar fault to the Czar shaft, thence southeastward along the southwest side of the Dividend fault to the contact with the Sacramento Hill porphyry near the hospital. Here the ore belt swings to the south, skirting the porphyry mass toward the Spray and the Calumet and Arizona shafts. Whether it continues to skirt the porphyry to the east, past the Gardner and Lowell shafts, toward the ice factory and Mule Gulch, is yet to be proved by underground work.

The Czar fault is a well-established but remarkably inconspicuous normal dislocation, with an estimated downthrow of about 500 feet to the southeast. The surface phenomena connected with it are described on page 9. The identification of the fault in the underground workings is by no means satisfactory, owing to the prevalent decomposition of the disturbed and altered limestone to the soft, ferruginous, clayey material known as "ledge matter." In general the fault seems to separate extensive areas of this "ledge-matter," containing large ore bodies and extending eastward toward the Holbrook shaft, from harder, less mineralized limestones on the northwest, in which no important ore bodies have yet been found on this level. It is probable, although by no means certain, that the "ledge matter" on the southeast of the supposed fault line is altered and decomposed Escabrosa limestone, and that the harder limestone on the northwest is Martin or perhaps, in part, Abrigo limestone.

It was probably in consequence of the Czar fault that so much difficulty was encountered in finding new ore bodies after the exhaustion of the original Queen stope. The great cylindrical ore mass was on the northwest side of the Czar fault, while the bodies afterwards discovered at lower levels have been in the downthrown southeast block.

The detailed relations of the ore bodies of the Copper Queen mine to the Dividend fault are very obscure. Large bodies of ore have been mined and are still being worked in the vicinity of this great fissure, but the ground is soft and openings in it are very difficult to maintain. Such crosscuts as have been run to the northeastward, beyond the ore bodies, are no longer accessible, and it is not known whether any of them penetrate the schist which, at the surface, forms the country rock northeast of the fissure. The ore bodies in this part of the mine were apparently formed for the most part in limestone, but the mineralization and subsequent alteration has been so intense that very little of the original country rock can now be identified. Masses of earthy oxidized ore and bodies of crumbling pyrite, more or less enriched with chalcocite, occur very irregularly amid abundant, soft, clayey, and limonitic material. The general parallelism of the ore bodies with the bedding planes of the limestone, elsewhere in these mines a noticeable feature, is much less distinctly shown in those workings that are regarded as being near the Dividend fault.

In that very productive part of the Copper Queen workings lying northeast of the Holbrook shaft, and in the corner formed by the Dividend fault and the contact of the limestones with the porphyry of Sacramento Hill, minor intrusions of porphyry, probably apophyses or offshoots from the main intrusive stock, have influenced the deposition of the ore to an extent recognized by the miners, who expect to find ore bodies in contact with them. They appear to have the form of irregular dikes or, occasionally, sills. They are sometimes impregnated with a little pyrite and are often decomposed to a white or yellow clay, which usually reveals its origin by the presence of grains of quartz representing former phenocrysts in the porphyry.

The presence of the porphyry dikes and sills in the limestones, while by no means a necessary condition to the formation of ore bodies, is yet favorable to their occurrence. The function of these minor porphyry intrusions with reference to ore deposition appears to have been similar to that of fissures in influencing the movements of the mineral-bearing solutions in their circulation through the limestones.

That there is a genetic connection between the porphyry mass of Sacramento Hill and the deposition of the ores is certain. The actual relation of the ore bodies to the porphyry-limestone contact is, however, nearly as obscure as in the case of the Dividend fault. On the surface the contact is concealed by superficial material in the gulch that comes down from the Spray shaft past the hospital. Even on the western slope of Sacramento Hill, where the rocks are well exposed, the porphyry and limestone are so much altered that the actual contact between the two is rather indefinite. Underground crosscuts have not been driven far enough to throw much light on the details of the relation between porphyry and ore. They have usually been stopped whenever anything supposed to be porphyry appeared at the face.

The general conclusion drawn from such meager data as are obtainable in regard to the contact between the Sacramento Hill porphyry and the limestones may be given in a few words. The contact is very imperfectly explored. It is apparently irregular, with conspicuous departures from a simple curved surface. It is the locus of pronounced metamorphism and mineralization which extend both into the limestones and into the porphyry. Pyrite occurs in great abundance in the immediate vicinity of the contact, characteristically in disseminated form but occasionally in considerable masses. The workable bodies of ore, owing their value to enrichment that took place subsequent to the primary pyritic mineralization, occur within the mass of the limestones, usually at some distance from the actual contact to whose curved course their distribution in the main conforms.

It is highly probable, if not reasonably certain, that other fissures than the Czar and Dividend faults have helped to determine the form and position of individual ore bodies. Such fissures, however, can not be satisfactorily studied in mines where ore values and extensive oxidation are so closely related and where workings in the soft, clayey ground soon close upon disuse. In the Lowell mine there is abundant evidence that ore deposition was facilitated by irregular fissuring of general north-south trend. Most of the disturbance appears to have consisted of differential movements along planes of bedding (bedding faults), though occasional irregular fractures of no great vertical persistency cut across the beds.

RELATIONS TO THE ESCABROSA LIMESTONE.

Although the ore bodies as a rule have their greater dimensions in the planes of bedding they are not confined to any particular bed or to any definite stratigraphic horizon. The original Queen ore body occurred in the lower part of the Escabrosa limestone. The ore in the Baxter tunnel, near the Holbrook shaft, occurs in part in the lower part of the Naco limestone. In the latter formation also occurs probably a portion of the ore in the Calumet and Arizona mine, and almost certainly that so far discovered in the Lowell mine. The problem of determining the stratigraphic horizon at which most of the great ore bodies of the Copper Queen and the Calumet and Arizona mines occur is a difficult one. Not readily distinguishable over the quadrangle at large, the Naco and Escabrosa limestones can not be separately identified in the mines, where metamorphism has altered the original texture and composition, obscured much of the structure, obliterated all of the fossils, and transformed both limestones to similar aggregates of silicates and pyrite. When upon such metamorphism there is further imposed widespread alterations into limonitic clays and oxidized ore, the possibility of distinction between the two original limestones vanishes. Structural relations (see structure sections) render it very probable that the great ore-bearing member of the Paleozoic series is the Mississippian or Escabrosa limestone, which has a thickness of about 700 feet. More exact and assured conclusions might be drawn from general structural relations as interpreted in the structure sections were there less local disturbance in the beds, were the presence and effect of faults in the limestones more readily determinable, and did the underground workings afford some direct check on the deeper structure as projected from studies on the surface. The probability, however, is strong that the Escabrosa limestone, while not the only ore-bearing formation, is the one that contains most of the great known ore bodies in the Copper Queen and the Calumet and Arizona mines.

Facts lending some additional support to this hypothesis are (1) the known occurrence of the original Queen ore body in the Escabrosa limestone; (2) the greater depth at which other ore bodies were subsequently discovered southeast of the Queen incline, suggesting that they were formed in the same limestone as the Queen ore body but occur at a lower level because that limestone had been dropped prior to the general mineralization by the Czar fault; and (3) the progressively greater depth at which large ore bodies are encountered in developments pushed toward the southeast. The correspondence between the increasing depth of the larger ore bodies and the augmenting thickness, from northwest to southeast, of the overlying wedge of relatively barren Naco limestone, while it can not be shown to be exact, is at least roughly demonstrable and can scarcely be a chance coincidence. It contains a strong suggestion that the maximum deposition of ore in the general zone thus far exploited was directly connected with the Escabrosa formation.

RELATIONS TO GROUND-WATER LEVEL.

The general ground-water level in the Bisbee district is rather difficult of definition. As in other arid regions it lies deep, and oxidation has been unable to convert all of the sulphides above it into what are commonly termed oxidized ores. As country rock and ore do not constitute homogeneous material there is thus a very irregular downward transition from the oxidized ores to the sulphide masses involving a zone several hundred feet in depth within which ores of both classes occur. It may be pointed out in passing that these conditions harmonize with other geological facts that indicate a more humid climate during the Quaternary period and consequently a former higher ground-water level.

Large masses of sulphide ore have been found on the second level of the Copper Queen mine, less than 200 feet below the surface, in the vicinity of the Dividend fault. In the Calumet and Arizona mine, on the other hand, partial oxidation has extended to a depth of over 1050 feet, as is shown by the abundance of cuprite and native copper, with some limonite and malachite. In the Lowell mine oxidation has penetrated irregularly to a depth of 1100 feet. At this depth the mine, formerly nearly dry, developed a flow of water amounting to about 175,000 gallons a day.

Within the transition zone between completely oxidized and unaltered sulphide ores, which has a maximum depth or thickness of about 900 feet, the oxidizing processes are controlled to a large extent by recent irregular fissuring and by the relative permeability of the various sulphide masses to generally descending solutions. Fissures cutting through masses of lean pyrite are almost invariably accompanied by streaks of rich ore, often containing chalcocite together with cuprite and native copper. Where there are several such fissures near one another, important ore bodies occur. The general association of profitable ore with fissured, broken, permeable ground is well recognized in practical operations and turned to good account in underground exploration.

Care has been taken to refer to the movement of the oxidizing solutions as *generally* downward. There is abundant evidence, however, that for comparatively short distances these solutions moved laterally and even upward. The occurrence of considerable masses of lean pyrite completely enveloped in rich ore consisting of chalcocite and the usual minerals of the oxidized zone is fairly common. Permeable or fissured masses of pyrite have been more or less thoroughly altered, while compact or unfissured masses have retained to a large extent their original character and contain but little copper.

GENESIS OF THE COPPER DEPOSITS.

GENERAL PROCESSES INVOLVED.

Two general processes have operated to form the ores as they are now exploited in the Bisbee quadrangle. These are (1) metasomatic alteration, including pyritic mineralization, and (2) oxidation and its attendant phenomena of transportation and enrichment. Concerning the precise boundary between these two general activities some difference of opinion is possible, but as regards the essential share of each in the genesis of the ores there can be no question. There are few known ore bodies in the Bisbee quadrangle which do not demonstrably owe their value to the cooperation of both processes. The existence of workable masses of ore that have resulted wholly from the primary metasomatic mineralization, while not denied, is still as far from proof as when Dr. Douglas published his excellent account of the Copper Queen mine three years ago.

PRIMARY METASOMATIC MINERALIZATION.

As shown in those underground workings which are below the intermediate zone penetrated by oxidizing reagents, the sulphide minerals ascribable to the early period of metasomatic alteration are common pyrite and perhaps also a little chalcopyrite and sphalerite. The occurrence of some cerussite in the limestones suggests that galena may also occur, although this mineral has not been seen. Associated with these sulphides are amphibole (tremolite), pyroxene (diopside), garnet (grossularite), vesuvianite, quartz, and chlorite, in the limestones; quartz, sericite, chlorite, perhaps kaolin, and a little epidote in the granite-porphyry; and quartz and sericite in the Pinal schist.

The metamorphic minerals mentioned are not distributed uniformly through the limestone but are arranged in zones about the porphyry mass of Sacramento Hill. Nearest the porphyry the former limestone is now a fine-grained aggregate consisting chiefly of quartz and calcite. Such is the rock of the Gardner shaft. The width of this siliceous zone has not been accurately determined, but may be roughly estimated at about 200 feet. It is probably very irregular and is not sharply defined at its outer border. Although heavily impregnated with pyrite it has not proved such favorable ground for the occurrence of ore bodies as the zone next to be described.

Encircling the siliceous zone are pale-green altered limestones in which pyrite, tremolite, diopside, grossularite, and probably vesuvianite are the characteristic minerals. In this zone quartz is comparatively rare. Calcite, however, is abundant, and may make up half or more of the altered limestone. At its inner edge this zone grades somewhat indefinitely into the siliceous zone. About its circumference it passes by obscure gradations into the unmetamorphosed limestones of the region. The rock of this zone of metamorphic silicates is softer than that of the inner siliceous zone. It is frequently traversed by little irregular surfaces of shearing, so that it tends to break along many curved surfaces into small fragments. The width of this zone can not be stated with precision on account of the indefinite character of its boundaries, but it may be very roughly estimated at about 1000 feet. The zone is not, however, limited in plan to a simple concentric band about the porphyry, but extends for a considerable distance to the northwest, toward the Czar shaft.

In general the zone in which the metamorphic silicates are developed is that in which most of the ore bodies are found. In the western part of the Copper Queen mine, however, extensive ore bodies occur in limestone that is perhaps outside of this zone. In other words, the deposition of metallic sulphides appears to have had a wider range and to have extended farther from the porphyry into the fissured limestones than did the formation of the metamorphic silicates.

As metasomatic alteration has affected the entire Sacramento Hill stock, it is impossible to procure any of the porphyry in its original condition for comparison with the altered rock. The intrusive mass is impregnated with pyrite throughout. This mineral is very abundant in the vicinity of the contact with the limestone, but as the dump of the Copper King mine shows, may be nearly or quite as abundant in the areal center of the stock. In addition to the introduction of pyrite, the alteration involves a general recrystallization, which in some places has obliterated the original porphyritic texture, in others left it still faintly recognizable. The microscope shows that the quartz phenocrysts have recrystallized as quartz aggregates, and that the feldspars and groundmass have become areas of sericite, quartz, and pyrite, with occasionally a little epidote, chlorite, zircon, and rutile. Kaolin also occurs in microscopic aggregates with the sericite and may be in part a product of the metasomatic alteration. Upon exposure to the weather the pyrite in the metamorphosed porphyry oxidizes and the sericite, probably through the action of the sulphuric acid so formed, becomes converted into kaolin. The porphyry as exposed on the surface is thus a siliceous mass containing nests of kaolin, which sometimes weather out, leaving empty cavities. It is superficially stained and streaked with oxide of iron, but is generally nearly white on freshly fractured surfaces.

The alteration of the Pinal schist in the vicinity of the Sacramento Hill stock has produced a rock which the closest examination does not always serve to distinguish with certainty from the altered porphyry. Like the latter it is composed chiefly of pyrite, quartz, and sericite. The schistose structure, however, is usually distinguishable and the rock does not exhibit the characteristic spotted appearance which is often all that remains of the original porphyritic texture of the intrusive rock. The alteration gradually fades out away from the porphyry, and at a distance of about a quarter of a mile the schists exhibit their normal character.

How were the pyritic ores formed and whence was their material derived? Not only are these questions of absorbing scientific interest, but in a region where ore bodies lie deeply buried, and where some knowledge of the relation of the ore to geological structure may prevent the costly failures of blind prospecting, they assume direct practical importance. Unfortunately they can not be fully answered; but even partial answers may be of service, if reasonable inductions from observed facts be kept distinct from more or less speculative hypotheses.

The spatial relation of the ores to the porphyry mass of Sacramento Hill is such as to justify the conclusion that there is some genetic connection between them and the intrusive stock. The fact that the pyrite was formed at substantially the same time as amphibole, pyroxene, garnet, and vesuvianite—minerals characteristic of contact zones in limestones—is not only additional evidence of such a general connection but indicates to some extent its specific character.

Not all of the masses in the quadrangle resulting from the intrusion and solidification of granitic magma are associated with important mineralization. The granitic stock of Juniper Flat is connected with no conspicuous mineralization of the inclosing schists, and is not itself mineralized. It is thus suggested that extensive mineralization may be dependent upon the juxtaposition of porphyry and a particular rock—limestone; but there are many porphyry dikes in the quadrangle that cut limestones without producing mineralization. These, however, are relatively small masses, and this fact leads to the further tentative suggestion that extensive mineralization, competent for the production of workable ore bodies, requires the fortunate conjunction of an intrusive mass of considerable size with limestones. These conditions are fulfilled in the vicinity of Sacramento Hill and nowhere else in the quadrangle. Here, too, occur the only important bodies of copper ore thus far discovered in the quadrangle. It might therefore possibly be concluded on this rather slender evidence that the conditions named were all that were necessary to produce the ores. But the case is not quite so simple.

Small bodies of copper ore occur at several points in the quadrangle in situations that show no discoverable simple connection with granite-porphyry. Fissuring in the limestones is frequently although not invariably accompanied by mineralization, even when no porphyry is near. At the Whitetail mine, for example, ore has been extracted from the vicinity of a bedding fault between the Abrigo and Martin limestones. At the Wade Hampton claim, northwest of Don Luis, near United States Land Monument No. 3, ore has been taken from a hanging wall of Abrigo limestone faulted against Bolsa quartzite. Hence it is concluded that fissures in the limestone are factors in the mineralization apart from any direct connection with intrusive masses.

The general relation of the great ore bodies of the Copper Queen mine to the Dividend and Czar faults has already been pointed out. The presence of these, and probably also of other less prominent fissures, constituted an additional important factor in determining the initial mineralization from which subsequent processes were to produce the workable bodies of ore that now lie about the southwest side of Sacramento Hill.

It is concluded that the original mineralization in the vicinity of Sacramento Hill was the result of extensive metasomatic metamorphism in some way due to the coincident occurrence of limestones, a considerable intrusive mass of porphyry, and prominent fissures extending to great depth.

The objection to regarding the metamorphism and mineralization as an ordinary case of contact action about an intrusive stock is twofold. The stock itself has been thoroughly altered and mineralized and could not have originally supplied from its own mass the large quantities of magnesia, sulphide of iron, and other constituents introduced into the adjacent limestones. The greater part at least of the mineralization must have taken place after the porphyry had solidified. It is probable, although perhaps not in this case susceptible of definite proof, that the mineralization and metamorphism were effected by heated aqueous solutions. The principal function of the porphyry, it is believed, consisted in supplying heat to such solutions as rose from great depth and in thus determining the locus of the chemical activity that resulted in the deposition of the ore.

The source of the ore materials is not known. They may have risen through the Dividend fault from depths far below the bottom of the syncline of Paleozoic rocks. They may have been collected by solutions moving through one or more of the Paleozoic limestones on their way down to the locus of deposition. Lastly, they may have been derived from both sources. The direct evidence on this question, however, is so meager and its slight weight so easily shifted from one side to the other by whatever bias may have been given to the observer's trend of thought by familiarity with other fields of ore deposition, that an expression of choice between the principal hypotheses can have little real value. Both are, in the nature of the case, speculative.

OXIDATION AND SECONDARY CONCENTRATION.

Few if any of the ore bodies now known and worked in the Bisbee quadrangle were formed directly by the original mineralization discussed in the preceding section. That process resulted, so far as underground workings show, mainly in the formation of bodies of cupriferous pyrite passing peripherally into metamorphosed and pyritized limestone. These bodies contained originally too little copper to be classed as ore, as that term is defined by present economic conditions of working. Further concentration was necessary, and the profitable ores of to-day have been derived from these pyritic masses by secondary processes involving general oxidation with all its attendant chemical phenomena, transfer of material, and the local enrichment of certain portions of the sulphide masses.

AGE OF THE COPPER ORES.

All of the ore of the Bisbee quadrangle is post-Pennsylvanian, since it is later than the granite-porphyry which cuts the Naco limestone. If, as there is reason to suppose, the heat of the intruded mass of porphyry forming Sacramento Hill was a factor in the original mineralization, then mineralization was probably initiated soon after the close of the Pennsylvanian epoch, perhaps in Permian or Triassic time. It may have continued with diminishing intensity into the Tertiary. That there has also been some post-Comanche (i. e., late Cretaceous or Tertiary) mineralization is shown by the occurrence of small mineralized veins in the Glance conglomerate near Juniper Flat and south of Gold Hill, by the introduction of chalcocite into the same conglomerate in the vicinity of the Glance mine, and by the occurrence of a gold ore in the Morita formation at the Easter Sunday mine.

The secondary processes connected with oxidation, which have transformed the low-grade pyritic masses near Bisbee into rich ore bodies, may have begun in Tertiary or even Cretaceous time, and are still in progress.

VALUE OF THE COPPER ORES.

The percentage of copper in the ore as mined is to a very large extent subject to control by those who direct mining operations. With ample facilities for extensive and economical operation, the grade of ore that can be handled sinks lower and lower. Thus while a large mine may contain ore as rich as it did when first opened, the average tenor of the ore now worked is usually very much lower than formerly.

This almost self-evident fact is well illustrated by the Copper Queen mine. The ore first worked, early in the eighties, averaged 23 per cent of copper. As the mine developed, as methods of treatment improved, and as transportation became less costly, the tenor of the ore was gradually reduced until the average at present is about 7 per cent, with a range from 4 to 20 per cent. The minimum grade, however, is mined only when it occurs with better ore, or when it is particularly desirable for fluxing purposes.

The average tenor of the ore from the Calumet and Arizona mine in 1902 was about 10 per cent of copper, according to Mr. I. L. Merrill, but the stopes were then recently opened and contained some remarkably good oxidized ore. As development progresses it will probably be found economical to work ores of lower average grade.

MISCELLANEOUS METALLIFEROUS DEPOSITS.

GOLD.

Easter Sunday mine.—In this interesting deposit the gold occurs free, rather irregularly distributed through some beds of light-colored quartzitic sandstone belonging to the Morita formation. The bulk of the ore occurs in a bed about 4 feet thick, dipping about 55 degrees to the north-northeast, but the mineralization is not entirely confined to this bed. The sandstone has been irregularly fractured, probably during the post-Cretaceous folding, and the resulting small fissures have been filled with veinlets of quartz and calcite. The gold is occasionally visible, usually in little calcite vugs stained with oxide of iron. It appears to have been introduced into the beds subsequent to fracturing.

The gold ore of the Easter Sunday mine is reported to run about $30 per ton when sorted; but as the small quantity of ore thus far produced has been accepted by the Copper Queen smelter upon the condition that the silica shall not fall below 84 per cent, the actual tenor that the ore would show if mined and treated directly as a gold ore, is unknown.

Placer deposits.—Small quantities of placer gold have been obtained from the upper part of Gold Gulch. This gold has been derived from the Glance conglomerate and concentrated in the sand and gravel of the present arroyo. It is not present in sufficient quantity to be of economic importance.

LEAD.

Cerussite of Hendricks Gulch.—This deposit, while not extensive, is of interest as being the first body of ore to be worked in the Warren mining district. The carbonate of lead occurs in impure, sandy form—the so-called "sand carbonate"—in Hendricks Gulch, about a quarter of a mile south of Bisbee, and forms very irregular bunches in the limestone in the vicinity of a fault fissure. It is still worked on a small scale by lessees. None of this ore was observed in connection with the copper ores of the larger mines.

NON-METALLIFEROUS DEPOSITS.

Clay and silica.—These materials are chiefly used in the form of an artificial plastic mixture—ganister—employed for lining the Bessemer converters. The clay used for this purpose in the Copper Queen smelter is stoped just above the second level in the southwestern part of the Copper Queen mine. It forms a considerable mass lying just west of the Czar fault, and has resulted from the decomposition or alteration of some of the sandy beds of the Abrigo limestone. The clay, which is somewhat arenaceous, passes irregularly into loose, fine sand and into undecomposed sandy limestone. Kaolin in various states of purity is commonly associated with the oxidized copper ores but is usually too much mixed with limonite or bog manganese to serve as converter lining.

Silica suitable for ganister occurs abundantly in the quadrangle, the quartzitic sandstones of the Morita and Cintura formations affording an inexhaustible supply in convenient proximity to the railroad. One of these beds is at present being worked near Glance station. The mineralized portion of another constitutes the gold ore of the Easter Sunday mine, which is utilized by the Copper Queen Company in its converters. For this purpose the amount of silica in the ore as delivered at the smelter is, as has already been stated, not allowed to fall below 84 per cent.

Fluxes.—The only flux used in the present treatment of the Bisbee copper ores is a small quantity of limestone, and of the purer varieties of this rock suitable for smelting, the Bisbee quadrangle affords an unlimited supply. The flux for the Copper Queen smelter in Bisbee is quarried from the Naco limestone at a point about 200 yards from the furnaces.

Building stone.—Rough blocks, used chiefly for foundations and walls, have been quarried from beds of Bolsa quartzite about half a mile west of the business center of Bisbee, but the quarry is not steadily worked. This stone is hard and durable but is not suitable for finished stone work. Good building stone might readily be quarried from the granite of Juniper Flat, but the lack of local demand for first-class stone and the cost of quarrying and dressing it prevent any exploitation of this resource. A fairly durable stone, easily worked, could probably be obtained from some of the thick beds of Escabrosa limestone.

WATER RESOURCES.

In the early days of mining development much difficulty was experienced in obtaining sufficient water for the water-jackets of the furnaces, and at one time the project of pumping water from the San Pedro River was seriously considered. Within the last few years, however, the Copper Queen Company, by sinking a well 118 feet deep, about a mile west of Naco, has succeeded in finding an adequate flow of good water, which is pumped up to Bisbee. The capacity of this well is 200 gallons a minute, which is sufficient to meet the needs of the company and to supply the Copper Queen Hotel and the ice factory. The town of Bisbee, however, is as yet unprovided with any general water system. A portion of the water used for domestic purposes is drawn from shallow wells in the bottoms of the ravines within which the town is built. Such wells are obviously open to contamination and their use is attended with grave danger. Another part of the supply comes from a spring in Brewery Gulch, the water being brought into town in canvas bags on the backs of burros. The town has outgrown these primitive and unsanitary conditions, and there is no good reason why the example of the Copper Queen Company should not be followed and an abundant supply pumped from one or more deep wells in the valley west of Naco. While it is not probable that artesian water will be found in the Espinal Plain, such an occurrence is not impossible, and it is reasonably certain that wells put down to depths from 100 to 150 feet in the lower part of the plain lying between the San Jose Mountains and the Naco Hills will reach abundant water which can be raised by pumping.

In the axial portion of the Sulphur Spring Valley wells encounter water in quantity at depths varying from 100 to 200 feet. One well put down by the Copper Queen Company near Douglas, after passing through a layer of clay encountered a thin bed of water-bearing gravel at a depth of 355 feet. The water from this stratum rose to within 3 feet of the surface, showing the existence of artesian conditions. As the bottom of the clays and gravels has not yet been reached and as the width and slope of the valley are sufficient to give considerable hydrostatic head, the prospects for finding flowing wells are fairly good. In spite of the generally arid climate large quantities of water annually pour from the mountains into this valley and sink along its margins into the unconsolidated deposits with which it is partly filled. Whether any part of this water will rise to the surface by artesian flow in the middle of the valley depends upon the extent of the impervious clay strata shown by wells to exist in the axial portion of the valley.

June, 1903.

SUPPLEMENT.

INTRODUCTION.

Eleven years of active mining development in the Bisbee district have passed since the foregoing folio text was written. During that period huge ore bodies, which were entirely unknown in 1902, when the geologic field work was done, have been discovered south of Sacramento Hill, and the exploitation of these deposits has been accompanied by many changes in the outward aspect of the district. Consequently the maps as here reprinted, without complete field revision, will be found inadequate in their representation of roads, buildings, and other works of man embraced by cartographers under what is technically termed "culture." The town of Bisbee, greatly improved since the removal of the Copper Queen smelter to Douglas, has increased in size and is connected by electric car service with the newer town of Lowell, south of Sacramento Hill, and with the residence suburb of Warren, north of Black Gap, in the center of what in 1902 was a desolate area of Glance conglomerate.

Although the ore bodies of the Copper Queen and Irish Mag mines were the only ones of importance known in 1902 the existence of those subsequently discovered south of Sacramento Hill was not unsuspected. In Professional Paper 21, "The geology and ore deposits of the Bisbee quadrangle, Arizona," published in 1904, it was stated (pp. 161 and 162) that—

> There is certainly a reasonable hope of finding ore bodies in the Martin and Abrigo limestones beneath the masses that have been so profitably worked in the overlying Carboniferous beds. The occurrence of small bunches of ore in the Abrigo limestone at the Whitetail and Wade Hampton claims shows that ore deposition may take place in these lower beds. * * *
>
> Less than half of the semicircular mineralized zone about the porphyry mass of Sacramento Hill has been explored at all. There still remains * * * an extensive area of unknown but promising ground, lying just south of Sacramento Hill and extending eastward toward the southeastern continuation of the Dividend fault—an area which is here concealed by the Glance conglomerate. This is the eastern half of the semicircular mineralized girdle about the intrusive mass of porphyry. * * * The exploration of this ground calls for no greater outlay or boldness than is already displayed in other parts of the district with less reasonable hope of reward.

The ground particularly referred to in the foregoing quotation is that in which the Junction ore body was soon afterward discovered. Immediately southwest of it have been developed the Hoatson and Briggs ore bodies and farther west those of the Lowell and Oliver mines. All these ore bodies have added enormously to the yield of the district. In the productive group should be included also the Shattuck mine, at present the westernmost member of the group.

The positions of some of the more important shafts sunk since 1902 have been ascertained and are indicated on the reprinted maps, but no attempt has been made to show the buildings that have been constructed in the vicinity of each shaft.

The notes which follow are based on a brief visit of five days in 1912. Had the plan of reprinting the Bisbee folio been under consideration at that time the observations then made might have been extended to include some details which are now lacking.

GENERAL GEOLOGY.

The account of the general geology given in the original folio requires very little modification. The granite mass of Juniper Flat, northwest of Bisbee, while recognized in 1902 as being older than some of the granite porphyry dikes, was supposed, in the lack of any evidence to the contrary, to be of the same general period of irruption as the porphyry of Sacramento Hill and was regarded as of Mesozoic age. Reexamination of the granite in 1912, in the light of wider acquaintance with the pre-Cambrian granitic rocks of Arizona, has thrown doubt on the earlier conclusion. Although the mass is nowhere, so far as known, in contact with Paleozoic rocks and although definite evidence of its age in relation to them is lacking, the general character of the granite is regarded as justifying its reference with strong probability to the pre-Cambrian or Archean, and it is so represented on the reprinted geologic maps.

The suggested correlation (p. 3) of the Bolsa quartzite with the "Tonto" (now the Tapeats) sandstone of the Grand Canyon section still lacks confirmation. The recognition, below the Devonian, in the Ray and Globe quadrangles, of two thick formations of quartzite or quartzitic sandstone separated by a formation that is lithologically almost identical with the Abrigo limestone, has raised questions that further field studies alone can answer. There is some evidence that the upper quartzitic formation of the Globe-Ray region is the equivalent of the Tapeats sandstone. If so, either the limestone under it is not the same as the Abrigo, which it closely resembles, or the Bolsa quartzite is not the stratigraphic equivalent of the Tapeats.

The Glance conglomerate, of the Cretaceous system, was originally estimated to have a maximum thickness of at least 600 feet. Later a drill hole was put down about half a mile south of Black Gap which, after going through the surficial "wash," is said to have continued to a depth of at least 3300 feet in Glance conglomerate. Whether the conglomerate actually attains this great thickness or has been repeated by faulting it is not possible to determine.

The account of the broad structural features given in the original Bisbee folio has been confirmed by careful and very detailed work subsequently done by the geologists of the Copper Queen and Calumet & Arizona companies,[1] who by continued study of the extensive underground exposures now open to them have gained much additional knowledge of the relation of the ore bodies to fissuring and to porphyry intrusion. They have ascertained that the Dividend fault dips 55°-60° SW. in the Copper Queen ground and becomes nearly vertical east of Sacramento Hill, in the Denn-Arizona ground. It has also been learned that the porphyry mass of Sacramento Hill is much larger than was suggested by its surface exposures. Extensive bodies of porphyry, apparently continuous with the porphyry of Sacramento Hill, have been found in the Junction, Hoatson, Lowell, and Oliver mines, especially below the base of the Naco limestone. In the Junction mine the porphyry is clearly a sheet, beneath which most of the ore occurs in limestone.

The mass of Carboniferous strata southeast of Black Knob, named the Glance block and described (p. 11) as overthrust from the east onto the Cretaceous, may, according to another interpretation, have once been continuous with the mass on Gold Hill and have been thrust from the west. If so, the thrust surface has probably suffered some deformation. The structure section has been modified to suggest this possibility.

ORE DEPOSITS.

PRODUCTION.

The production of the Warren mining district is given in the following tables. Table 1 shows the output of "black" copper by the Copper Queen mine, which, for the period covered, was the only considerable producer in the district. The data are taken from the publication Mineral Industry and do not include quantity or value of silver and gold produced. In the earlier years, however, the precious metals were not recovered, as the copper was not electrolytically refined. Statistics of the gold and silver production for later years, during the period when the precious metals were recovered.

[1] Notman, Arthur, Geology of the Bisbee ore deposits: Inst. Min. and Met. Trans., vol. 22, pp. 550-560, 1913.

are not available in the records of the United States Geological Survey.

The figures in Table 2 are those of the division of mineral resources, United States Geological Survey, which began collecting data of mine output of the precious and related base metals in 1902.

The total value of the metal output of the Warren district from 1880 to the end of 1912, as shown by these two tables, is $265,293,376. This is short of the actual total value by the relatively small value of the gold and silver recovered by electrolytic refining during the few years for which figures are not at hand, as explained above, and by the value of some lead produced from carbonate ore in the early days of the district. The total output of copper in the district to the end of 1912, as the tables show, was 1,553,168,189 pounds.

TABLE 1.—*Production of copper in the Warren (Bisbee) district, Ariz., 1880 to 1901, inclusive.*

Year.	Pounds.	Value.	Year.	Pounds.	Value.
1880	1,397,940	$295,307	1892	12,916,416	$1,498,304
1881	3,866,581	703,718	1893	13,795,618	1,489,927
1882	7,744,278	1,479,157	1894	12,968,372	1,231,995
1883	7,523,981	1,241,457	1895	15,741,732	1,684,365
1884	7,668,617	996,920	1896	23,298,150	2,516,200
1885	6,663,782	719,688	1897	23,999,873	2,879,985
1886	3,797,256	421,495	1898	33,749,390	4,184,924
1887	5,707,728	787,666	1899	36,901,684	6,310,188
1888	12,031,614	2,021,311	1900	34,382,309	5,707,468
1889	12,152,910	1,640,643	1901	39,781,333	6,643,483
1890	13,120,934	2,046,866		342,215,455	48,168,000
1891	13,022,957	1,666,938			

TABLE 2.—*Production of metals in the Warren (Bisbee) district, Ariz., 1902 to 1912, inclusive.*

Year.	Crude ore.	Gold.	Silver.	Copper.	Lead.	Total value.
	Short tons.	*Fine oz.*	*Fine oz.*	*Pounds.*	*Pounds.*	
1902	255,608	6,748.27	182,896	37,930,045	....	$4,464,098
1903	289,801	6,202.06	354,650	62,801,825	....	8,518,120
1904	615,160	7,638.12	588,129	90,346,205	....	11,595,056
1905	819,256	9,597.00	600,411	107,927,761	....	17,397,796
1906	1,010,349	17,030.59	681,243	129,163,126	....	25,349,274
1907	934,607	11,149.94	556,261	109,332,148	....	22,464,062
1908	1,000,479	17,510.83	827,379	126,409,212	195,829	17,494,733
1909	1,124,576	18,233.12	963,236	139,336,773	437,601	19,010,387
1910	1,191,124	25,419.65	980,207	140,235,296	713,471	18,896,059
1911	1,095,895	33,849.06	1,637,164	128,767,150	....	47,162,298
1912	1,238,408	39,410.00	1,526,987	138,703,193	2,971,923	24,778,538
	9,575,363	192,778.64	8,848,553	1,210,952,734	4,318,824	217,125,376

STRUCTURAL RELATIONS.

Very briefly summarized, the principal structural features to which the occurrence of the ores is related are (1) the northwest-southwest Dividend fault, with a normal throw that has brought Paleozoic beds on the southwest side of the fissure against Pinal schist on the northeast side; (2) a small stock of granite porphyry, intruded on the line of the fault and invading the contiguous schist and particularly the Paleozoic beds, which contain many irregular sills, dikes, and less regular bodies of the irruptive rock; (3) zones of fissuring, some of the more persistent of which extend radially outward from the main porphyry mass; (4) an open synclinal structure in the down-faulted Paleozoic beds, which dip in part toward the porphyry stock and in conjunction with the fault plane form a trough pitching to the southeast; and (5) a gentle tilt to the southeast, as shown by the present slope of the pre-Comanche erosion surface. The ore bodies occur in the down-faulted fragment of a syncline, are disposed in roughly semicircular fashion around the porphyry stock, and have radial prolongations along certain zones of fissuring.

The largest bodies of ore, estimated by Notman[1] to have yielded about 90 per cent of the production to date, have been found in the Escabrosa and Martin limestones. The Naco limestone also contains a few pay shoots, and recent developments have shown that ore in considerable quantity occurs in the Abrigo limestone.

FORM OF THE ORE BODIES.

While very irregular in form, the ore masses as a rule are roughly lenticular and tend to conform to the bedding of the limestones. The average thickness of all the known ore bodies up to 1912 has been calculated by the engineers of the Copper Queen Co. to be about 33 feet. Bedding planes, however, are far from being the only structural determinants of form. The shape and position of many of the bodies have been controlled by zones of fissuring and by the uneven surfaces of intruded porphyry masses, many of which do not extend directly upward to the surface.

At the Copper Queen mine, near the northwest end of the structural trough, the ore bodies, as already described, come to the surface. As underground development was pushed south and east, around and beyond the exposed porphyry mass of Sacramento Hill, through the Holbrook, Stray, Irish Mag, Gardner, Oliver, Lowell, Hoatson, Junction, and Briggs shafts, the ore was found at increasing depths. This progressive southward increase in depth is shown in figure 40, which is a somewhat generalized vertical projection of the principal stoped ore bodies of the district, based on a larger-scale projection compiled by the engineers of the Copper Queen Co. It is to be remembered that this illustration shows only the ore actually stoped up to January 1, 1912, and takes no account of ore in reserve or as yet unknown. The general distribution of the stopes as projected on a horizontal plane is shown in figure 41, which also has been constructed mainly from data furnished by the Copper Queen Co.

The great ore body of the Junction mine, whose existence was unknown when Professional Paper 21 and the Bisbee folio were written, extends from a point 10 feet above the 1300-foot level to the 1500-foot level. It is 500 feet long and from 10 to 120 feet wide, in plan, part of this width being due to faulting. South of the curved chain of mines mentioned lie the Briggs and other large ore bodies connected with zones of north-northeast fissuring in the limestone. In the Briggs mine the ore bodies grade outward into a huge mass of partly oxidized pyrite about 1500 feet long and in places 800 feet wide.

RELATION TO PORPHYRY MASSES.

The general relation to the porphyry of the ore bodies exploited in the older workings of the Copper Queen mine has already been described. As a rule, in the present Copper Queen mine (which includes what are sometimes separately designated the Czar, Holbrook, Stray, Gardner, Sacramento, and Lowell mines) and in the Hoatson mine the ore bodies are confined to the vicinity of intrusive masses of porphyry. In the Junction mine the connection between ore and porphyry is less close, and in the Briggs mine no porphyry was seen in 1912. Apparently the bodies of porphyry, like the fissures in the limestones, played an important part in controlling the movement of the ore-bearing solutions, but it is not likely that any considerable part of the ore constituents came from the porphyry masses now visible. The metallic elements and the sulphur had deeper and more distant sources.

Of late years, stimulated by the successful exploitation of disseminated copper ores in other districts, the Copper Queen Mining Co. has actively prospected the porphyry mass of Sacramento Hill

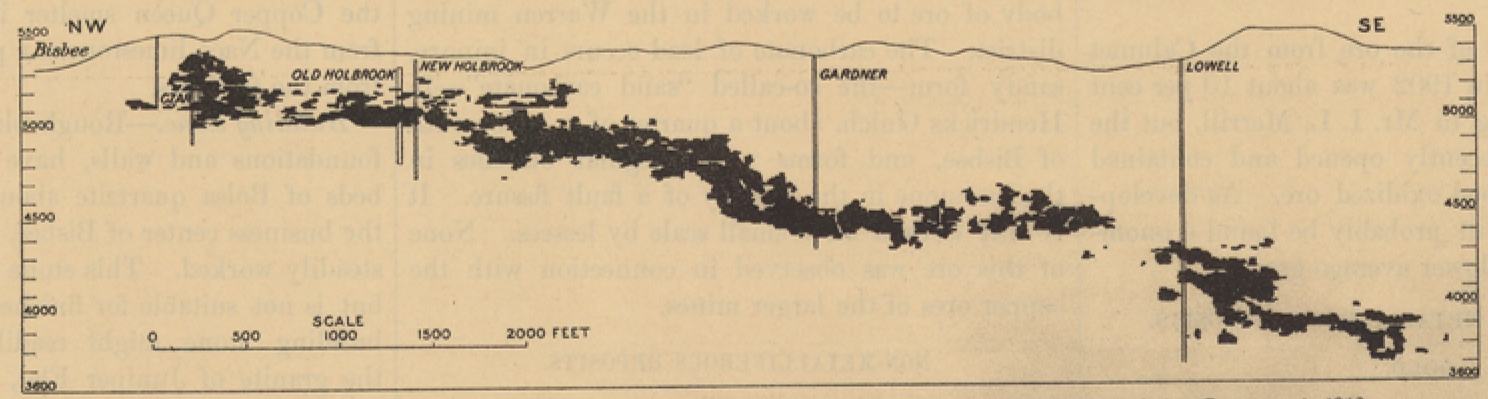


FIGURE 40.—Generalized vertical projection of stoped ore bodies in Warren district, Bisbee, Ariz., January 1, 1912.

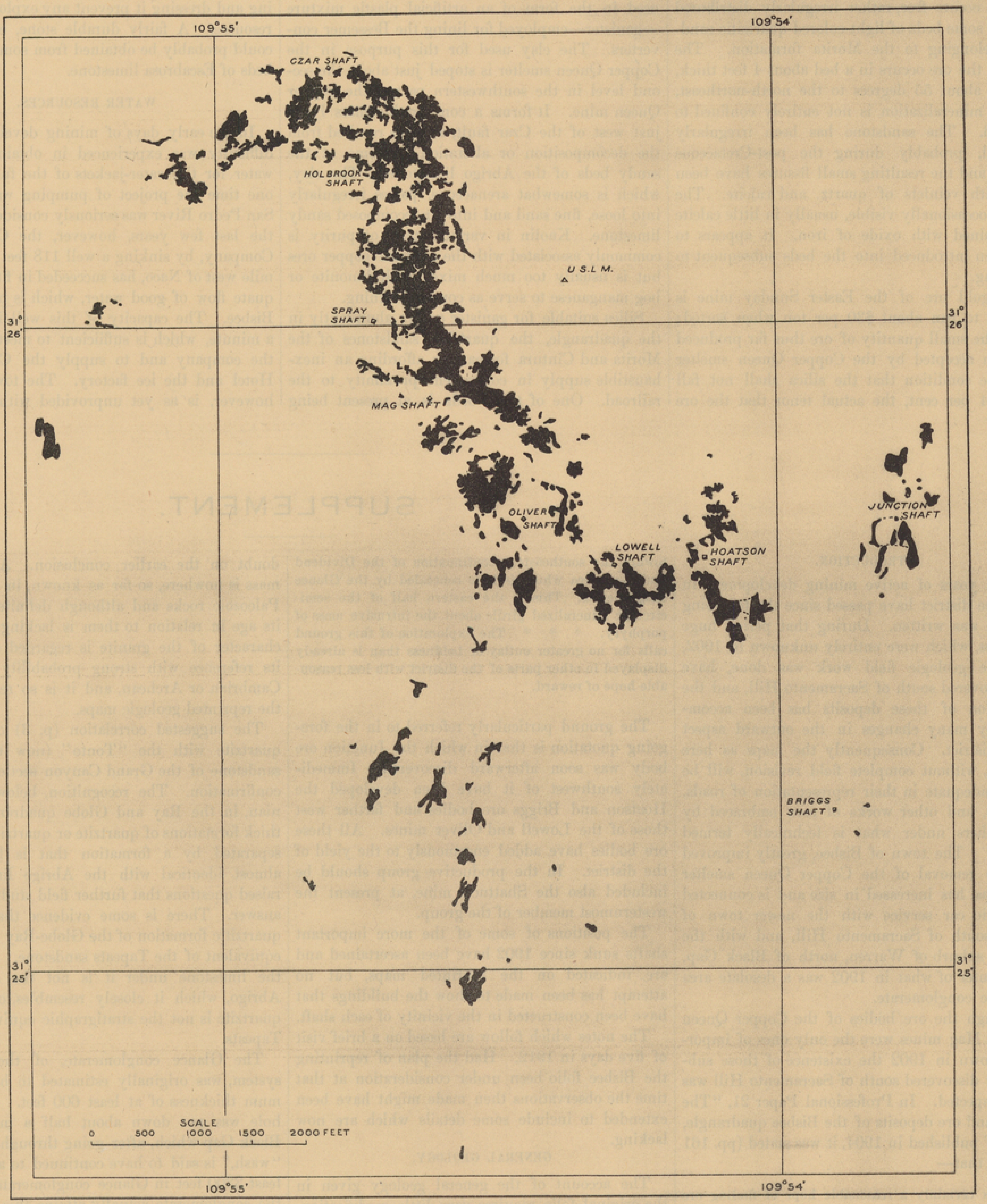


FIGURE 41.—Horizontal projection of stoped ore bodies in Warren district, Bisbee, Ariz., January 1, 1912.

[1] Op. cit., p. 552

This work resulted in the discovery of considerable bodies of disseminated ore, containing chalcocite, some bornite and chalcopyrite, and, of course, pyrite. According to J. B. Tenney[1] the ore lies immediately beneath a barren oxidized surface zone which is practically free from copper. At the date of writing (March, 1914) a concentrating mill is being built to treat the ore from the porphyry.

CHARACTER OF ORE.

Up to the year 1904 nearly all the copper obtained at Bisbee came from oxidized or enriched ore. In later years, however, primary ores have furnished a large part of the output. The Junction ore body, which in the present stope faces averages over 9 per cent of copper, is a nearly solid mass of sulphides which appear to have undergone little or no general enrichment since they were originally deposited. The huge pyritic mass of the Briggs mine, with its included bodies of more cupriferous material, is largely primary, as are also the ore lenses in the Abrigo limestone.

The most abundant sulphides in the primary ore are pyrite and chalcopyrite. With these may be associated considerable bornite and, in certain ore bodies, magnetite. Recently both sphalerite and galena have been found in considerable quantity near the porphyry of Sacramento Hill, but these minerals are not widely distributed through the copper ores. No pyrrhotite has been noted.

OXIDATION AND ENRICHMENT.

The ground water at Bisbee, as already mentioned, lies deep, and the first considerable pumping was done at the Lowell mine, from a depth of 1100 feet. Afterward the Junction shaft, 1800 feet deep, drained the Lowell. For a time, when the lower Junction levels were kept open, the pumps raised over 6,000,000 gallons in 24 hours.

[1] Bisbee porphyry deposits: Eng. and Min. Jour., vol. 97, pp. 467-468, 1914.

The natural ground-water surface and the lower limit of oxidation are neither coincident nor parallel. In general in the northern part of the productive area much enriched sulphide ores lie above the original water level, and in the southern part there is considerable oxidized material below it. In the Junction mine, for example, there is oxidized and leached material on the 1500-foot level (corresponding to a depth of 1750 feet in the Lowell shaft), and oxidized ore is mined in places on the 1600-foot (bottom) level of the Lowell mine. The lower depth of oxidation ranges from 200 to at least 1600 feet.

Although the relative importance of the enriched chalcocite ores at Bisbee has been diminished by the discovery of large bodies of profitable primary ore, they still supply a large proportion of the total copper produced. The lower limit of enrichment is irregular and ill defined but, like the lower limit of oxidation, is deeper in the southern part of the productive area than in the northern part. Secondary (supergene) chalcocite occurs in the bottom level of the Lowell mine (1600 feet) and on the "1300-foot" level (1400 feet deep) of the Briggs mine. How much deeper it may go is not known. In some places sulphide enrichment has worked down to the bottom of a pyritic ore body; in others it has worked around and under residual masses of unenriched pyritic material; and in parts of the Briggs mine large masses of leached and oxidized material rest directly on unenriched, low-grade pyrite. The enriching mineral is generally chalcocite. In some loose, friable ore the chalcocite may occur as thin shells around grains of pyrite and as a sooty interstitial powder. Elsewhere the replacement is more nearly complete, the original chalcopyrite and much or all of the pyrite having been converted into massive chalcocite. Secondary chalcopyrite has been noted,[1] but the greater part of this mineral is probably a primary constituent of the Bisbee ores. Careful study of the ores by metallographic methods may, however, necessitate a modification of this statement.

The great depths to which oxidation and enrichment have penetrated at Bisbee and the inclined position of the zones of alteration with reference to the present underground-water level and their approximate parallelism with the old pre-Comanche erosion surface, as brought out by later mining development, indicate that much of the oxidation and enrichment was effected before the deposition of the Cretaceous formations. This conclusion was suggested but not adequately stated in the first edition of this folio. It was definitely expressed in 1913 in a note on the Bisbee district supplied by Ransome[2] and in the paper by Notman[3] already referred to.

Minerals to be added to those listed in the original folio as occurring with the oxidized ores are delafossite,[4] a cuprous metaferrite somewhat resembling micaceous hematite in general habit and appearance, alunite,[5] and gibbsite.[5]

GENESIS OF THE ORES.

In the original Bisbee folio the question of the source of the ore constituents was left without definite answer. It was recognized that the ore bodies are related in their occurrence to the porphyry mass of Sacramento Hill, but it was realized also that the intrusion of that mass was not accompanied by general contact-metamorphic phenomena at all comparable in intensity with the size of the copper deposits. Measured by the development of characteristic contact-metamorphic silicates the effect of the porphyry at Bisbee upon the intruded limestones was notably feeble.

[1] Ransome, F. L., The geology and ore deposits of the Bisbee quadrangle, Arizona: U. S. Geol. Survey Prof. Paper 21, p. 132, 1904.

[2] Emmons, W. H., The enrichment of sulphide ores: U. S. Geol. Survey Bull. 529, p. 182, 1913.

[3] Notman, Arthur, op. cit., p. 561.

[4] Tovote, W. L., Bisbee—a geological sketch: Min. and Sci. Press, vol. 102, p. 206, 1911. Rogers, A. F., Delafossite, a cuprous metaferrite from Bisbee, Ariz.: Am. Jour. Sci., 4th ser., vol. 35, pp. 290-294, 1913.

[5] Notman, Arthur, op. cit., p. 560.

Mining operations at Bisbee during the last ten years have shown that the porphyry is much more abundant than could well have been inferred from exposures known in 1902, and this fact tends to emphasize the closeness of the genetic relationship between the ore and the porphyry. It is true that some large bodies of ore have no obvious connection with porphyry masses; but the important conclusion to be drawn from what is now known of the occurrence and distribution of that rock is that all of the porphyry which is at present within sight is probably more or less directly connected with larger and deeper masses of the same irruptive material.

During this same period evidence from other parts of Arizona has accumulated to show that the most valuable copper deposits in that State have in common one geologic feature, namely, their close association with intrusive siliceous rocks of granitic or quartz monzonitic character. This fact, taken in connection with all that is known of the genesis of similar copper deposits, suggests that the Bisbee ore bodies are to be regarded as belonging to the general class of contact-metamorphic deposits, although, as already indicated, they are by no means typical of that class as regards the general intensity of the metamorphic action measured by the development of silicate minerals in the limestone.

March, 1914.

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH
DIRECTOR

TOPOGRAPHY

ARIZONA
(COCHISE COUNTY)
BISBEE QUADRANGLE

LEGEND

RELIEF
printed in brown

Altitude
above mean sea level instrumentally determined

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

Stream wash

DRAINAGE
printed in blue

Intermittent streams

Waterhole

CULTURE
printed in black

Roads and buildings

Private or secondary road

Trails

Railroad

U.S. township and section lines

International boundary line

Bench mark

U.S. locating monument

Mine

E. M. Douglas, Geographer in charge.
Triangulation and topography by T. M. Bannon.
Surveyed in 1901-1902.

APPROXIMATE MEAN DECLINATION 1901

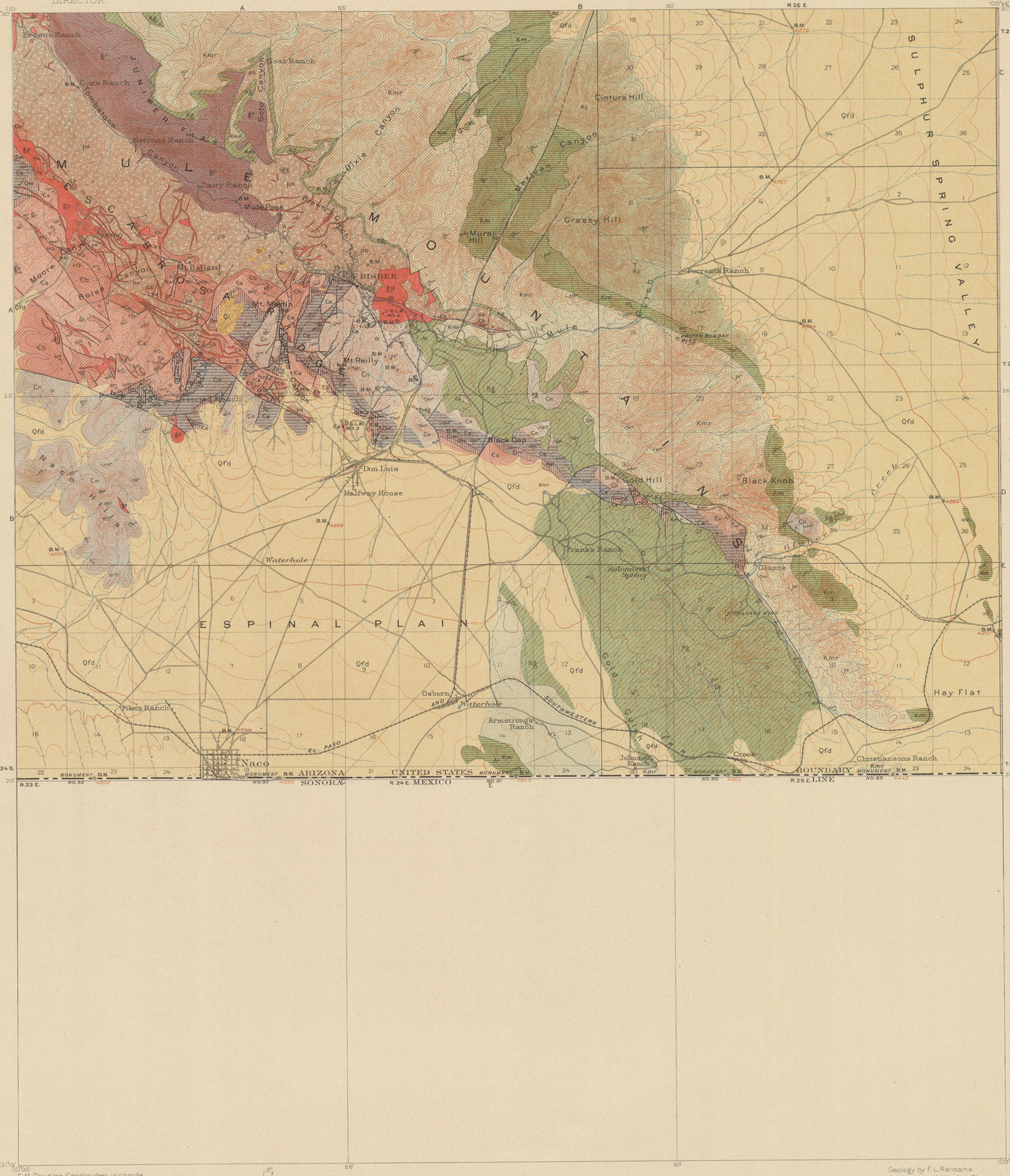
Scale $\frac{1}{62500}$
1 ½ 0 1 2 3 4 Miles
1 ½ 0 1 2 3 4 5 Kilometers
Contour interval 50 feet.
Datum is mean sea level.

Edition of April 1910, reprinted April 1914.

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH
DIRECTOR

AREAL GEOLOGY

ARIZONA
(COCHISE COUNTY)
BISBEE QUADRANGLE



LEGEND

UNCLASSIFIED ROCKS

Ql — Landslides

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

Qfd — Fluviatile deposits *(conglomerates with imperfectly rounded pebbles, gravels, and sands)*

CRETACEOUS — *Bisbee group of Comanche series*

Kc — Cintura formation *(alternating beds of dull-red shale and tawny sandstone, with occasional grits and limestone lenses)*

Km — Mural limestone *(thick-bedded, gray limestone underlain by dark, thin-bedded, arenaceous limestone; highly fossiliferous)*

Kmr — Morita formation *(alternating beds of dull-red arenaceous shale and tawny sandstone, with occasional grits and limestone lenses)*

Kg — Glance conglomerate *(basal conglomerate of varying character; pebbles imperfectly rounded and chiefly schist and limestone; roughly bedded and contains some shale and sandstone)*

UNCONFORMITY

CARBONIFEROUS

Pennsylvanian series

Cn — Naco limestone *(thin-bedded to thick-bedded, compact, non-magnesian, white, gray or pinkish limestone, with subordinate shale; fossils abundant)*

Mississippian series

Ce — Escabrosa limestone *(thick-bedded, non-magnesian, white, crinoidal limestone of granular texture)*

DEVONIAN

Dm — Martin limestone *(dark-gray, compact, non-magnesian limestone in beds of moderate thickness; fossils abundant; subordinate, pink, calcareous shale)*

UNCONFORMITY ?

CAMBRIAN

Ca — Abrigo limestone *(thin-bedded, cherty, laminated, impure limestone with some calcareous shale; locally magnesian; sandy in upper portion)*

Cb — Bolsa quartzite *(thick-bedded, pebbly, arkose grits and fine-grained vitreous quartzite with basal conglomerate)*

UNCONFORMITY

PRE-CAMBRIAN — *Metamorphic*

ps — Pinal schist *(fine-grained, fissile quartz-sericite schist; probably metamorphosed sediments)*

IGNEOUS ROCKS

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

TRIASSIC OR JURASSIC

gp — Granite porphyry *(with some rhyolite; masses, dikes, and sills intrusive into Carboniferous and older rocks)*

PRE-CAMBRIAN

gr — Granite *(intrusive in Pinal schist)*

Known faults *(occasionally accompanied by mineralization)*

Probable faults

Concealed faults *(covered by younger deposits)*

20° Strike and dip of stratified rocks
Strike of vertical beds
Horizontal beds
Strike of vertical schists
70° Dip of fault planes
T. indicates overthrust side of thrust faults

Mines, chiefly copper

Economic data: *Copper ores in important deposits as replacements in limestone adjacent to porphyry masses and along zones of fissuring. Some copper ore of undetermined importance in porphyry. Minor deposits of gold, silver, lead, and zinc ores, in part associated with the copper ores. Limestone chiefly from the Carboniferous formations, and rough building stone available but not extensively utilized.*

E. M. Douglas, Geographer in charge.
Triangulation and topography by T. M. Bannon.
Surveyed in 1901-1902.

APPROXIMATE MEAN DECLINATION 1901.

Scale $\frac{1}{62500}$

Contour interval 50 feet.

Datum is mean sea level.

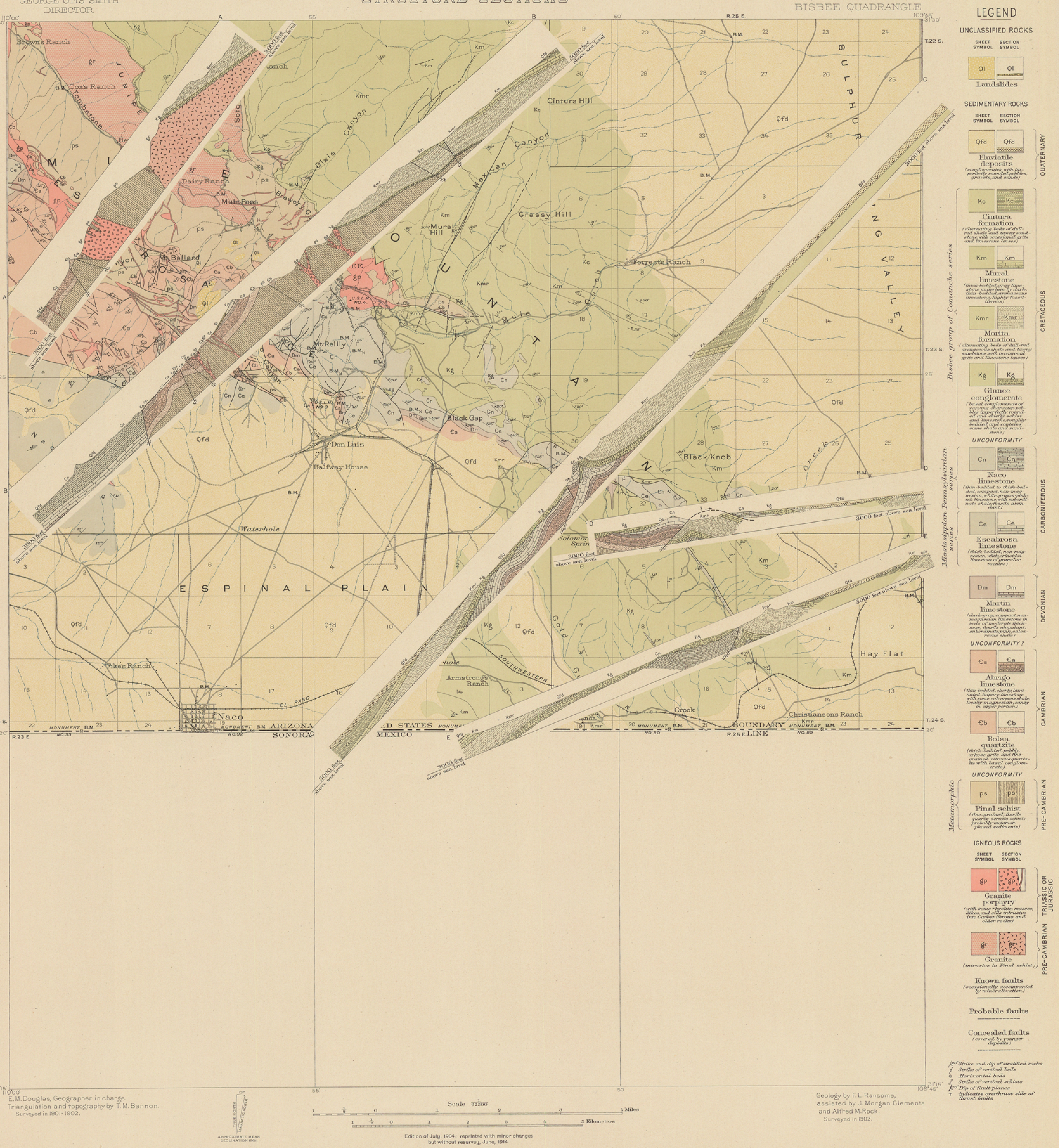
Edition of March, 1904; reprinted with minor changes but without resurvey, June, 1914.

Geology by F. L. Ransome.
Assisted by J. Morgan Clements and Alfred M. Rock.
Surveyed in 1902.

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH
DIRECTOR

STRUCTURE SECTIONS

ARIZONA
(COCHISE COUNTY)
BISBEE QUADRANGLE



E. M. Douglas, Geographer in charge.
Triangulation and topography by T. M. Bannon.
Surveyed in 1901-1902.

Edition of July, 1904; reprinted with minor changes but without resurvey, June, 1914.

Geology by F. L. Ransome, assisted by J. Morgan Clements and Alfred M. Rock.
Surveyed in 1902.

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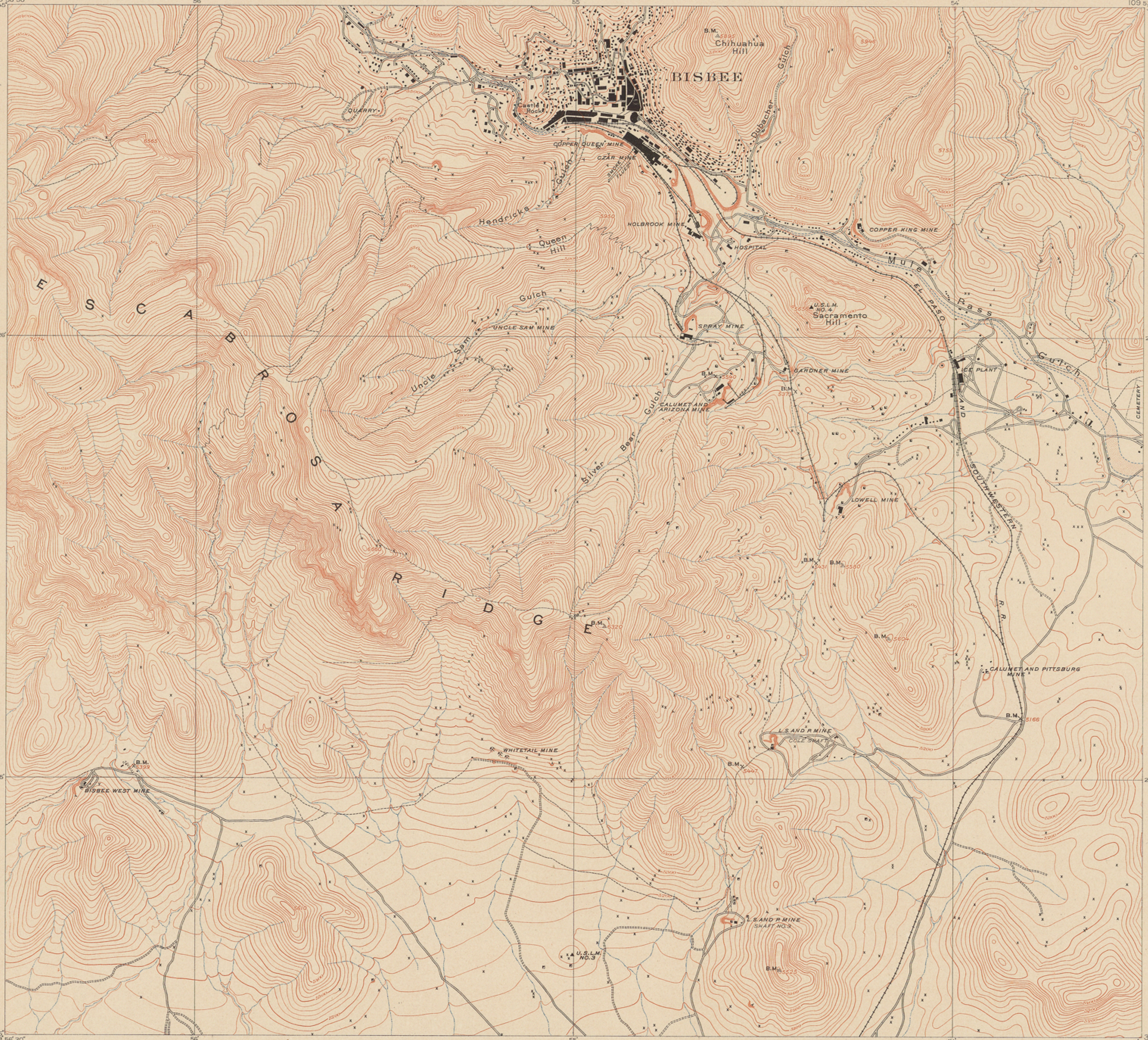
TOPOGRAPHY

ARIZONA
(COCHISE COUNTY)
BISBEE AND VICINITY



109°56'30" 31°26'45" — 56' — 55' — 54' — 109°53'30" 31°26'45"

26' — 25'

31°24'25" 109°56'30" — 109°53'30" 31°24'25"

E.M. Douglas, Geographer in charge.
Triangulation by T.M. Bannon.
Topography by Richard T. Evans.
Surveyed in 1902.

APPROXIMATE MEAN DECLINATION 1901.

Scale $\frac{1}{12000}$

0 — ¼ — ½ — ¾ — 1 Mile
1000 500 0 1000 2000 3000 4000 Feet.
200 100 0 500 1000 Meters

Contour interval 20 feet.
Datum is mean sea level.

Edition of Dec. 1906, reprinted April 1914.

LEGEND

RELIEF
printed in brown

Altitude
above mean sea level instrumentally determined

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

Depression contour

Mine dump

Stream wash

DRAINAGE
printed in blue

Intermittent streams

CULTURE
printed in black

Roads and buildings

Private or secondary road

Trail

Railroad

Bench mark

U.S. locating monument

Shaft

Open cut

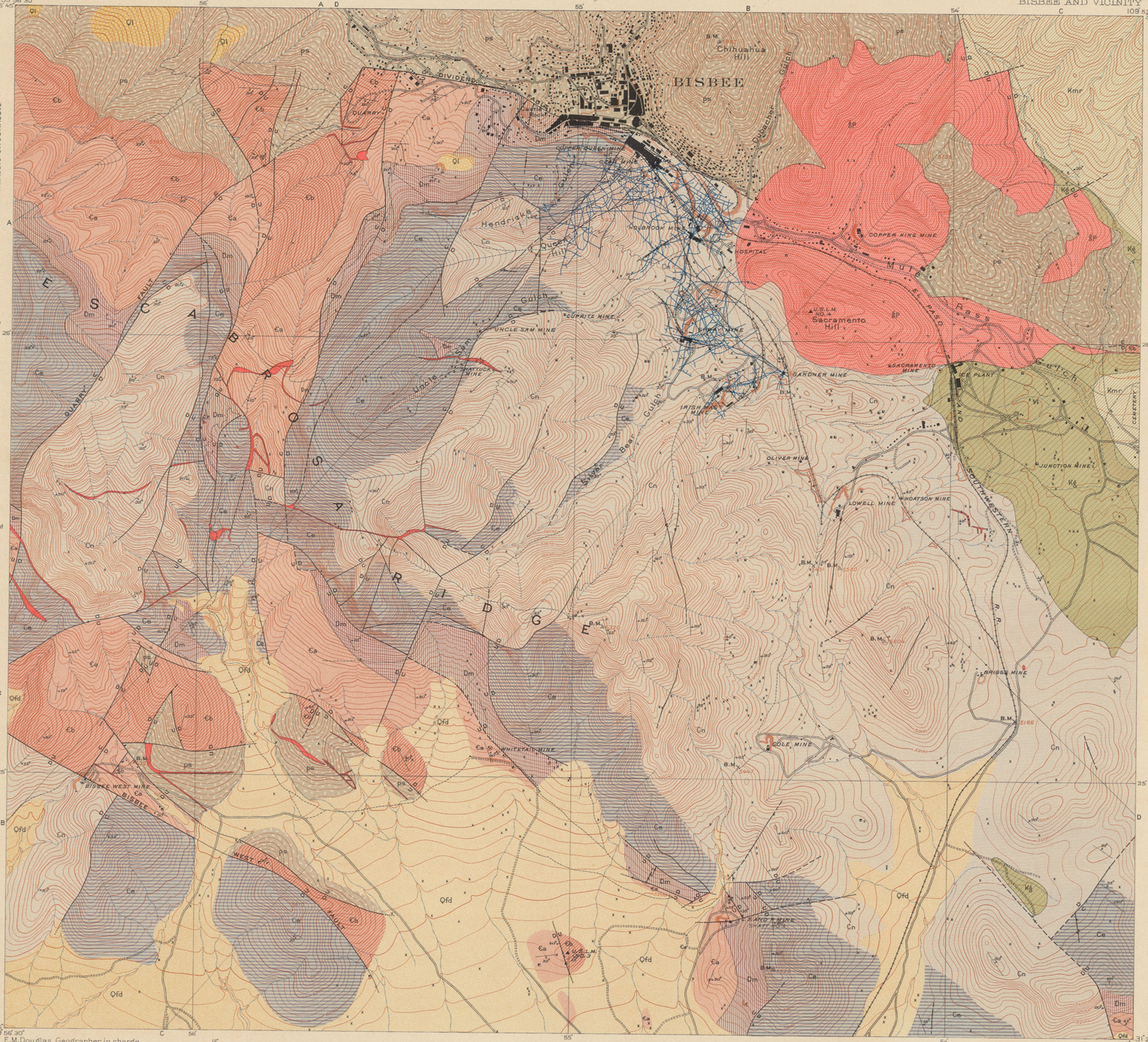
Tunnel

Prospect

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH
DIRECTOR

ECONOMIC GEOLOGY

ARIZONA
(COCHISE COUNTY)
BISBEE AND VICINITY



Scale 1/24000

Contour interval 20 feet.
Datum is mean sea level.
Edition of March, 1904; reprinted with minor changes but without resurvey, June, 1914.

E.M. Douglas, Geographer in charge.
Triangulation by T.M. Bannon.
Topography by Richard T. Evans.
Surveyed in 1902.

Geology by F.L. Ransome.
Surveyed in 1902.

LEGEND

UNCLASSIFIED ROCKS

Ql — Landslides

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

Qfd — Fluviatile deposits (conglomerates with imperfectly rounded pebbles, gravels, and sands)

CRETACEOUS — Bisbee group of Comanche series

Kmr — Morita formation (alternating beds of dull-red arenaceous shale and tawny sandstone, with occasional grits and limestone lenses)

Kg — Glance conglomerate (basal conglomerate of varying character; pebbles imperfectly rounded and chiefly schist and limestone; roughly bedded and contains some shale and sandstone)

UNCONFORMITY

CARBONIFEROUS

Pennsylvanian series

Cn — Naco limestone (thin-bedded to thick-bedded, compact, non-magnesian, white, gray or pinkish limestone, with subordinate shale; fossils abundant)

Mississippian series

Ce — Escabrosa limestone (thick-bedded, non-magnesian, white, crinoidal limestone of granular texture)

DEVONIAN

Dm — Martin limestone (dark-gray, compact, non-magnesian limestone in beds of moderate thickness; fossils abundant; subordinate, pink, calcareous shale)

UNCONFORMITY ?

CAMBRIAN

Ꞓa — Abrigo limestone (thin-bedded, cherty, laminated, impure limestone with some calcareous shale; locally magnesian; sandy in upper portion)

Ꞓb — Bolsa quartzite (basal conglomerate, thick-bedded, pebbly, arkose grits, and fine grained vitreous quartzite)

UNCONFORMITY

PRE-CAMBRIAN — Metamorphic

ps — Pinal schist (fine-grained, fissile, quartz-sericite schist; probably metamorphosed sediments)

Legend is continued on the left margin.

LEGEND (continued)

IGNEOUS ROCKS

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

TRIASSIC OR JURASSIC

gp — Granite porphyry (with some rhyolite; masses, dikes, and sills intrusive into Carboniferous and older rocks)

Known faults (occasionally accompanied by mineralization)

Probable faults

Concealed faults (covered by younger deposits)

- Strike and dip of stratified rocks
- Strike of vertical beds
- Dip of fault planes
- U Upheaved side of faults
- D Downthrown side of faults
- Shafts
- Open-cut workings
- Tunnels
- Prospect pits

Mine workings (projected to the surface)

Note: The underground workings have been greatly extended to the southeast since this area was surveyed.

MINES

Owned by the Copper Queen Consolidated Mining Company

Czar
Holbrook
Spray
Gardner
Sacramento
Copper King
Cuprite
Uncle Sam
Lowell
Whitetail

Owned by the Calumet & Arizona Mining Company

Irish Mag
Oliver

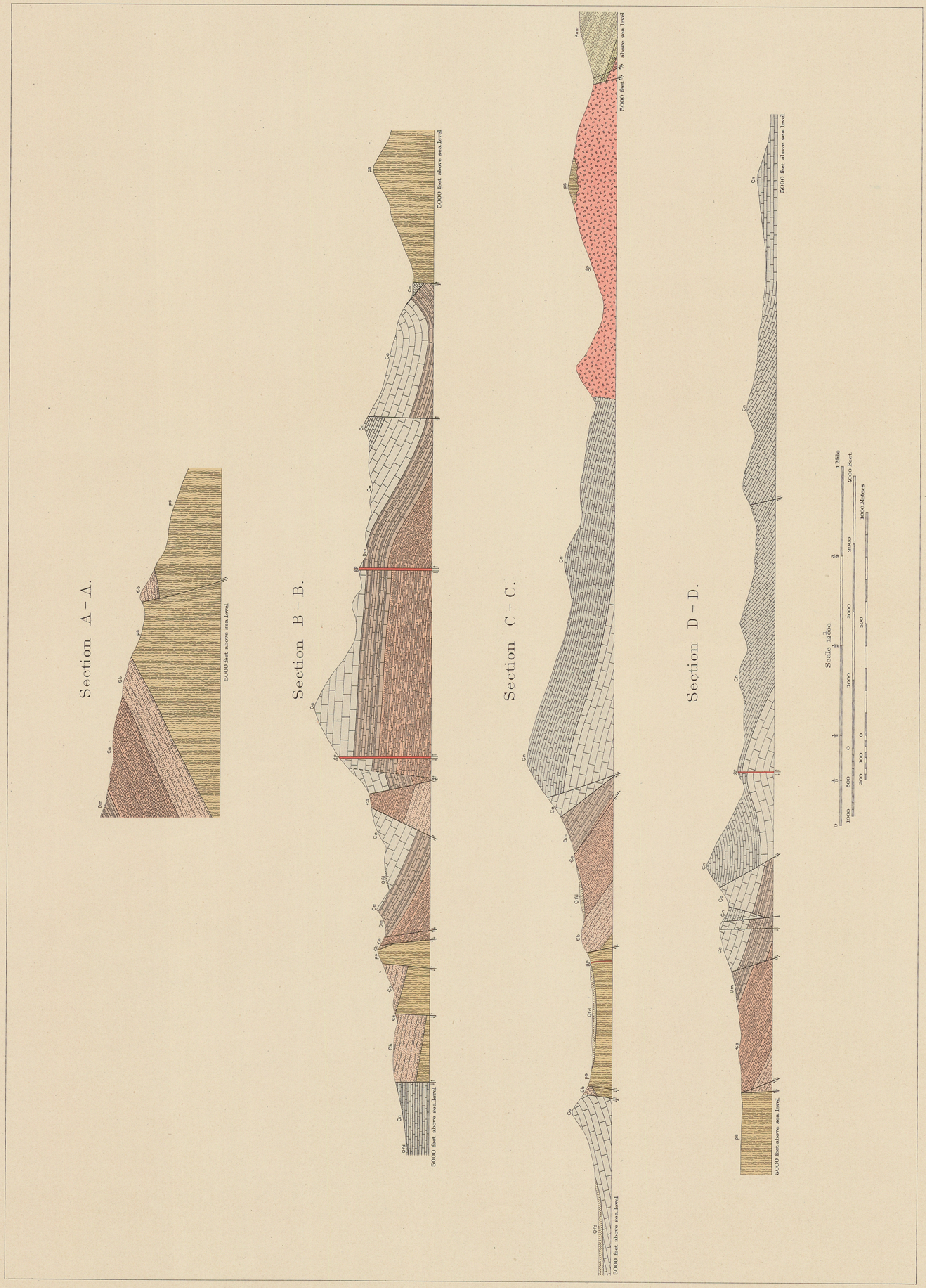
Owned by the Superior & Pittsburg Mining Company

Junction
Hoatson
Briggs
Cole

Owned by the Shattuck-Arizona Copper Company

Shattuck

STRUCTURE SECTIONS



LEGEND

SEDIMENTARY ROCKS

QUATERNARY

Qfd — **Fluviatile deposits** *(conglomerates with imperfectly rounded pebbles, gravels, and sands)*

CRETACEOUS — *Bisbee group of Comanche series*

Kmr — **Morita formation** *(alternating beds of dull-red arenaceous shale and tawny sandstone, with occasional grits and limestone lenses)*

Kg — **Glance conglomerate** *(basal conglomerate of varying character; pebbles imperfectly rounded and chiefly schist and limestone; roughly bedded and contains some shale and sandstone)*

UNCONFORMITY

CARBONIFEROUS

Pennsylvanian series

Cn — **Naco limestone** *(thin-bedded to thick-bedded, compact, non-magnesian, white, gray or pinkish limestone, with subordinate shale; fossils abundant)*

Mississippian series

Ce — **Escabrosa limestone** *(thick-bedded, non-magnesian, white, crinoidal limestone of granular texture)*

DEVONIAN

Dm — **Martin limestone** *(dark-gray, compact, non-magnesian limestone in beds of moderate thickness; fossils abundant; subordinate, pink, calcareous shale)*

UNCONFORMITY ?

CAMBRIAN

€a — **Abrigo limestone** *(thin-bedded, cherty, laminated, impure limestone with some calcareous shale; locally magnesian; sandy in upper portion)*

€b — **Bolsa quartzite** *(basal conglomerate, thick-bedded, pebbly, arkose grits, and fine-grained vitreous quartzite)*

UNCONFORMITY

PRE-CAMBRIAN — *Metamorphic*

ps — **Pinal schist** *(fine-grained, fissile quartz-sericite schist; probably metamorphosed sediments)*

IGNEOUS ROCKS

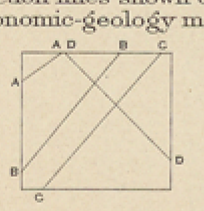
TRIASSIC OR JURASSIC

gp — **Granite porphyry** *(with some rhyolite; masses, dikes, and sills intrusive into Carboniferous and older rocks)*

Known faults *(occasionally accompanied by mineralization)*

Probable faults

Section lines shown on Economic-geology map



Note: *Although sections B-B, C-C, and D-D are known to pass through important ore bodies, these are not here shown as the data for their accurate delineation are not at hand.*

Edition of June, 1904, reprinted with minor changes, June, 1914.

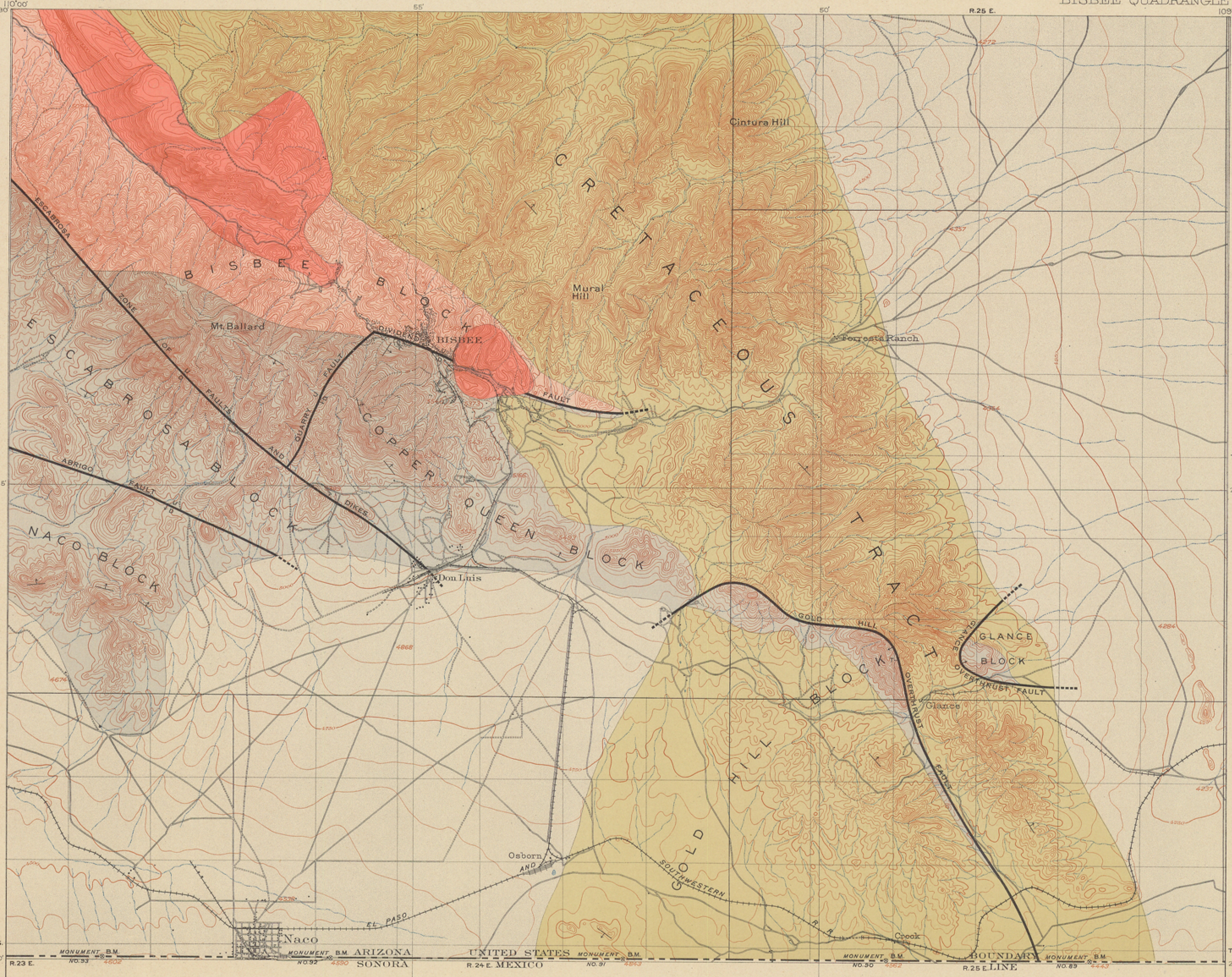
Geology by F. L. Ransome.
Surveyed in 1902.

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH
DIRECTOR

DIAGRAM OF THE BISBEE QUADRANGLE

SHOWING MAJOR FAULTING AND GENERAL DISTRIBUTION OF THE ROCKS

ARIZONA
(COCHISE COUNTY)
BISBEE QUADRANGLE



LEGEND

(General distribution of the rocks shown by colors and patterns)

- Quaternary deposits
- Mesozoic rocks
- Paleozoic rocks
- Pre-Paleozoic metamorphic rocks
- Intrusive rocks

- Great faults or fault zones
- D Downthrown side of faults
- U Upheaved side of faults
- T Overthrust side of thrust faults
- Dip of faults
- Vertical faults
- Dip of strata

E. M. Douglas, Geographer in charge.
Triangulation and topography by T. M. Bannon.
Surveyed in 1901-1902.

APPROXIMATE MEAN DECLINATION 1901.

Scale $\frac{1}{62500}$

Contour interval 50 feet.

Datum is mean sea level.

Edition of June, 1904, reprinted June, 1914.

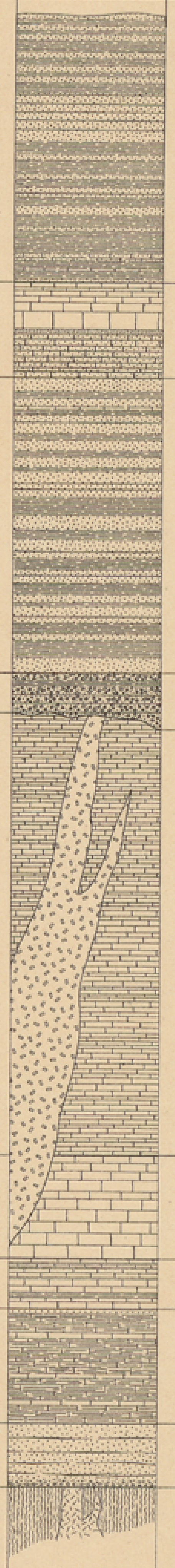
DIAGRAM OF TOWNSHIP

F. L. Ransome.
Geologist.

COLUMNAR SECTION

COLUMNAR SECTION OF THE SEDIMENTARY ROCKS OF THE BISBEE QUADRANGLE.

SCALE: 1 INCH = 1000 FEET.

System.	Series.	Formation Name.	Symbol.	Columnar Section.	Thickness in Feet.	Character of Rocks.
CRETACEOUS	COMANCHE (BISBEE GROUP)	Cintura formation.	Kc		1800+	Red nodular shales with cross-bedded, buff, tawny, and red sandstones; a few beds of impure limestone near base.
		Mural limestone.	Km		650	Thick-bedded, hard, gray, fossiliferous limestone. Thin-bedded, arenaceous, dark, fossiliferous limestone.
		Morita formation.	Kmr		1800-2000+	Buff, tawny, and red sandstones and dark-red shales, with an occasional thin bed of impure limestone near the top.
		Glance conglomerate.	Kg		25-500	Bedded conglomerate with rather angular pebbles, chiefly of schist and limestone, and some shale and sandstone. Rests on irregular surface of erosion.
		UNCONFORMITY				
CARBONIFEROUS	PENNSYLVANIAN	Naco limestone.	Cn		3000+	Principally light-gray, compact limestone in beds of moderate thickness with very subordinate shale. Contains abundant fossils.
		Granite porphyry.	gp			Erupted into Carboniferous and older rocks.
	MISSISSIPPIAN	Escabrosa limestone.	Ce		700	Thick-bedded white and light-gray granular limestone. Contains abundant crinoid stems.
DEV.		Martin limestone.	Dm		340	Dark-gray fossiliferous limestone in beds of moderate thickness with subordinate pink calcareous shale.
		UNCONFORMITY ?				
CAMBRIAN		Abrigo limestone.	€a		770	Thin-bedded, impure, cherty limestones with some calcareous shales, sandy toward the top.
		Bolsa quartzite.	€b		430	Moderately thick, cross-bedded quartzites and arkosic grits, with basal conglomerate.
		UNCONFORMITY				
PRE-CAMBRIAN		Pinal schist.	ps			Sericite schists.
		Granite.	gr			Intrusive in the schists.

F. L. RANSOME,

Geologist.

FIGURE 2.—BISBEE FROM SACRAMENTO HILL.
Holbrook shaft in foreground; Czar shaft in middle ground.

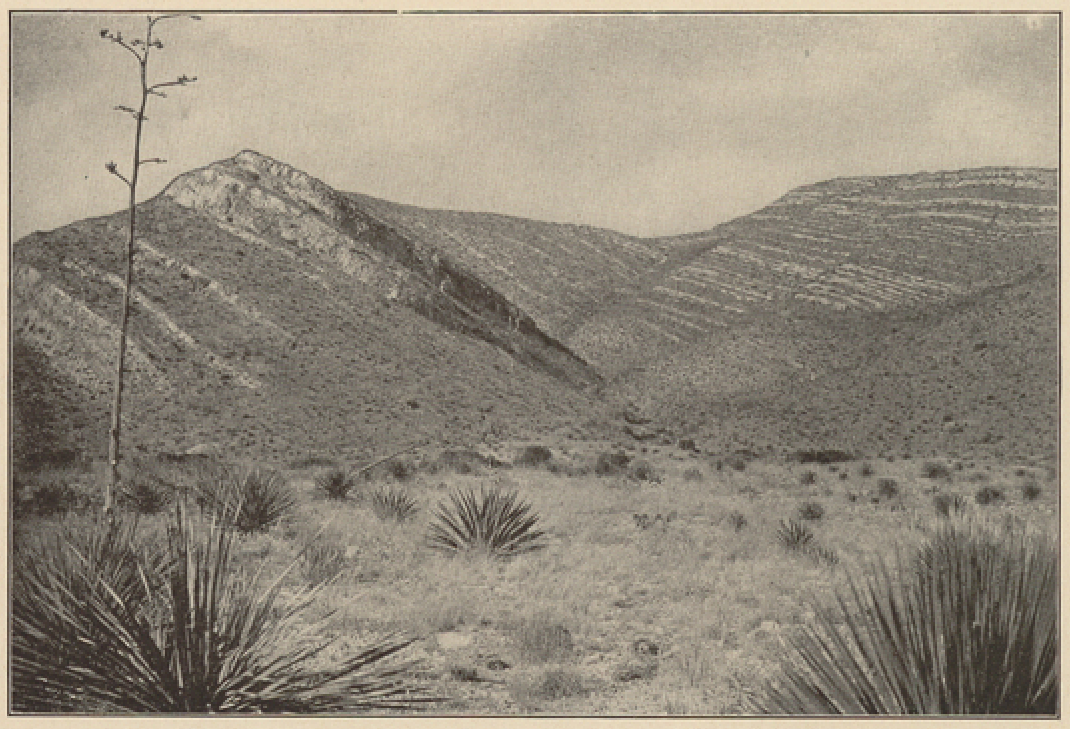


FIGURE 3.—ESCABROSA LIMESTONE CONFORMABLY OVERLAIN BY NACO LIMESTONE, 1 MILE NORTH OF DON LUIS.
The hill on the left is formed of Escabrosa limestone. The base of the Naco limestone outcrops about halfway up the slope on the right.

FIGURE 4.—THE MOUNT MARTIN PALEOZOIC SECTION, ON THE NORTHEAST SLOPE OF ESCABROSA RIDGE, WEST OF BISBEE.

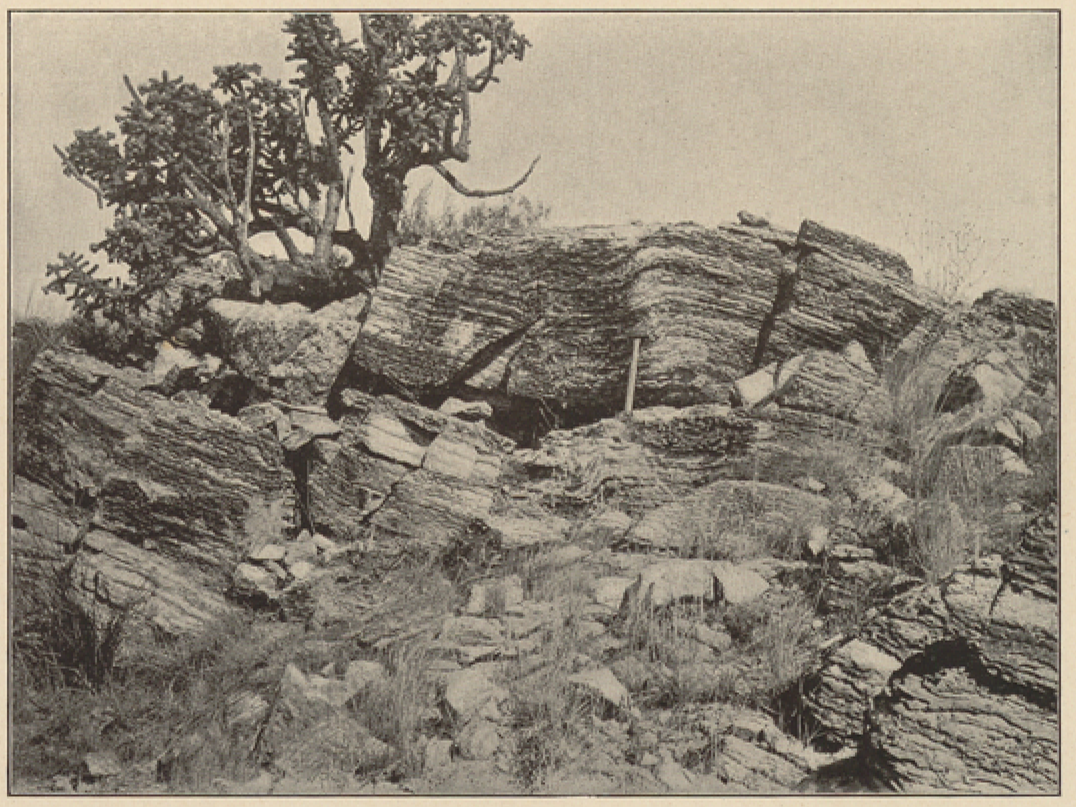


FIGURE 5.—CHERTY BANDING OF ABRIGO LIMESTONE.

FIGURE 6.—NACO HILLS FROM POINT NEAR MOUNT REILLY, ON THE CREST OF ESCABROSA RIDGE.
In the foreground, near the mouth of Escacado Canyon, are hills composed of faulted masses of Pinal schist and the various Paleozoic formations. In the distance, beyond the Naco Hills, to the west and southwest, is San Pedro Valley, stretching southward into Mexico. On the distant left appears an outlying spur of the San Jose Mountains, beyond which on a clear day may be seen the town of Cananea.

FIGURE 7.—HILLS CARVED FROM CRETACEOUS BEDS EAST OF BISBEE.
View is northward across Mule Gulch. The prominent white band is the upper member of the Mural limestone, forming the top of Mural Hill on the left and showing the dislocation due to the Mexican Canyon fault.

ILLUSTRATIONS II

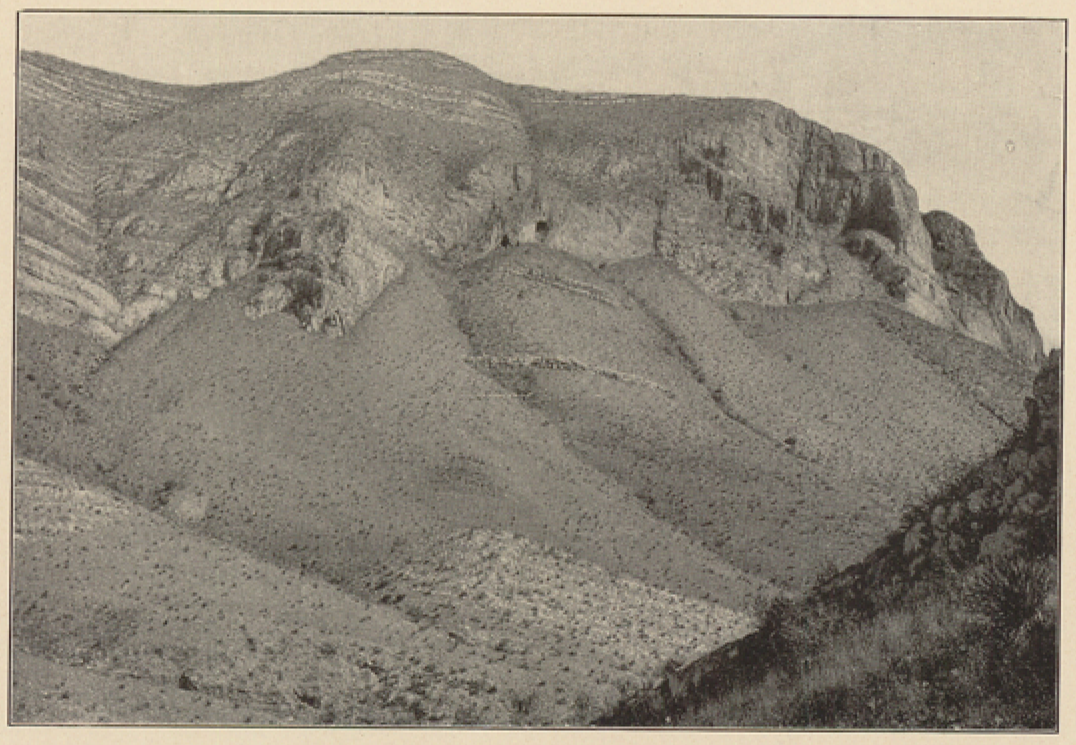


FIGURE 8.—DETAIL OF FAULTED STRUCTURE ON THE EAST SIDE OF ESCACADO CANYON.
The cliffs are formed of Escabrosa limestone, overlain by Naco limestone. The slope below is underlain by Martin and Abrigo limestones, behind which the Escabrosa has been dropped by faults along the base of the cliffs. In the middle foreground are knolls of Escabrosa limestone, which has been faulted down against the Abrigo.

FIGURE 9.—GLANCE CONGLOMERATE RESTING UPON IRREGULARLY ERODED NACO LIMESTONE, 1 MILE NORTHEAST OF BLACK GAP.
The obscurely bedded conglomerate is thickest at the left and thins out at the saddle on the right. The distinctly bedded rock is all Naco limestone. The summit of Gold Hill is visible through the saddle.

FIGURE 10.—GRANITE MASS OF JUNIPER FLAT FROM ESCABROSA RIDGE.
Shows an outlier of Cretaceous strata resting upon an even surface of erosion.

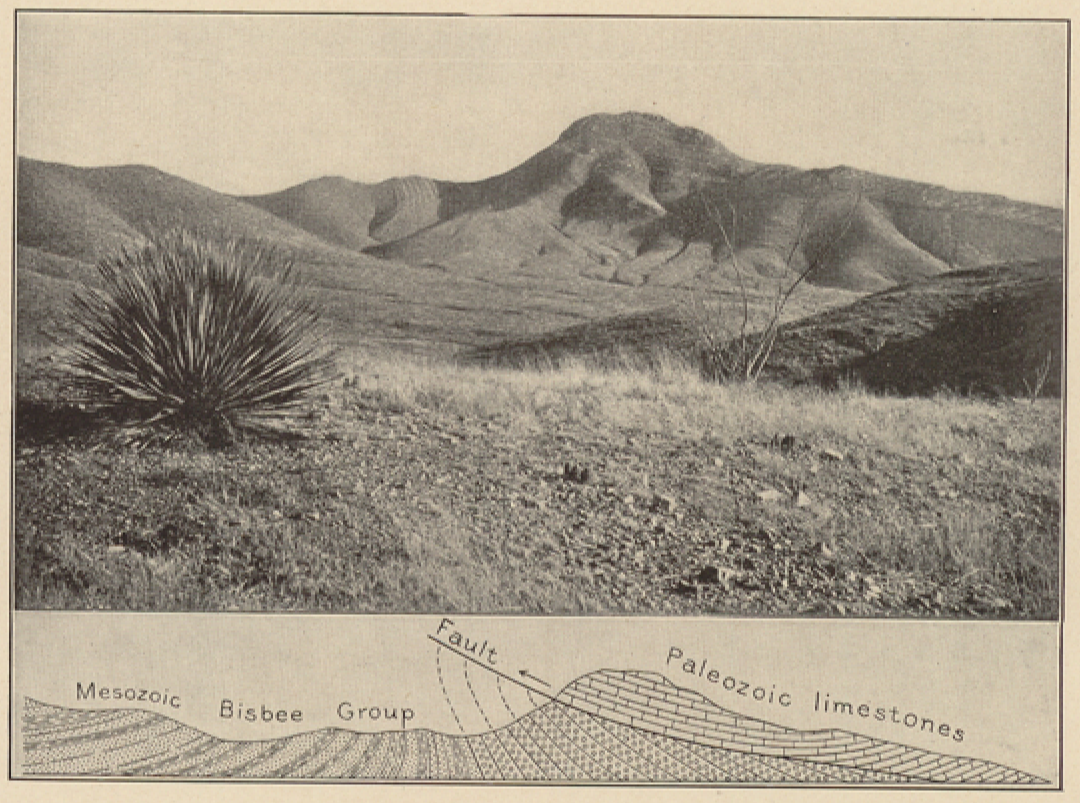
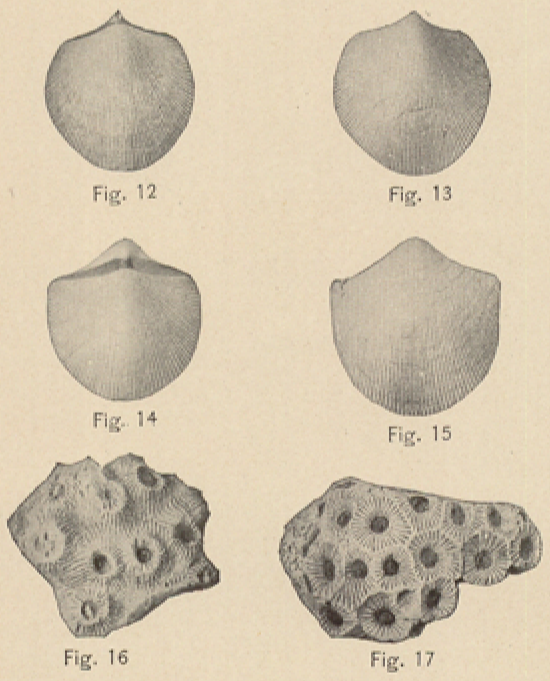
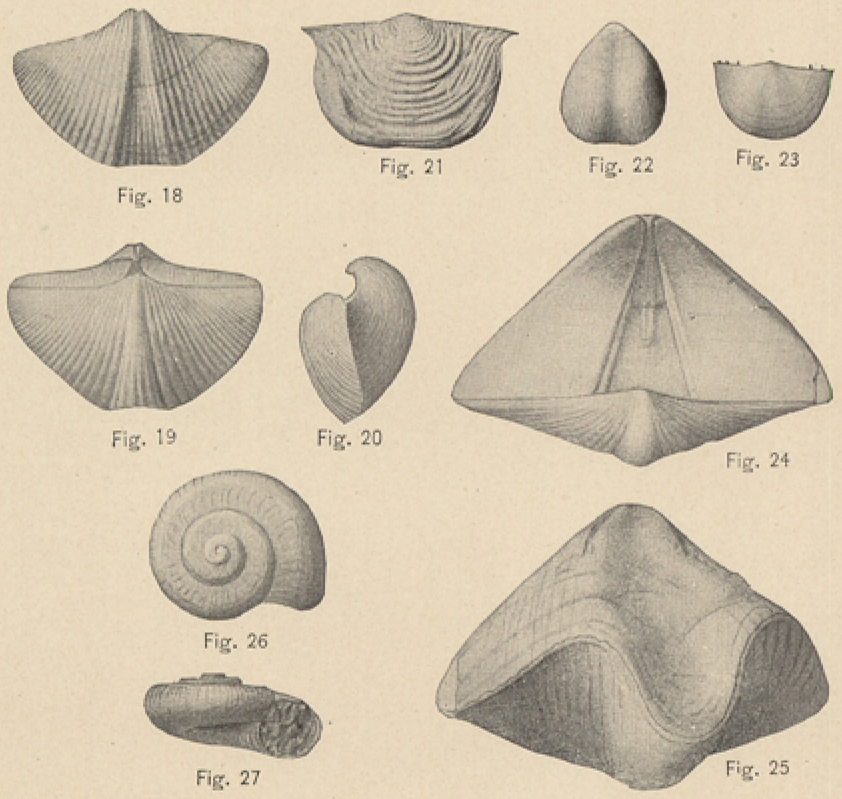


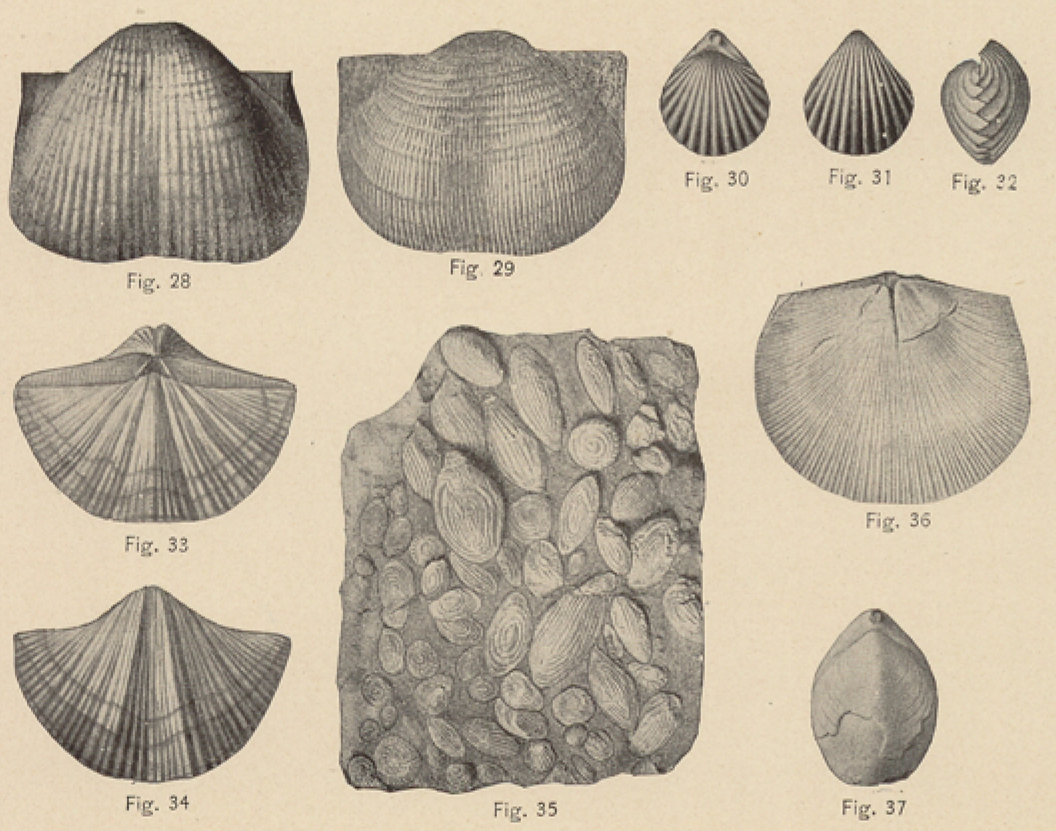
FIGURE 11.—GOLD HILL FROM THE NORTHWEST SHOWING OVERTHRUST FAULT.



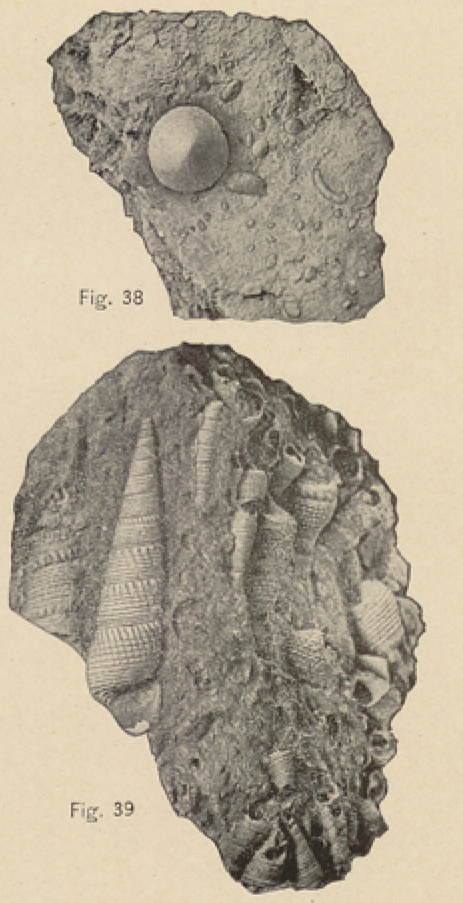
FOSSILS CHARACTERISTIC OF THE MARTIN LIMESTONE (DEVONIAN).



FOSSILS CHARACTERISTIC OF THE ESCABROSA LIMESTONE (MISSISSIPPIAN).



FOSSILS CHARACTERISTIC OF THE NACO LIMESTONE (PENNSYLVANIAN).



FOSSILS CHARACTERISTIC OF THE BISBEE GROUP (CRETACEOUS).

Devonian.

Fig. 12. Atrypa reticularis. Dorsal view.
Fig. 13. Atrypa reticularis. Ventral view of larger specimen.
Fig. 14. Spirifer hungerfordi. Ventral view.
Fig. 15. Spirifer hungerfordi. Dorsal view of larger specimen.
Fig. 16. Pachyphyllum woodmani. Composite corallum showing several corallites, natural size.
Fig. 17. Acervularia davidsoni. Colony showing wall separating individual corallites, natural size.

Mississippian.

Fig. 18. Spirifer centronatus. Ventral view.
Fig. 19. Spirifer centronatus. Dorsal view.
Fig. 20. Spirifer centronatus. Side view. This species is common in the Escabrosa limestone. Forms similar to it, however, are also found in the Pennsylvanian.
Fig. 21. Leptæna rhomboidalis. Ventral valve.
Fig. 22. Rhipidomella thiemei. Ventral valve. Very characteristic of the Escabrosa limestone

Mississippian—Continued.

Fig. 23. Chonetes loganensis. Ventral valve. This species is very characteristic of the Escabrosa limestone.
Fig. 24. Syringothyris carteri. Posterior view.
Fig. 25. Syringothyris carteri. Anterior view.
Fig. 26. Straparollus luxus. Seen from above.
Fig. 27. Straparollus luxus. Side view. This is a small specimen. The genus occurs in the Pennsylvanian but not the same species.

Pennsylvanian.

Fig. 28. Productus semireticulatus. Ventral valve. This species is common in the Naco limestone but does not occur in the Mississippian.
Fig. 29. Productus inflatus ?. Ventral valve.
Fig. 30. Hustedia mormoni. Dorsal view. Enlarged $1\frac{1}{2}$ times.
Fig. 31. Hustedia mormoni. Ventral view. Enlarged $1\frac{1}{2}$ times.
Fig. 32. Hustedia mormoni. Side view. This form is peculiar to the Pennsylvanian

Pennsylvanian—Continued.

Fig. 33. Spirifer cameratus. Dorsal view.
Fig. 34. Spirifer cameratus. Ventral view. This species is not found in the Escabrosa limestone.
Fig. 35. Fusulina cylindrica. A block of limestone containing a number of specimens partly weathered. Enlarged 2 times.
Fig. 36. Derbya crassa. Ventral valve. The specimen is weathered so that the vertical plate on the inside of this valve is shown. This form is often abundant in the Naco limestone but does not occur at all in the Mississippian. A form resembling it very closely is found in the Escabrosa limestone, but it is without the vertical plate, which of course does not show on the outside of the shell.
Fig. 37. Seminula subtilita. Dorsal view. An elongated specimen of medium size.

Cretaceous.

Fig. 38. Orbitulina texana. Enlarged 2 diameters.
Fig. 39. Turritella sp. Enlarged $1\frac{1}{2}$ diameters.

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		Ꞧ	Peacock-blue.
Paleozoic	Carboniferous	Permian Pennsylvanian Mississippian	C	Blue.
	Devonian		D	Blue-gray.
	Silurian		S	Blue-purple.
	Ordovician		O	Red-purple.
	Cambrian		Ꞓ	Brick-red.
	Algonkian		A	Brownish red.
	Archean		Æ	Gray-brown.

SURFACE FORMS.

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

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

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

THE VARIOUS GEOLOGIC SHEETS.

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

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

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

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

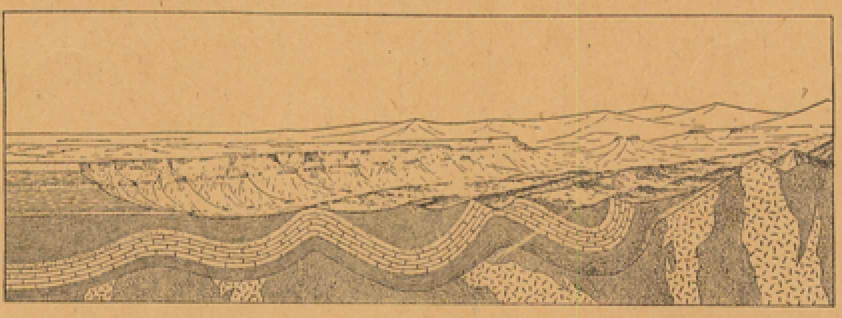


FIGURE 2.—Sketch showing a vertical section at the front and a landscape beyond.

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

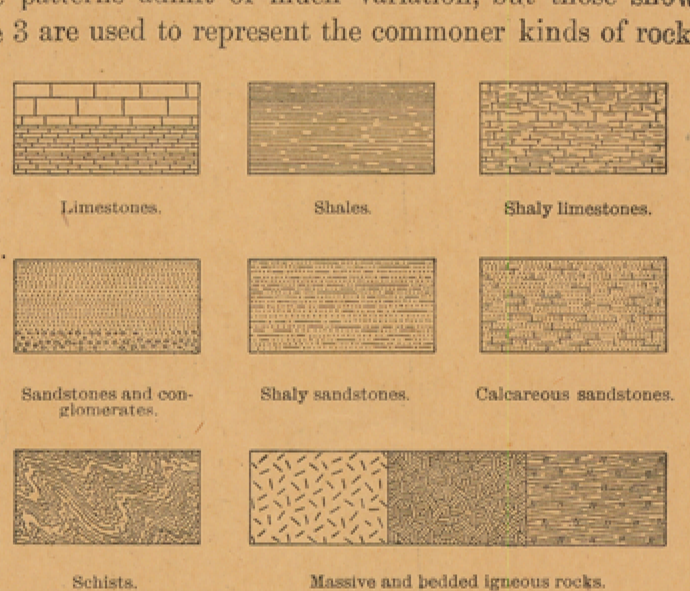


FIGURE 3.—Symbols used in sections to represent different kinds of rocks.

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

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

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

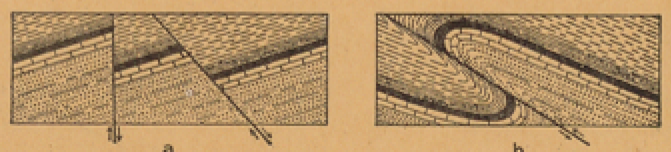


FIGURE 4.—Ideal sections of strata, showing (a) *normal* faults and (b) a *thrust* or *reverse* fault.

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

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

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

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

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

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

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

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

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

GEORGE OTIS SMITH,
Director.

May, 1909.

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