DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

GEOLOGIC ATLAS

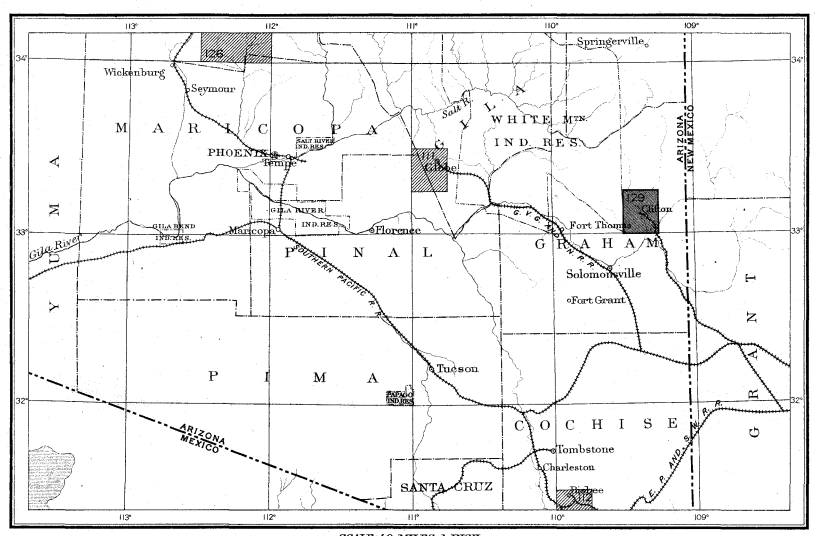
OF THE

UNITED STATES

CLIFTON FOLIO

ARIZONA

INDEX MAP



SCALE: 40 MILES-1 INCH

CLIFTON FOLIO

OTHER PUBLISHED FOLIOS

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

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GEOLOGIC AND TOPOGRAPHIC ATLAS OF UNITED STATES.

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

THE TOPOGRAPHIC MAP.

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

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

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

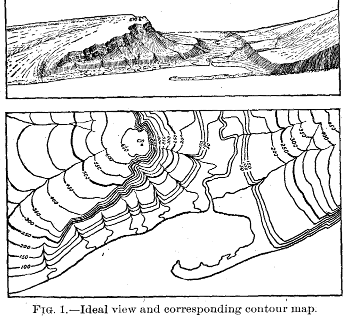


FIG. 1.—Ideal view and corresponding contour map.

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

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

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

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

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

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

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

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

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

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

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

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

THE GEOLOGIC MAPS.

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

KINDS OF ROCKS.

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

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

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

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

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

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

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

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

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

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

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

FORMATIONS.

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

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

AGES OF ROCKS.

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

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

(Continued on third page of cover.)

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

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

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

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

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

Symbols and colors assigned to the rock systems.

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

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

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

SURFACE FORMS.

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

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

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

THE VARIOUS GEOLOGIC SHEETS.

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

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

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

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

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

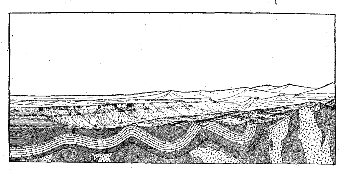


Fig. 2.—Sketch showing a vertical section at the front and a landscape beyond.

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

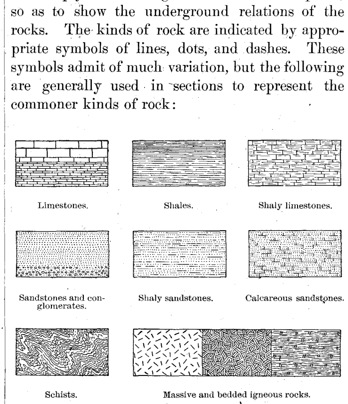


Fig. 3.—Symbols used in sections to represent different kinds of rocks.

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

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

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

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

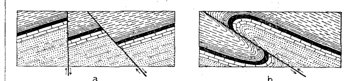


Fig. 4.—Ideal sections of strata, showing (a) *normal* faults and (b) a *thrust* fault.

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

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

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

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

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

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

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

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

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

CHARLES D. WALCOTT,

Director.

Revised January, 1904.

DESCRIPTION OF THE CLIFTON QUADRANGLE.

By Waldemar Lindgren.

GEOGRAPHY.

Location and area.—The Clifton quadrangle lies between meridians 109° 15′ and 109° 30′ west longitude, and parallels 33° and 33° 15′ north latitude. It is 17.25 miles long and 14.5 miles wide, and has an area of 249.76 square miles. The whole area falls within the eastern part of Graham County, in the southeastern part of the Territory of Arizona. The dividing line between Arizona and New Mexico is 11 miles distant from its eastern boundary, and the Mexican frontier lies 115 miles south of its southern boundary.

Outline of geography and geology of province.—The Territory of Arizona may be divided into three physiographic regions (see fig. 1). The northeastern part of the Territory is included within the Plateau Region. In this province the bedded

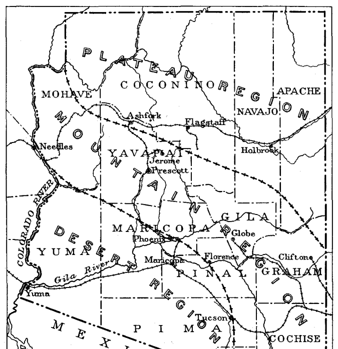


FIG. 1.—Map showing physiographic regions of Arizona.
The Clifton quadrangle is in the central-eastern portion of the State around the town of Clifton.
Scale, approximately, 1 inch=100 miles.

rocks lie nearly horizontal and consist chiefly of Paleozoic sediments resting on granite and schists of pre-Cambrian age. Colorado River with its several affluents forms the main drainage line, and has eroded those wonderful deep and abrupt canyons for which the region is famous. Volcanic masses of large volume and comparatively recent origin cover the plateau in many places, the best known being the imposing extinct volcano San Francisco Mountain. The southern boundary of the Plateau Region is for a long distance marked by steep cliffs of horizontal strata, which form a very conspicuous landmark.

The second province, called the Mountain Region, adjoins the plateau on the southwest and extends in a broad belt through the Territory from northwest to southeast. It is characterized by a great number of short, nearly parallel ranges which rarely exceed 50 miles in length and 8000 feet in elevation and which are separated by valleys deeply filled with fluviatile and lacustrine deposits. The general trend is northwest and southeast, but this changes near the Mexican and New Mexican borders to more nearly north and south, and the region is continued by the short ranges in New Mexico and by the Sierra Madre of Mexico. To the north it continues through the Basin Range system of Nevada and Utah.

These short ranges ordinarily consist of Paleozoic sandstones and limestones, resting with marked unconformity on pre-Cambrian schists and granites. The prevailing structure is monoclinal, due to faulting, which often finds topographic expression in the steep frontal scarps of the ranges. In places the older rocks are covered by flows of basalts, rhyolites, and andesites of Tertiary age.

Near Clifton the features described above are not so clearly developed. The boundary between the Plateau and Mountain regions is obscured by heavy volcanic flows, chiefly of basalt, which cover a very large area along the New Mexican boundary between San Francisco and Salt rivers and occupy the northern, eastern, and western parts of the Clifton quadrangle, leaving a comparatively small area in the central part in which the older rocks come to light. These heavy lava flows effectually hide the range structure in this vicinity and produce an irregular topography without central or dominating features. The detrital plains developed so extensively between the ranges and along Gila River are represented by a considerable area in the southeastern part of the quadrangle. The structure of the older rocks is intermediate between that of the Plateau Region and that of the Mountain Region, and the Clifton quadrangle would perhaps best be regarded as the broken edge of the plateau. The slightly inclined sedimentary rocks occupy high levels in the central and northern parts of the quadrangle, while toward the south and southeast on the whole they sink successively lower along profound dislocations. In detail they very frequently form monoclinal blocks faulted on either or both sides.

The third province, the Desert Region, occupying the southwestern part of Arizona, is similar in general structure to the Mountain Region, but the ranges are lower and are separated by broad desert plains. It can not be sharply distinguished from the adjoining province.

The main drainage of the Mountain and Desert regions is transverse to the ranges, through Gila and Salt rivers.

TOPOGRAPHY.

Relief.—Looking northward toward Clifton from the valley of Gila River one can distinguish several high ridges and complexes of rugged hills on the horizon, but neither from this place nor from better points of vantage nearer the foothills is it possible to discern any well-defined range system or any dominating central feature. Topographically the whole mountain region north of the river appears as a maze of short ridges, minor plateaus, and peaks.

The geological structure explains this condition of affairs very clearly. A core of older rocks—granites, limestones, and sandstones—lying chiefly between the two most important northern tributaries of the Gila in this region and reaching elevations of over 7000 feet, was first deeply and irregularly eroded, and later, during the Tertiary period, was covered by immense masses of volcanic flows, chiefly rhyolites and basalts, varying greatly in thickness and character. A constructive drainage was laid out over the lava flows and extensive erosion followed. The result of these conditions is an extremely irregular topography.

The lowest point in the quadrangle, with an elevation of 3350 feet, is in San Francisco River near the southern boundary, and the highest point, 7947 feet, is a sharp basalt peak in the northern part.

A more careful consideration brings the many confusing features into a semblance of order. Several plateaus may be discerned, some of them very faintly marked and all of them greatly dissected by deep canyons. Different causes, such as sedimentation and uplift, or volcanic accumulations, have contributed to form these plateaus. The lowest and best defined is the plateau of the Gila conglomerate, which stretches along the foot of the mountains in the southeastern part of the quadrangle, with a general elevation of 4000 to 4500 feet. It descends gently southward from the edge of the mountains and extends from Eagle Creek to the eastern margin of the quadrangle. The lower parts of the two main watercourses trench it to depths reaching 700 feet, leaving grayish or brownish bluffs of lavas or gravels lining the watercourses. The plateau is furrowed by a maze of shallow, spreading ravines, rapidly deepening to box-like canyons near the main rivers. The formation is chiefly the semiconsolidated detritus of the Gila conglomerate.

Traces of the same plateau extend northward along San Francisco River to the margin of the quadrangle. In the same manner it is indicated along Eagle Creek by level-topped bluffs and by the basin in the lower courses of Whitewater and Tule creeks.

The central part of the region contains two strongly marked features, the first being the dome-shaped and flat-topped mass of Coronado Mountain, the second the Copper King Ridge, extending as a series of abrupt red bluffs for 6 miles along San Francisco River from Markeen Mountain almost to Sardine Creek. Coronado Mountain reaches an elevation of 7400 feet and slopes gently westward toward Eagle Creek, while it drops more rapidly on its north and south sides. The Copper King Ridge has an elevation of 6800 feet at its highest point, but slopes off to the northeast to 5500 feet. The two are separated by the canyon of Chase Creek, cut to a depth of 1000 feet.

South of Coronado Mountain lie two smaller and greatly cut-up plateaus. The first is marked by the Morenci hills, which rise to an average elevation of 5000 feet and contain small peaks of porphyry and short ridges or sloping tables of limestone. The watercourses here spread out in open basins near their headwaters, but cut through the rim of the mountains in narrow canyons. Gold Creek, Morenci Canyon, and the several intervening gulches are of this character. The second plateau finds expression in the level-crested ridge south of the Coronado mine; its elevation is about 6000 feet.

The general level of the flat ridges or gentle domes of Coronado and Copper King is continued in the well-marked basaltic plateau which occupies the whole northeast corner of the quadrangle and which has been so deeply and sharply scored by Sardine Creek. Above this rise again the high, irregular ridges about Granville, marking the once dome-shaped rhyolitic and basaltic masses which now have been deeply dissected by the several branches of Whitewater Creek. Here is found the highest elevation in the quadrangle—7947 feet.

In the southwest corner of the quadrangle, west of Eagle Creek, a number of black basaltic ridges rise to elevations of 6520 feet. They probably form a part of a large dome-shaped mass of basalt flows which stretches far westward into the Apache Reservation.

Chase Creek Canyon, cutting throuhg the heart of the copper-producing district, is a most interesting and picturesque topographic feature. Three miles northwest of Clifton the monotonous gray bluffs of semiconsolidated gravels are replaced by granite walls, ranging upward to a thousand feet in height. Near the Longfellow incline the granite on the west side is capped by bluffs of quartzite and limestone, while a similar, though smaller, faulted-down quartzite table caps its eastern slope. For 1½ miles above the Longfellow incline the canyon is very narrow and deep. The prevailing rock is an altered granite, which is impregnated with decomposing pyrite; owing to this it weathers in most fantastic forms, overhanging cliffs alternating with deeply incised gorges and needle-like pinnacles, the dark-red color of the rock lending additional weirdness to the scene, especially when colors and shadows are emphasized by the setting sun. A little stream of bright-green water trickles along the bottom, numerous mining tunnels are opened along the sides, and the available level space is frequently insufficient for the track of the Coronado Railroad, which follows the canyon up to Metcalf.

A mile below Metcalf the canyon widens as the softer porphyry is entered, and small spaces of alluvial gravel appear, probably brought down from the great amphitheaters of the Coronado and Santa Rosa canyons.

At the town of Metcalf two important tributaries join Chase Creek. From the west Coronado and Santa Rosa gulches descend in narrow canyons with precipitous grade, draining the eastern slope of Coronado Mountain. Three thousand feet west of Metcalf they join, and continue down to Chase Creek in an open valley with a bowlder-covered bottom several hundred feet wide, bearing ample evidence of the frequent occurrence of violent cloudbursts on the flanks of Coronado Mountain. From the east King Gulch descends in a narrow, extremely rocky canyon broken by one sudden drop of a hundred feet, and having a grade of 500 feet in 1 mile; it heads 3 miles to the northwest, near Malpais Mountain, 7000 feet high, which, as its name implies, is carved in jagged outlines from the great Tertiary lava flows. A débris fan of great bowlders at the mouth of the canyon shows the torrential character of the watercourse, which ordinarily is entirely dry.

The most prominent feature of the topography at Metcalf is Shannon Mountain, rising in pyramidal form 1200 feet above the town, with yellowish-gray lower slopes broken by rough crags of decomposed porphyry, and surmounted by the black iron cap of the outcrops of the Shannon mine.

Above Metcalf the canyon of Chase Creek contracts again and for 1½ miles forms a less conspicuous duplicate of the lower granite canyon. The grade is about 200 feet to the mile. Garfield Gulch, on which several important mines and prospects are situated, enters from the east. Above this gulch the most conspicuous features are the great granite bluffs on the west side, which drop off almost perpendicularly for a thousand feet to a sloping mass of débris near the creek. The head of Chase Creek is only a few miles distant, among the high lava peaks of the northern part of the quadrangle. The total drainage area of Chase Creek is about 22 square miles.

The area which drains directly into San Francisco River north of Clifton possesses divers topographic features. The well-graded river, which has a fall of 20 feet per mile, emerges from the older rocks at Clifton, where it has carved picturesque cliffs from the lavas underlying the gravel terraces of the Gila formation. For a few miles above Clifton it flows in a canyon about a thousand feet deep, with moderate slopes, which occasionally break into precipitous bluffs of limestone or granite. Above this point the canyon may be said to be a double one. The tortuous river course is adjoined by steep lava bluffs from 500 to 700 feet high, beyond which is a gentler slope that gradually leads up to the high, black lava peaks on the east side. On the west side this gradual ascent leads up to precipitous, dark-red, granite bluffs, 1500 to 2000 feet high, in places flat-topped, which are surmounted on the south by the great masses of Markeen and Copper King mountains, rising 3300 feet above the river, and on the north by the lava peaks of Malpais, all of which form part of the divide between Chase Creek and San Francisco River. The canyon of the latter stream is not the result of a single and simple period of erosion, but is rather the consequence of orographic movements and at least two periods of erosion.

The canyon of Eagle Creek is cut in volcanic rocks except where it intersects the narrow granite ridge of Coronado Mountain. The northern part of this canyon is rather open, but at the point where it passes through the rhyolite tuff south of the pump station its walls form almost perpendicular and very picturesque bluffs about 500 feet high.

Drainage.—Three main lines of drainage, converging southward, intersect the quadrangle from north to south. San Francisco River lies on the east side, Eagle Creek occupies a corresponding position on the west side, and Chase Creek, a tributary of San Francisco River, flows through the central part. A transverse drainage by secondary watercourses, trending chiefly southeast or southwest, is fairly distinct in the southern half of the quadrangle, but westward- and eastward-draining creeks are strongly developed in the northern part, heading in a high divide between San Francisco River and Eagle Creek.

The principal stream of the region is San Francisco River, which heads in New Mexico, about 100 miles farther north, among the Mogollon, Tularosa, Datil, and San Francisco ranges, and joins the Gila 12 miles below Clifton, Ariz. About 40 miles north of Clifton it receives an important tributary called Blue River, which heads among the basaltic plateaus of the Prieto Range in Arizona. There are few other tributaries of importance, the principal one being Chase Creek, which heads among the high lava peaks 12 miles north-northwest of Clifton. It carries permanent water from Garfield Gulch to below the Longfellow incline; beyond that place the water which it contains is derived from the concentrating works at Morenci.

Along the bold scarp of Copper King Ridge the river receives only a few gulches as tributaries, but Sardine Creek, 9 miles long, flowing in a canyon 1500 feet deep in the northeastern part of the quadrangle, joins it just east of the boundary. The upper course of this creek contains permanent water of excellent quality.

The next important stream of the region is Eagle Creek, which joins the Gila a few miles below the mouth of the San Francisco. Eagle Creek flows southward and southeastward and is about 40 miles long, its source being among the basaltic mountains of the Prieto Plateau. Like the San Francisco, it is bordered by narrow bottom lands along nearly its whole southerly course, and it flows in a canyon deeply incised in the volcanic rocks. It is a permanent stream and, like the San Francisco, is subject to sudden freshets, during which the volume of the water is for a short time amazingly increased. The tributaries from both sides are merely dry gulches which carry water only during times of heavy precipitation. In the northern part of the quadrangle it receives Tule and Whitewater creeks from the east, which head at the divide between Eagle Creek and San Francisco River and which contain a few small perennial springs in their upper courses.

Climate and vegetation.—The climate, like that of southern Arizona in general, is arid, and this is clearly shown by the character of the vegetation. The temperature in the low valleys, with elevations of about 3500 feet, frequently rises above 100° F. in the summer, and snow rarely remains on the ground in the winter, although hard frosts are of common occurrence. At the elevation of Morenci, 4800 feet, the summers are cooler and light snow may remain on the ground for a few days. In the mountains, at elevations of from 6000 to 8000 feet, the summers are delightfully cool, and a few feet of snow may remain for several weeks during the winter. Of the total precipitation, which for elevations of 5000 feet probably averages 12 to 15 inches, a part falls in July and August and the remainder usually in the autumn or winter. The rainstorms are often violent and are apt to produce destructive freshets in San Francisco River and Eagle Creek. After the heavy showers in earliest spring or late summer the hills are for a brief period covered with verdure and flowers.

The lower foothills are for the most part practically barren, bearing only a few desert bushes and cactus plants. In many places, however, the thorny, long-stemmed bush known as *Fouquiera splendens* grows thickly. During the spring months the bare stems of this bush are covered with brilliant scarlet flowers. Up to elevations of 6000 feet the ridges generally support no arboreal growth, although a number of species of agave, yucca, and low cactus, not common on the lower plains, are found on them. Above 6000 feet, in sheltered locations, stunted trees of juniper and cedar are fairly common, and are extensively used as firewood. A growth of manzanita bushes and stunted oak is also found on the higher slopes.

Groves of such vegetation cover the upper part of the slopes of Coronado, Copper King, and Malpais mountains, as well as areas at corresponding elevations all over the northern part of the quadrangle, but they are being rapidly removed by woodcutters, whether on the public domain or not.

Yellow pine begins to appear at the highest elevations, and several square miles about the headwaters of Whitewater Creek, Pigeon Creek, HL Canyon, and Sardine Creek are covered with merchantable timber of this kind, the trees often reaching a diameter of 2 or 3 feet. For many years sawmills have been actively at work here, and the best lumber is cut out.

Along the principal rivers and creeks the cottonwood trees grow to imposing size, and their bright-green foliage contrasts strongly with the dull brown of the lava cliffs usually lining the stream beds. Fairly large live oaks occupy the broad washes in some localities, as in the middle part of Horseshoe Gulch, southwest of Coronado Mountain.

Culture.—The population of the Clifton quadrangle is almost wholly, directly or indirectly, dependent on the copper-mining industry. There are three towns—Clifton, Morenci, and Metcalf. Clifton is picturesquely but inconveniently situated along the narrow bottom lands of San Francisco River and Chase Creek, at an elevation of 3500 feet. The railroad terminus and the large smelting plants of the Arizona Copper Company and the Shannon Copper Company are located here, and the population numbers several thousand. Morenci lies at an elevation of 4800 feet, at the head of Morenci Canyon. The principal mines of the Detroit and Arizona companies, concentrating plants of both, and smelting works of the former are found in its immediate vicinity. The population of Morenci probably exceeds 6000. Here also the situation is inconvenient and access to the town is difficult, for the slopes are so steep that streets are largely dispensed with and the necessary supplies are carried to the houses by packing on horses or burros. Metcalf, situated on Chase Creek at an elevation of 4400 feet, is a smaller settlement where the mines of the Shannon Company and some of those belonging to the Arizona Copper Company are located. The majority of the population in these three mining towns are laborers of Mexican nationality or Mexican descent.

The Arizona and New Mexico Railroad connects Clifton with Lordsburg, on the main Southern Pacific line, in New Mexico. The Morenci Southern Railroad, a narrow-gage line, connects Morenci with a station on the former road on Gila River. The four complete loops in the last mile of this road near Morenci form a remarkable feature in railroad construction. Finally a local railroad belonging to the Arizona Copper Company extends from Clifton to Metcalf along Chase Creek.

The wagon roads are few. One follows San Francisco River upstream from Clifton and forms the means of communication with the ranches on the upper river. Another extends from Metcalf to Pigeon Creek, and was built chiefly for the convenience of the sawmills of that vicinity. There is no wagon road between Clifton and Metcalf or between Morenci and Metcalf, but a good road connects Clifton with Morenci.

Little remains to be said about the population outside of these towns. There are scattered settlements of miners at Coronado, Copper King Mountain, Garfield Gulch, and other places. A few ranches are located along San Francisco River above Clifton and at some places successful attempts have been made to raise fruit, including peaches. The climate is too cold for citrus trees. Along the narrow bottom lands of Eagle Creek Mexicans have located and are engaged in truck growing by irrigation on a small scale.

A sawmill was in operation on Pigeon Creek in 1902, and camps of woodcutters are frequently found in places where the juniper grows large enough for firewood. Small herds of cattle browse over the hills along Eagle Creek and San Francisco River, but the range appears overstocked. There is no cattle ranch of importance within the quadrangle. The breeding of goats is attempted in a few places with fair success.

GENERAL GEOLOGY.

Preliminary statement.—The oldest rocks of the Clifton quadrangle are pre-Cambrian granite and quartzitic schists, separated by an important unconformity from the covering Paleozoic strata. The latter comprise a total thickness of 1500 feet. At the base lie 200 feet of probably Cambrian quartzitic sandstone, succeeded by 200 to 400 feet of Ordovician limestones. About 100 feet of Devonian (?) shale and argillaceous limestones cover the Ordovician beds, and the uppermost part of the Paleozoic sediments consists of heavy-bedded limestones of Carboniferous age, with a thickness of 500 feet.

The Paleozoic strata are overlain in certain areas by Cretaceous shales and sandstones that have a thickness of several hundred feet, and are at least in part equivalent to the Benton group. A second unconformity, much less pronounced than the first, exists between the Paleozoic and the Cretaceous.

Great masses of granitic and dioritic porphyries were intruded in the older rocks after the deposition of the Cretaceous series, and form stocks, dikes, laccoliths, and sheets.

All of the above-mentioned rocks have participated in an uplift and a warping or doming succeeded by faulting. The effects of vigorous faulting are especially striking. These movements took place during latest Cretaceous or earliest Tertiary time.

During the Tertiary age enormous masses of lavas—basalt and rhyolite, with some andesite—covered all the rocks described above. These lavas now form a broad frame inclosing the comparatively little-exposed older rocks in the center. Tertiary sediments are not known in the quadrangle.

Erosion has sculptured the rock masses of the quadrangle since early Tertiary time, and a part of the removed detritus—that carried away by the streams during Quaternary time—still lies spread out at the foot of the mountains as coarse and roughly bedded deposits—the Gila conglomerate. A change of level during later Quaternary time increased the erosive power of the streams and forced them to cut through the Gila conglomerate in box-like canyons a few hundred feet in depth, in which the waters now flow over sandy beds along well-graded river courses.

DESCRIPTION OF THE ROCKS.

Pre-Cambrian Rocks.

The old basement upon which the Paleozoic and later sedimentary systems have been deposited and through which the much later intrusions of porphyry and overflows of basalt and rhyolite have forced their way will first be described. Although the Cambrian system has not been proved to exist in this region by full paleontological evidence, there can be little doubt that the Coronado quartzite represents the Cambrian period, and it is certain that its base marks the most prominent unconformity in the early geological history of this vicinity. The pre-Cambrian basement consists chiefly of granitic rocks, but to a smaller extent also of schists.

PINAL SCHIST.

Name.—In the Globe and Bisbee folios the name Pinal schist is applied to the fundamental crystalline metamorphic rocks of the Pinal Range and the Mule Mountains. These are shown to consist chiefly of quartz-sericite-schist of sedimentary origin and to be separated from the oldest Paleozoic strata by a profound unconformity. Although Clifton is 80 miles east of the Pinal Range and 130 miles north of Bisbee, the similarity in geological relations and lithological character of certain schists of the Clifton quadrangle to those referred to above is so great that the application of the name Pinal schist to them appears fully justified.

Distribution.—The Pinal schist outcrops in two distinct areas in this quadrangle, separated by a high basaltic ridge. The larger area, which occupies scarcely 2 square miles, is situated at the heads of Chase Creek and the south branch of Sardine Creek. Its principal features are two high, precipitous bluffs of dark brownish-red color. The northern and larger of the bluffs rises to a height of 1000 feet and is covered with quartzite and limestone. The second area forms a narrow strip exposed by erosion in the main fork of Sardine Creek for a distance of 1 mile.

Character.—The Pinal schist is usually reddish or reddish brown, not differing greatly in color from the Cambrian quartzite. The cleavage is usually imperfect, but in Sardine Creek fissile varieties occur, with a satiny luster on the surfaces. Its texture is ordinarily so fine that the individual grains are rarely recognizable by the naked eye. Under the microscope it proves to consist of an interlocking aggregate of quartz containing many small foils of sericite with an orientation parallel to the schistosity.

Smaller and ill-defined masses of amphibolitic rocks occur subordinately in the prevailing quartzitic schist. Several of these were noted in Sardine Creek. The microscope shows them to be greatly pressed and to consist of a felted mass of amphibole needles with a little zoisite and a few feldspar grains. They are probably pre-Cambrian intrusives of dioritic character, very much altered by metamorphic processes.

Structure.—The schistosity of the Pinal formation varies so capriciously in strike and dip that it has not been possible to unravel its structure. Moreover, many sets of joint planes appear in the bluffs at the head of Chase Creek and greatly complicate the structure. Planes of sedimentation are shown in places, but the thickness of the beds can not be deciphered with certainty.

In Sardine Creek the schistosity strikes east-west and dips about 70° S. The same strike and a dip of 55° S. were noted in the deep canyon at the south end of the main schist area, but close by are heavy benches, probably indicating stratification, which dip 32° NE. At the lower end of the same canyon closely spaced sheets standing nearly vertical and striking north-northwest were observed. The two principal bluffs referred to above show a very marked structure. Heavy benches of quartzite striking northeast stand nearly vertical or are slightly curved, dipping north or south at steep angles. In all probability they represent stratification, and if so the beds must have a thickness of at least 2000 feet. At the head of Sardine Creek a banding occurs with a strike of N. 31° E. and a dip of 55° SE. This probably also represents stratification.

Intrusives.—The foot of the bluff at the contact with the basalt marks an important fault, bringing the Carboniferous down at least 1000 feet. Near this line an irregular mass of granite is contained in the schist, although its intrusive origin is not clearly proved. In the various branches of Sardine Creek some aplitic rocks and small dikes of pegmatite appear near the eastern limit of the schist area. The quartz-sericite-schists of the Pinal formation were undoubtedly once quartzose sandstones and have been greatly altered by regional metamorphism.

Age.—In the absence of more detailed studies of the fundamental rocks of Arizona, it will be best to simply designate the Pinal schists as pre-Cambrian. The profound unconformity between them and the Cambrian quartzite marks a most important break in the geological history of the region.

GRANITE.

Occurrence and distribution.—A normal granite, consisting of orthoclase, albite, quartz, and biotite, generally underlies the Paleozoic sedimentary series. The orthoclase prevails over the other constituents and may be so abundant as to cause transitions to quartz-syenites and even syenites.

Broadly speaking, the granite exposed by the erosion of the Paleozoic rocks forms an irregular belt several miles wide, extending diagonally across the quadrangle between the sunken limestone blocks of the southern foothills and the heavy lava flows of the northern mountains. There are two prominent dome-shaped masses, rising to elevations of 7000 feet, separated by the deep trench of Chase Creek and scarred by many deep ravines. Coronado Mountain forms the western dome, while the complex of Markeen and Copper King rises between San Francisco River and Chase Creek.

Several smaller areas of granite are inclosed between the faulted blocks northwest of Morenci; the Copper King granite extends across Chase Creek and follows the margin of the foothills for several miles south of Morenci; and a smaller detached area outcrops a couple of miles southeast of Clifton between the Gila conglomerate and the Coronado quartzite. The boundaries of the areas are formed by the covering or intruding later formations, which may consist of Cambrian quartzite, irruptive porphyries, Tertiary lavas, or Quaternary gravels; or again by fault lines which may bring any one of the formations present in the area in contact with the granite.

The prevailing color of the granite is red, ranging from a yellowish red to deep brownish-red tones, all due to the finely disseminated ferric oxide so common in the orthoclase. The outcrops are large and rounded, but do not exhibit, except locally, a very marked "woolsack structure." In places where erosion has not acted with unusual vigor the surface is covered by a thin layer of coarse sand due to disintegration. The steep slopes of ravines and fault scarps, especially those on the west side of Chase Creek above Metcalf, show a prominent sheeting or jointing, the joints usually having a northeast to north direction and standing almost vertically, separating the rock into thick benches.

The weathering on Copper King Mountain is of a similar character, the gentle sandy slopes contrasting with the imposing dark-red cliffs facing San Francisco River. Irregular joint planes divide the outcrops into angular blocks.

The granite of Chase Creek between Morenci and Metcalf is altered by quartz cementation and pyritic impregnation; oxidation has given it specially bright red and yellow colors, while the outcrops are extremely rough and irregular, with pinnacles and deep recesses. Fresh granite is obtainable only at points of intense erosion or where mining operations have penetrated the decomposed surface. The coarse-grained character remains constant over the whole area.

Petrography.—The typical granite as shown, for instance, at Sycamore Gulch, near the Poland prospect, is a reddish-brown, coarse-grained rock, consisting of reddish, only occasionally light-green, feldspar grains, averaging perhaps 5 mm. in diameter, light-gray quartz in smaller grains often intergrown with the feldspar, and a small amount of black biotite in inconspicuous aggregates; occasionally a grain or two of hornblende is present, but never, so far as known, any muscovite. The ferromagnesian silicates are rarely seen in specimens from the surface, having been decomposed to dull grayish or greenish secondary minerals.

In thin section the large grains of orthoclase are most prominent. Microperthite is also very common, occurring in intergrowth with orthoclase. A few grains of plagioclase with narrow striation were noted in some specimens. They are greatly sericitized, making determination difficult, but appear to be albite. Quartz abounding in fluid inclusions is always present, but often as small grains and in micropegmatitic intergrowth with orthoclase or perthite. Magnetite and zircon are accessories. The structure of the rock is normally granitic. In nearly all specimens from near the surface the feldspars are clouded by kaolin and sericite, while the biotite is entirely converted to sericite and chlorite. Occasional modifications occur, but are seldom conspicuous. As mentioned above, the orthoclase may locally increase, changing the rock to a quartz-syenite. Hornblende may increase, as shown in the cuts of the Coronado Railroad, 850 feet above the place where the wagon road leaves Chase Creek and ascends the hill toward Morenci. This rock is a normal granular aggregate of orthoclase, microperthite, and quartz, probably also a little individual albite with rather abundant prisms and grains of green hornblende and a considerable amount of magnetite or ilmenite. The quartz is present in only moderate quantity, and partly in granophyric intergrowth with the feldspars. Sericite, chlorite, epidote, and pyrite have developed as secondary minerals.

Local modifications of still more basic character are very uncommon, the only one observed being in the bottom of a gulch 2 miles south of the point where the Coronado vein crosses the ridge summit. The granite here contains a small mass consisting chiefly of hornblende, soda-lime feldspar, and grains of magnetite or ilmenite.

Dikes.—Dikes of coarse pegmatite are almost wholly absent, but in many places appear irregular masses or well-defined dikes of granitic aplite, a medium-grained rock identical in composition with the normal granite, but of a more even-grained, "sugary" texture. These aplitic dikes are genetically connected with the granite and have not been separated from it on the map. Dikes of rhyolite, basalt, or various intrusive porphyries are abundant in places and are described under their proper headings.

Origin.—The intrusive character of the granite is inferred, no direct proof being available in this quadrangle. There are strong reasons, however, for believing that the Pinal schist is the older of the two pre-Cambrian terranes and that the granite is intruded into it. The contacts between the two are poorly exposed, but the irregular mass of granite projecting into the schist at the foot of the bluff near the head of Chase Creek and the dike-like bodies of aplite and small masses of pegmatite a mile farther north form strong points in favor of that view.

Paleozoic Sedimentary Rocks.

General statement.—Above the granite lies a thickness of about 1500 feet of Paleozoic stratified rocks, comprising the Cambrian, Ordovician, Devonian (?), and Carboniferous systems. They have been subdivided into the following formations:

Coronado quartzite (probably Cambrian).
Longfellow formation (Ordovician).
Morenci formation (probably Devonian).
Modoc limestone (Mississippian, or Lower Carboniferous).
Tule Spring limestone (Mississippian and Pennsylvanian, or Lower and Upper Carboniferous).

While the first four formations are generally distributed wherever the Paleozoic strata occur, the Tule Spring limestone, which contains the Upper Carboniferous, is found only in the northern part of the Clifton quadrangle. There is no known unconformity in the whole Paleozoic column, though by no means all the subdivisions of the systems have been shown to be present.

Compared to other places in Arizona the thickness of the Paleozoic column is slight. In the Globe quadrangle 1700 feet of Paleozoic strata have been measured, and in the Bisbee quadrangle over 5000 feet.

CAMBRIAN (?) SYSTEM.

CORONADO QUARTZITE.

General character and distribution.—Resting immediately on the granite basement, the Coronado quartzite has a wide distribution and is everywhere easily recognized. It consists chiefly of heavy beds of brown, pink, or maroon quartzitic sandstones. Its lowest member is a quartzite conglomerate up to 50 feet thick, but this is missing in many sections. Several smaller areas of this formation conspicuously crown the summit and western slope of Coronado Mountain. The largest area, covering several square miles, lies a thousand feet lower, on the south side of the great Coronado fault fissure, and forms a fault block broken by many minor dislocations, but on the whole dipping gently westward. Minor patches cover the granite in the upper Chase Creek Valley, or are bounded by short fault planes, and similar areas cap the granite bluffs farther east, overlooking San Francisco River. At lower elevations a continuous band of this formation begins near the Longfellow incline, on the west side of Chase Creek Canyon, and after following the canyon for about 2 miles swings southwest with the foothills facing the gravel plains of the Gila conglomerate and continues to a point 3 miles south of Morenci. A few exposures of the formation resting on granite are found also on the east side of San Francisco River.

In many places erosion has left only a thin cover of quartzite upon the granite. Where the whole thickness of the formation remains, as near Morenci, it attains a maximum of 250 feet, but this is not maintained at all exposures; near the mouth of Apache Gulch, due south of Morenci, only from 100 to 150 feet are exposed. The basal conglomerate, consisting of a maximum of 50 feet of well-washed quartzitic cobbles, cemented by granitic sand and gradually changing into sandy beds, is exposed at the bluff forming the summit of Coronado Mountain and at many other localities, but is not a universal feature. At the foot of the Longfellow incline it is only 2 feet thick.

Near the mouth of Apache Gulch, south of Morenci, the conglomerate is lacking, sandstones resting directly on the granite.

In the great fault block covering the western slope of the ridge south of the Coronado mine clearly defined stratification planes are often wanting; the basal conglomerate is occasionally present in slight development, while as frequently it is missing. In such cases the exact line of demarcation between granite and detrital rock may be difficult to perceive; the underlying granite appears disintegrated, bearing evidence of pre-Cambrian weathering. Thin strata of olive-colored shale were observed in a few places near the top of the formation—for instance, on the summit of Coronado Mountain and in the gulch just south of the Longfellow incline on Chase Creek.

Two miles southwest of Morenci the following section was observed:

Geological section of Coronado quartzite 2 miles southwest of Morenci.

	Feet.
White quartzitic sandstone	50
Banded pink and maroon quartzitic sandstone, forming precipitous bluff	162
Conglomerate with quartzite pebbles	10
Sandstone	3
Conglomerate with quartzite pebbles	8
Coarse sandstone	10
Granite.	
Total	243

Petrography.—The rock is usually thick bedded, though sometimes delicately banded in detail, and shows various colors from light pink to darkest maroon; the distinguishing color of the outcrops is dark brown. Properly speaking, it is a hard quartzitic sandstone of varying grain, most commonly, however, showing grains averaging 1 mm. Near the base are intercalated beds of coarser grain which at many places change into coarse conglomerates. The clastic grains almost universally consist of light-gray granitic quartz, are generally rounded, and contain abundant fluid inclusions. Grains of sericitized orthoclase are occasionally found, but no other rocks are represented. The cement consists chiefly of sericitic particles, mixed with fine granitic detritus. The whole indicates very clearly derivation by slow processes from a disintegrating granite, the feldspar of which has had ample time to become converted into sericite and kaolin.

In a few places near Morenci this quartzite carries pyrite and chalcocite, developed metasomatically by secondary processes, in both quartz grains and cement, and is mined as ore.

The conglomerate consists exclusively of well-washed cobbles and pebbles of a hard quartzite or quartzitic schist; neither granite nor aplite was found in it at any of the numerous places at which it was examined. The pebbles are undoubtedly derived from the pre-Cambrian quartzite referred to as Pinal schist, large outcrops of which occur in the northern part of the quadrangle. The absence of granite fragments affords still further evidence of the deep pre-Cambrian disintegration of the granite.

Conditions of deposition.—While the even bedding of the body of the Coronado formation shows deposition in a large body of water, and while the marine origin of the top strata is proved by the occurrence of fossil shells, it seems probable that the lowest conglomerate is a fluviatile deposit gradually merging into a marine formation. Its very irregular occurrence and thickness, as well as the disintegration of the underlying granite, seems to tend to this conclusion. The pre-Cambrian land surface was evidently of gentle outline except for some projecting masses of old quartzites and schists. The present surface of contact between the granite and the Coronado formation is greatly modified by warping and dislocation.

Age and correlation.—The determination of the Coronado formation as Cambrian is largely circumstantial, being based chiefly on its well-defined position as a distinct division of quartzose sediments below Ordovician limestone and above an unconformity of the first importance. The only fossils thus far found in this formation were discovered by Mr. Boutwell in olive shales 25 feet below the top of the quartzite, in a section just south of the Longfellow incline in Chase Creek. They consist of small lingula-shaped shells determined by Mr. C. D. Walcott as a lingulella similar to those found in the middle Cambrian of the section in the Grand Canyon of the Colorado. The species could not be identified.

The quartzites at the base of the Paleozoic section have a very wide distribution in Arizona. Mr. E. T. Dumble (Trans. Am. Inst. Min. Eng., vol. 31, p. 14) describes such quartzites from the Dragoon, Whetstone, Chiricahua, and Mule mountains, and refers to them as the Dragoon quartzites. A similar but much thicker and more variable group of formations is mapped on the Globe quadrangle as the Apache group. The equivalent formation on the Bisbee quadrangle is referred to as the Bolsa quartzites and has a thickness of 500 feet. No fossils have been found at either of these localities.

ORDOVICIAN SYSTEM.

LONGFELLOW FORMATION.

General character and distribution.—Under this formation name are grouped from 200 to 400 feet of strata conformably overlying the Cambrian Coronado quartzite and consisting of limestones that are usually more or less dolomitic and gradually grow more siliceous near their lower limit. The upper 150 feet always form a prominent bluff of brownish limestone, while the lower 250 feet contain more shaly strata, usually forming a more gentle slope leading down to the steep quartzite bluff underneath.

The formation is extensively developed in the southern marginal mountain region. Bluffs of it line San Francisco River for about 2 miles north of Clifton, the areas forming deeply faulted blocks at the foot of Copper King Mountain. An area aggregating a few square miles is exposed east and south of Morenci, and here again the formation constitutes a series of faulted blocks. Another block, about 1 square mile in area, lies north of Gold Creek on the slope toward Eagle Creek. Many smaller detached masses occur in the northern part of the quadrangle near the line where the older formations dip below the great lava flows.

Detailed sections.—One of the type localities examined is on the west side of Chase Creek Canyon. The best section obtained runs northeast from the high limestone point one-fourth mile south of Modoc Mountain, the beds being well exposed below the Carboniferous and Devonian along the steep slope of the canyon.

Geological section of Longfellow limestone in Chase Creek Canyon one-fourth mile south of Modoc Peak.

	Feet.
Buff limestone	15
Quartzitic sandstone	10
Bluff of brownish-gray cherty limestone	140
Shaly limestone	90
Coarse gray sandstone	10
Sandy and shaly limestone (base)	115
Total	380

The section given below begins at the top of the bluff which overlooks Chase Creek $1\frac{3}{4}$ miles southeast of Morenci, but here the upper part of this formation is not fully represented.

Geological section of Longfellow limestone $1\frac{3}{4}$ miles southeast of Morenci.

	Feet.
Buff limestone	8
Bluffs of brownish cherty limestone	110
White sandstone with cross-bedding	15
Calcareous shales, lead gray to maroon or yellowish gray in color	75
Total	208

A part of the lower shales is probably displaced by an intrusion of porphyry which here separates the Longfellow limestone from the Coronado quartzite.

The section at Square Butte, 2 miles southeast of Morenci, is more complete:

Geological section of Longfellow limestone at Square Butte, 2 miles southeast of Morenci.

	Feet.
Brownish bluffs of limestone with cherty bands	200
Brown limestone with bands of quartzite	50
Sandy limestone with some thin strata of quartzite; near bottom thin strata of shale	150
Total	400

Near Garfield Gulch, 2 miles north of Metcalf, in Chase Creek Canyon, the series, of which the whole thickness seems to be present, amounts to only 140 feet. The upper part consists of heavy brown limestone, the middle of gray sandy limestone, and the lower division of lime shales.

At the small isolated limestone mass of Shannon Mountain, near Metcalf, 200 to 250 feet of dolomitic limestone were measured lying between the Morenci shales and the Coronado quartzite. The color is yellowish brown, the upper part being heavy bedded and the lower more shaly.

The most northerly exposures are at the head of Chase Creek and Whitewater Creek and in the lower canyon of Sardine Creek. The thickness is here from 200 to 300 feet and the formation preserves the same general character, the upper part being formed of a high bluff of brownish cherty limestone and the lower part of impure and shaly maroon limestones, with some beds of brown sandstone, forming a gentler slope.

Petrography and analyses.—A typical specimen of the cherty limestone shows that it is composed chiefly of coarsely crystalline calcite in irregular grains, with but little dolomite; few of the rocks thus far examined consist of typical dolomite, but certain irregularly distributed strata of the formation contain a considerable amount of magnesia. The rock contains many small quartz grains, probably largely of clastic origin. The chert occurs in irregular bands or nodules which, under the microscope, appear as an aggregate of greatly varying grain, some of it consisting of irregular quartz grains, while other parts contain much cryptocrystalline and fibrous chalcedonic material. Ragged calcite grains lie embedded in this mass, giving distinct evidence of the metasomatic origin of the chert from siliceous waters by replacement of calcite. The normal rocks contain no pyrite or other sulphides. The Longfellow limestone is, as a rule, too siliceous to be used for quicklime or smelting flux. A number of partial analyses made of it at Morenci in the laboratory of the Detroit Copper Company show that it contains from 55 to 91 per cent of calcium carbonate and 0.5 to 35 per cent of magnesium carbonate, the latter figure being very exceptional. From 5.4 to 27.6 per cent of silica is present. The increase of this constituent toward the base of the formation is very noticeable.

The Longfellow limestones exposed on Shannon Mountain are largely metamorphosed; many of them would seem to be somewhat dolomitic in composition. An analysis made for the Shannon Copper Company of a hard, blue, fine-grained limestone from the Black Hawk tunnel 30 feet above the top of the Coronado quartzite runs as follows:

Analysis of limestone from Black Hawk tunnel.

	Per cent.
$CaCO_3$	39.2
$MgCO_3$	22.9
SiO_2	27.0
Fe_2O_3	8.3
Al_2O_3	3.0

It is probable, however, that the specimen analyzed contained some pyroxene and epidote, due to metamorphic processes.

Age and correlation.—Fossils are very scarce throughout the Longfellow limestone. In the lower, shaly part, the only occurrence of fossils thus far found is in the section $1\frac{3}{4}$ miles southeast of Morenci, where, 20 feet above the top of the quartzites, a few small lingulas were found, together with crinoidal remains. Mr. C. D. Walcott states that, while no very certain determination of age can be based on them, they probably indicate the uppermost part of the Cambrian; there is thus a possibility that a part of the Longfellow formation may be of Cambrian age. The best fossils were found in a layer of yellowish-gray shaly limestone at the top of the same section and consist of gasteropods and fragments of trilobites, the latter in part very large. A similar fauna was found one-half mile farther northwest on the same ridge, in the same stratigraphical position, and also in a gulch one-quarter mile northeast of Newtown, in the same vicinity.

The fossils were submitted to Mr. E. O. Ulrich, who states that they are on the whole so poorly preserved and incomplete that specific identification is difficult. Still the general aspect of the collections and, in particular, the "association" of generic types leave no doubt concerning the age indicated by the fossils.

The four lots all indicate practically the same time interval (it is not unlikely that they are all derived from the same bed), which the evidence in hand warrants placing in the Beekmantown age (early Ordovician).

All four lots contain a species of *Raphistomina* or of some related gasteropod genus, an *Ophileta*, a *Dalmanella* similar to *D. hamburgensis* Walcott, a species of *Camarella* or *Syntrophia*, a new type of Cephalopoda near *Endoceras*, an early type of *Asaphus*, a small *Dikellocephalus* (?), and a larger trilobite related to *Bolbocephalus*.

Four miles west of Morenci, on the slope toward Eagle Creek, is a large area of the upper part of Longfellow limestone. Flat gasteropods similar to *Raphistomina* were observed in the center of this area and near the principal trail crossing it.

So far as known this is the first discovery of the occurrence of the Ordovician system in Arizona. No rocks indicating this age have been found in the Globe or the Bisbee district; in both places, apparently, Devonian limestones directly overlie the Cambrian rocks.

A broad belt, in which the Ordovician strata are abundantly developed, is found in western Nevada, extending from the vicinity of Eureka down to within 40 miles of the great bend of Colorado River and the Arizona line.

The distribution of the system within this area is discussed in the reports on the explorations along the fortieth parallel,in the monographs by Hague and Walcott on the Eureka district, and in a recent bulletin by Mr. J. E. Spurr (Bull. U. S. Geol. Survey No. 208). The point nearest to Clifton in this belt is about 300 miles distant in a westerly direction. Along the Grand Canyon of the Colorado River the Ordovician is not thus far known; neither does it occur in southwestern Colorado. On the other hand, Mr. G. B. Richardson has recently found the system strongly developed at El Paso and other places in western Texas. North of this point it is known to occur in eastern Colorado, as, for instance, in the Pikes Peak quadrangle. Mr. Ellis Clark (Trans. Am. Inst. Min. Eng., vol. 34, 1894, p. 138) reports its presence, possibly together with Silurian, at the Lake Valley silver mines, in the southern-central part of New Mexico, and more careful search will probably show its presence at many other points in that Territory.

DEVONIAN SYSTEM.

MORENCI FORMATION.

General character and distribution.—Between the Modoc limestone of the Carboniferous and the Longfellow formation of the Ordovician there is conformably intercalated a group of strata which have been tentatively referred to the Devonian system. The rocks consist of about 100 feet of clay shales underlain by 75 feet of compact and fine-grained argillaceous limestone; this lower part is, however, missing in some parts of the Clifton quadrangle, and as it can not conveniently be mapped separately it has been grouped with the shales into one formation.

Though not occupying large surface areas, the Morenci formation is ordinarily present wherever the compassing formations occur, as on San Francisco River north of Clifton, in the vicinity of Morenci, near Garfield Gulch, and in the lower part of Sardine Creek. It usually forms a gentler slope between the bluffs of Modoc and Longfellow limestone.

In the most northern Paleozoic areas, southeast of Grey Peak and about Granville, this formation has not been observed in its customary place, although it appears with a thickness of 75 or 100 feet in the areas 2 miles north of Coronado Mountain and at the head of the south fork of Sardine Creek.

Petrography and analyses.—The clay shale is a fissile black rock, fairly hard when fresh but crumbling easily and softening on exposure. The weathered outcrops are light gray to reddish in color. Under the microscope it shows the usual cryptocrystalline aggregate of clay shales, occasionally with minute greenish flakes and fibers, probably consisting of glauconite. Small cubes of pyrite occur sparingly. Calcium carbonate is often entirely absent. A slightly hardened but otherwise typical rock taken 40 feet east of the big dike crossing the trail from Newtown to the top of the Longfellow incline, near Morenci, gave the composition shown by the accompanying analysis.

The analysis indicates a fairly typical clay shale, the high percentage of K_2O being characteristic of many of these rocks. Less common is the large amount of CaO, which evidently is not present as carbonate, but as some silicate. The rock is somewhat hardened by the adjacent intrusive mass and slight changes may have taken place, transforming some carbonates to amphiboles. The copper and zinc present in minute quantities are also believed to be derived from the intrusive rock; at least, the clay shale far away from the porphyries never shows the presence of copper in weathered outcrops where a small quantity of that metal might easily be visible as green carbonates. In the section near Morenci, one-fourth mile south of Modoc Mountain, the shale contains near its top strata a dark-gray fine-grained dolomite, weathering yellowish red.

The limestone underlying the shales appears in most typical form at Morenci, while north of Metcalf a corresponding member could not be found.

Analysis of clay shale from the Morenci formation near Morenci.

[W. F. Hillebrand, analyst.]

	Per cent.
SiO_2	61.25
Al_2O_3	15.60
Fe_2O_3	1.35
FeO	3.04
MgO	4.16
CaO	3.40
Na_2O	.44
K_2O	6.74
$H_2O-100°$	.62
$H_2O+100°$	2.09
TiO_2	.66
CO_2	None.
P_2O_5	.08
SO_3	None.
MnO (partly MnO_2)	.07
BaO	Faint trace.
SrO	None.
Li_2O	Trace.
FeS_2	.25
$CuFeS_2$	.03
ZnO	.03
Total	99.81

This limestone, about 75 feet thick, is nearly black when fresh, extremely fine grained, and breaks under the hammer with a ringing sound into shelly fragments. The outcrops are well stratified in thin benches which appear peculiarly pitted by weathering and have a bluish-gray color, altering on oxidation to a yellowish tone. In thin sections the rock is very fine grained, consisting chiefly of calcite, though some small rhombohedrons of dolomite are present. Minute cubes of pyrite are scattered through the mass.

A specimen from the lower part of this member, taken opposite the smelter of the Detroit Copper Company, gave the following result:

Analysis of limestone of the Morenci formation from vicinity of Detroit smelter.

[L. R. Wallace, analyst.]

	Per cent.
SiO_2	6.4
Fe	1.5
Al_2O_3	4.2
CaO	46.8
MgO	.9
Cu	.2
S	None.

The total percentage of carbonates would be 85.4. Silica and alumina are both high, indicating admixture of clayey substance.

Age and correlation.—While no fossils have been found in the shales, the argillaceous limestone contains at many points near Morenci a scant fauna of corals and gasteropods, all of them noticeably stunted and small in development. On these Prof. H. S. Williams reports as follows:

The material presents a few fragments of fossils and is probably all from a single formation. There is very little, however, that is thoroughly diagnostic of a particular horizon. The species are:

? Zaphrentis sp	A small form.
Crinoid stems	Too imperfect to identify generically.
Loxonema sp	Not sufficient for specific definition.
? Pleurotomaria sp	
Schizophoria cf. ivanofi Tsch.	A small imperfect specimen, described below.

The specimen of *Schizophoria* approaches the *Orthis ivanofi* Tsch. type of Russia more closely than our eastern forms of *Schizophoria McFarlani*, which is quite consistent with the hypothesis that it belongs to the same fauna as that of the Devonian sent by Ransome from the Globe quadrangle.

Although the typical species of the Globe and Bisbee quadrangles Devonian are not present, the *Schizophoria* is so diagnostic of the same general fauna that I am of opinion that you will be safe in calling it Devonian, though nothing in the lot will certainly exclude it from either Silurian or Carboniferous so far as the present evidence goes. I would classify the horizon as probably Devonian, awaiting more perfect fossil evidence for a closer correlation.

A well-developed Devonian horizon has been found by Mr. F. L. Ransome at Bisbee, Ariz., consisting of 340 feet of dark-colored, compact limestones with some intercalated shales, which he names the Martin limestone. At Globe, Ariz., the same geologist has discovered 700 feet of buff and gray limestones, which he refers to the same age, but which seem to present petrographically no similarity to the Clifton-Morenci occurrence.

In the Grand Canyon section Mr. C. D. Walcott found 100 feet of Devonian strata resting with slight unconformity on the Cambrian Tonto group.

CARBONIFEROUS SYSTEM.

MODOC LIMESTONE.

General character and distribution.—The Modoc formation, which represents the Mississippian series, equivalent to the Lower Carboniferous, consists of about 170 feet of coarse blue or gray limestones, with subordinate strata of quartzite and dolomite. The gray limestone, which forms a prominent cliff, is the characteristic part of the formation.

The areas covered by the Modoc limestone are not extensive, aggregating scarcely more than 1 square mile, but the formation is of the greatest interest and importance in connection with contact-metamorphic phenomena and copper deposits. Small areas outcrop on the top of some bluffs along the river north of Clifton; others cover Modoc Mountain near Morenci and the opposite (west) side of Morenci Canyon; still others cap Shannon Mountain and several hills in the watershed of Garfield Gulch and on the divide between Chase Creek and Knight Creek.

Detailed descriptions.—The several sections studied at Morenci are practically identical. One of them extends from the summit of a high limestone point one-fourth mile south of Modoc Mountain down toward Chase Creek, forming the upper part of a complete general section from Carboniferous to Cambrian and to the granite; another extends westward from the first railroad loop below the Morenci smelter. Cretaceous strata here cap the Modoc formation. Beginning from the top the following succession is noted at these places:

Geological section of Modoc formation at Morenci.

	Feet.
1. Blue, coarse, fossiliferous limestone, in benches 2 to 3 feet thick	4–10
2. Light-gray, coarse limestone with crinoid stems, 2-foot benches, vertical joints (referred to as the "Gray Cliff" member)	75-85
3. Light grayish-brown dolomitic limestone	60
4. White or reddish calcareous quartzite forming sharply defined stratum	15–17
5. Massive bench of gray limestone (referred to as the "coralliferous limestone")	8–10
Total	162–182

On Shannon Mountain the dolomitic stratum seems to be lacking. The section observed here is as follows:

Geological section of Modoc formation on Shannon Mountain.

	Feet.
"Gray Cliff" limestone	132
Quartzite	20
"Coralliferous limestone"	10
Total	162

In the faulted limestone block just west of the mouth of Garfield Gulch, in Chase Creek Canyon above Metcalf, the brown dolomitic stratum is again absent and the formation consists simply of 150 feet of light-gray bluffy limestone, equivalent to No. 2 in the first section.

Petrography and analyses.—In contrast to the siliceous limestone of the Longfellow formation, the Modoc limestones are exceptionally pure. The top stratum in the first section consists of coarse bluish, almost pure limestone. The second stratum, the "Gray Cliff," as it may be appropriately designated, is likewise a coarse granular rock of dark-gray color on fresh fracture, but weathering in lighter-gray tints. Specimens from Morenci consist of large, irregular grains of calcite, the only other constituents noted being a few shreds of bright-red ferric oxide or hydrate. This gray limestone is extensively used as flux, being quarried at Morenci by both of the principal mining companies and on Shannon Mountain by the Shannon Copper Company. The companies interested have made many technical analyses of it, a few of which are here quoted:

Partial analyses of limestones from the Modoc formation.

	$CaCO_3$.	$MgCO_3$.	SiO_2.	Al_2O_3 and Fe_2O_3.*	Insoluble.
Limestone quarry of Arizona Copper Company at Morenci, Modoc Mountain	95.52	0.69	......	0.92	1.06
Limestone quarry of Detroit Copper Company at Morenci, near smelting plant	94.00	......	1.00	2.70	......
Limestone quarry on Shannon Mountain, near summit	82.50	9.54	1.34	1.66	......

* Mostly ferric oxide.

It will be noted that the rock from Shannon Mountain, though similar in appearance and texture to that from Morenci, contains much more magnesium carbonate.

The beds immediately underlying the "Gray Cliff" limestone consist of heavy benches of light brownish-gray limestone, weathering drab, and containing a few minute crystals of pyrite. In thin section it proves to be a fine- and even-grained dolomite.

Partial analyses of dolomite underlying pure limestone near the Morenci smelter.

[L. R. Wallace, analyst.]

	$CaCO_3$	$MgCO_3$	SiO_2	Fe_2O_3	Al_2O_3
West end of quarry.......	57.50	37.60	0.3	1.8	0.4
East end of quarry.......	56.00	36.00	1.0	2.8	
Pure dolomite............	54.35	45.65	.....	.....	.....

Bed No. 4 in the first detailed section underlying the brown dolomite is very constant near Morenci, and is also developed at many other places. The most northern locality where it has been observed is on the divide between Knight Creek and Chase Creek. It consists of a hard, quartzitic sandstone, the grains being well rounded and cemented by calcite. The basal member of the formation is a heavy bed of bluish-gray limestone which apparently does not contain much dolomite.

Age and correlation.—The Modoc limestone is fossiliferous throughout, well-preserved species being found in the top, basal, and intermediate members. The determinations by Dr. G. H. Girty show that the formation throughout belongs to the Mississippian series of the Carboniferous system—i. e., to the Lower Carboniferous. The determinations are as follows:

1. On the trail to Silver Basin, 1½ miles southeast of Morenci, from coralliferous limestone, basal member of Modoc formation:

 Rhipidomella michelini?
 Spirifer centronatus.
 Seminula humilis.

2. Section one-fourth mile south of Modoc Mountain, Morenci, from coralliferous limestone:

 Zaphrentis sp.

3. Gap 1000 feet south of Modoc Mountain, from coralliferous limestone:

 Zaphrentis sp.
 Spirifer centronatus or S. forbesi.

4. Eight hundred and fifty feet S. 18° E. from Modoc Mountain, top of "Gray Cliff" limestone, No. 2 of first detailed section:

 Orthis sp.

5. Eight hundred and fifty feet S. 18° E. from Modoc Mountain, elevation 5100 feet, heavy blue limestone, No. 1 of first detailed section:

 Lithostrotion? sp.
 Menophyllum sp.
 Favosites sp.
 Granatocrinus sp.
 Platycrinus sp.
 Fenestella sp.
 Schuchertella inæqualis?
 Spirifer near Spirifer keokuk.
 Spiriferina sp.

6. Spur 1⅝ miles south of Granville, bench of coralliferous limestone, elevation 6500 feet:

 Leptæna rhomboidalis.
 Spirifer centronatus.
 Athyris lamellosa.
 Camarotœchia metallica.

7. Gap between Chase Creek and Knight Creek, elevation 6500 feet, limestone, in part cherty:

 Schuchertella inæqualis?
 Chonetes loganensis?
 Spirifer centronatus.
 Spiriferina sp.
 Camarotœchia metallica.

As is well known, the Mississippian (Lower Carboniferous) series is extensively developed throughout the West. At Globe, Ariz., Mr. Ransome has found this series present in the upper part of the Globe limestone, while at Bisbee 700 feet of strata are referred to the same horizon under the name of the Escabrosa limestone.

TULE SPRING LIMESTONE.

Occurrence and character.—In the southern part of the quadrangle and up to latitude 33° 10′ the Modoc formation, belonging to the Mississippian series of the Carboniferous system, is the only terrane of that age known. But in the northern third of the quadrangle fossils of the Pennsylvanian (Upper Carboniferous) series have been found in several places, and faunas of the Mississippian series are also present. The rocks which here conformably cover the Devonian Morenci shales, or the Ordovician Longfellow limestone where the shales are absent, consist of at least 500 feet of heavy-bedded bluish-gray limestones which unquestionably represent both the Mississippian and the Pennsylvanian. In a general way the lower 200 feet are equivalent to the Modoc formation, although its several members recognized farther south can not be identified, and the upper 300 feet represent the Pennsylvanian. It is not possible, however, to draw a dividing line, and the whole has therefore been included in a single formation named the Tule Spring limestone, after a typical locality in the northwestern part of the quadrangle. The three principal exposures of this formation are at the head of Tule Creek, where faunas of both the Mississippian and Pennsylvanian are present; at the headwaters of Whitewater Creek and about Granville; and in the limestone bluffs on both sides of the canyon of lower Sardine Creek, in the northeastern part of the quadrangle.

The Tule Spring limestone generally forms bluffy ridges with light-colored bluish-gray exposures of heavy benches. The ridges generally slope westward with the prevailing slight dip of the beds.

The main spur of the western area on Tule Creek consists of gray cherty limestone, the siliceous brown and pink bands of which contain brachiopods and corals. The next spur, forming the divide between Tule and Whitewater creeks, shows gray to dark-gray coarse limestone, locally cherty and containing several horizons of rich faunas. At the south end of this spur the limestone overlies laminated brown sandstone, impure mottled maroon and olive limestone, and brown shales of the Longfellow formation (Ordovician). Below this and somewhat farther up the creek a small area of the Coronado quartzite outcrops.

Fossils.—The following fossils have been determined by Dr. G. H. Girty:

PENNSYLVANIAN SERIES.

1. One and one-half miles west of Grey Peak:

 Chætetes milleporaceus.
 Zaphrentis? sp.
 Productus cora.
 Marginifera wabashensis.
 Spirifer cameratus.
 Spirifer rockymontanus.
 Squamularia? perplexa.

2. Three-fourths of a mile N. 5° E. of Tule Springs, on nose of spur; elevation, 5980 feet.

 Fenestella sp.
 Schizophoria resupinoides White (non Cox).
 Orthotetes robusta?
 Aviculipecten sp.
 Pseudomonotis kansasensis?
 Myalina apachesi.
 Pleurophorus sp.
 Lepetopsis? sp.
 Bellerophon cf. crassus.
 Bulimorpha chrysalis.
 Phillipsia major?

3. One and one-tenth miles N. 6° E. of Tule Springs, west slope of knob just west of Corral Spring, 20 feet above basalt in creek bottom:

 Monilipora sp.
 Productus inflatus.
 Productus nebraskensis.
 Spirifer rockymontanus.
 Seminula subtilita.
 Dielasma hastatum.
 Aviculopecten sp.

4. On main trail from Tule Springs to Metcalf, on slope descending to Whitewater Creek, 25 feet above bottom of canyon; elevation, 5245 feet:

 Schizophoria resupinoides White (non Cox).
 Squamularia? perplexa.
 Aviculipecten sp.
 Monopteria sp.
 Myalina apachesi?
 Schizodus wheeleri?
 Pleurophorus sp.
 Phillipsia major.

5. On main trail from Tule Springs to Metcalf, at bottom of Whitewater Canyon, 500 feet east of trail:

 Schizophoria resupinoides White (non Cox).
 Productus cora.
 Aviculipecten? sp.
 Myalina apachesi.
 Pinna? peracuta.
 Edmondia sp.
 Allerisma? sp.
 Lepetopsis sp.

6. Knob 13, 1.1 miles southwest of Grey Peak:

 Fusulina sp.
 Productus cora.
 Productus inflatus.
 Spirifer cameratus.

MISSISSIPPIAN SERIES.

1. Near Cabin Mitchell's camp, three-fourths mile north of Granville:

 Menophyllum excavatum.
 Leptæna rhomboidalis.
 Rhipidomella michelini.
 Schuchertella inæqualis.
 Chonetes loganensis.
 Productus gallatinensis.
 Spirifer centronatus.
 Spirifer striatus?
 Syringothyris carteri?
 Cleiothyris sp.
 Camarotœchia metallica.

2. One-half mile N. 63° E. from Granville:

 Productella concentrica.
 Productus (several indeterminable fragments).
 Spirifer near S. striatus var. madisonensis.
 Reticularia cooperensis.

3. One and five-eighths miles N. 7° W. of Tule Springs, on north side of main ridge north of Tule Creek, 15 feet below the top:

 Zaphrentis sp.
 Cystodictya sp.
 Rhipidomella cf. michelini.
 Spirifer near S. peculiaris and S. subcardiiformis.
 Spirifer keokuk.
 Syringothyris sp.

4. One-fourth mile N. 30° W. of Tule Springs, 150 to 200 feet below top of knob:

 Schuchertella inæqualis?
 Chonetes loganensis.
 Productus lævicosta.
 Spirifer centronatus.

The determination of faunas indicates that the limestones about Granville and Mitchell's camp belong to the Mississippian series; that the western part of this main area, just north of the bend in Whitewater Creek is Pennsylvanian; that the northeast extremity of the western area, adjacent to Corral Spring, is Pennsylvanian; and that the area immediately to the south of this and north of Tule Springs is Mississippian. The present position and structure of these areas fail to show any division between the two series, nor do lithologic and stratigraphic characteristics indicate any division, although it was specially sought in the field. Accordingly, for the present at least, pending more detailed stratigraphic work, it is not practicable to divide the Mississippian and Pennsylvanian in this quadrangle.

CRETACEOUS SYSTEM.

While the Jurassic and Triassic systems are absent in this area, Cretaceous sedimentary rocks have been found in the vicinity of Morenci.

PINKARD FORMATION.

Occurrence and character.—This formation consists of a series of sandstones and shales of undetermined thickness, which, however, certainly exceeds 200 feet. The best exposures are found in Silver Basin Creek, 2 miles southwest of Morenci, and in the Eagle Creek foothills, 4 miles distant in the same direction. The gently upturned strata here surround an oval mass of diorite-porphyry, intruded in them. In the porphyry stock of Gold Creek many smaller and partly metamorphosed patches of the same strata occur. Modoc Mountain at Morenci is capped by a small area of the same strata, and a somewhat larger mass is exposed on the ridge overlooking the head of Morenci Canyon on the south and west sides; it is here again intruded and partly metamorphosed by porphyries.

The lowest part of this formation consists of black shales which occupy considerable areas in Silver Basin; the upper part is made up of alternating shales and yellowish-gray sandstone, in places calcareous. A section carried eastward from the top of the hill one-fourth mile southwest of the Morenci smelter shows the following succession, the beds here being somewhat metamorphosed:

Geological section of Cretaceous sedimentary rocks southwest of Morenci smelter.

	Feet.
Top of hill; elevation, 5140 feet.	
Reddish hard shales, containing some epidote	50
Heavy light-gray quartzitic sandstones (with some interbedded shale).....................	50
Black, fissile shales..........................	30
Banded green and yellowish-brown shales....	45
Top of Modoc limestone at the base of the series.	
Total....................................	175

On the trail to Silver Basin, 1½ miles southwest of Morenci, is an outcrop of the Morenci shales covered by a thin bench of limestone, evidently corresponding to the base of the Mississippian (the coralliferous limestone, No. 5 in detailed section). Above this lie knotty arenaceous shales of greenish-gray color and a thin layer of yellowish limestone, clearly corresponding to the base of the Pinkard formation, and overlain to the north by the shales of Silver Basin.

Thin strata of epidotized brown and greenish shales cover the summit of Modoc Mountain, overlying the uppermost stratum of the Modoc formation.

Relations.—There is evidently an unconformity between the Mississippian and the Cretaceous, for at various points near Morenci the Pinkard formation overlies various members of the Modoc formation. The same relation is also indicated by the fact that in the northern part of the quadrangle the Pennsylvanian covers the lower part of the same system conformably, while at Morenci Cretaceous strata rest directly on the Mississippian limestones. It is rather an unconformity by erosion than a profound structural break.

Age and correlation.—Fossils were found in a calcareous sandstone overlying shale in a gulch one-half mile southeast of the porphyry hill with bench mark 5175, 2½ miles south-southwest of Morenci. The elevation is here close to 4000 feet. The fossil bivalves are well preserved and some of the species are rather abundant. On this collection Dr. T. W. Stanton reports as follows:

The fossils submitted include:

 Mactra sp. related to M. warreneana M. & H.
 Corbula sp.
 Cardium sp.
 Astarte? sp.
 Cyrena? sp.
 Turritella sp.
 Dentalium sp.
 Glauconia coalvillensis Meek.
 Tugnellus fusiformis Meek.

The last two species are characteristic forms of the Colorado group, and elsewhere are known only in the upper part of the Benton group and its equivalents.

At the eastern side of Silver Basin, 1½ miles southwest of Morenci, a great number of small specimens of *Astarte* n. sp. occur in the lowest horizon of the Pinkard formation, almost immediately above the basal member of the Modoc formation. While these fossils afford no conclusive evidence as to age, there can be no doubt that the strata are equivalent to the fossiliferous horizon described above. Notwithstanding careful search no fossils have thus far been found in any other part of the Pinkard formation.

Cretaceous and Jurassic strata are known from the Plateau Region of northeastern Arizona. Mr. E. T. Dumble recently discovered the Cretaceous at Bisbee, and Mr. F. L. Ransome has described it more in detail in the text of the Bisbee folio; over 4000 feet of Cretaceous strata are here present, which are referred to as the Bisbee group and subdivided into four formations. The upper surface at Morenci, as at Bisbee, is everywhere one of erosion and thus the original thickness is in both cases unknown. From considerations of topography it is scarcely likely, however, that the total thickness at Morenci ever approached that at Bisbee. The Bisbee group belongs certainly in part and probably as a whole to the lower or Comanche series, while the Morenci Cretaceous is referred to the Colorado group, which belongs in the upper part of the Cretaceous system. At Globe and other points in the interior of Arizona the Cretaceous has thus far not been found.

QUATERNARY SYSTEM.

No sediments of Tertiary age have been found. The volcanic flows of that period apparently always rest on a deeply eroded land surface. Strata of Quaternary age are, however, extensively developed, the most important formation being known as the Gila conglomerate.

GILA CONGLOMERATE.

General character and distribution.—This name was first applied by Mr. G. K. Gilbert to extensive and deeply eroded valley deposits extending along Gila River from the mouth of the Bonito up into western New Mexico. Mr. Gilbert (Mon. U. S. Geog. Surv. W. 100th Mer., vol. 3, Geology, 1875, p. 540) characterizes the formation as follows:

The bowlders of the conglomerate are of local origin, and their derivation from particular mountain flanks is often indicated by the slopes of the beds. Its cement is calcareous. Interbedded with it are layers of slightly coherent sand and of trass and sheets of basalt, the latter, in some cliffs, predominating over the conglomerate. One thousand feet of the beds are frequently exposed, and the maximum exposure on the Prieto is probably 1500 feet. They have been seen at so many points by Mr. Howell and myself that their distribution can be given in general terms. Beginning at the mouth of the Bonito, below which point their distinctive characters are lost, they follow the Gila for more than 100 miles toward its source, being last seen a little above the mouth of the Gilita. On the San Francisco they extend 80 miles; on the Prieto, 10; and on the Bonito, 15. Where the Gila intersects the troughs of the Basin Range system, as it does north of Ralston, the conglomerate is continuous with the gravels which occupy the troughs and floor the desert plains. Below the Bonito it merges insensibly with the detritus of Pueblo Viejo Desert. It is, indeed, one of the "Quaternary gravels" of the desert interior, and is distinguished from its family only by the fact that the watercourses which cross it are sinking themselves into it and destroying it, instead of adding to its depth.

The Gila conglomerate occupies about 30 square miles in the southeast corner of the Clifton quadrangle. It skirts the flanks of the Morenci hills and the southeastern slopes of Copper Mountain, attaining marginal elevations of about 4500 feet, the ridges sloping thence southward at a grade of 100 to 200 feet to the mile until they abruptly drop off into the canyon of the San Francisco, 400 to 500 feet deep. A long bay of this formation extends northward into the mountain area, following the western side of the river up to a point 10 miles north of Clifton, where it forms small patches on basalt and rhyolite at elevations of 4500 feet. The thickness exposed near Clifton is 600 feet, while along the river canyon, due east of Copper King Mountain, it reaches almost 900 feet. Along San Francisco River it does not extend more than 25 miles north of the Gila.

The material of which the Gila formation is built consists almost exclusively of coarse subangular gravels, appearing more or less distinctly stratified by nonpersisting streaks or lenses of sand, and containing fragments of all the older rocks of the mountains. In most places basalts and rhyolites predominate, as is natural to expect when we consider that at the time when these deposits were being accumulated a much larger part of the quadrangle was covered by volcanic flows than at present. Other rocks may, however, locally preponderate—for instance, below the area of porphyry a few miles southwest of Morenci, where the gravels consist almost exclusively of coarse diorite-porphyry, often, indeed, difficult to distinguish from the deeply weathered outcrops of the same rock. Along the lower part of Eagle Creek volcanic rocks are extremely abundant in the Gila conglomerate, and the dividing line between this and the underlying basaltic and rhyolitic tuffs in places becomes indistinct.

Along San Francisco River and Chase Creek erosion has in many places produced steep or nearly perpendicular bluffs, usually pitted by reason of the gradual weathering out of the larger pebbles. Where volcanic rocks predominate the conglomerate is often well cemented and in many places along railroad cuts and tunnels it is even necessary to blast it.

From Morenci down to Clifton the gravels are roughly stratified and largely subangular; the pebbles rarely attain a diameter of 1 foot. Volcanic rocks, granite, limestone, and quartz-porphyry are mixed. They are not greatly consolidated, though forming small cliffs in places. The gravels contain a considerable amount of sand, but this is intimately mixed with the coarse material and rarely occurs in isolated streaks. The color of the Gila conglomerate is reddish to grayish white, especially in places where long-continued exposure has had opportunity to oxidize the iron.

In Ward Canyon the gravels rest against the granite along a steep fault plane, and patches of gravel lie on the plateau 400 feet higher toward the north, at an elevation of 4300 feet. These probably were once connected with the great table of gravel south of the canyon, and this seems to show that there has been no considerable dislocation since their deposition.

Along the main river the gravel bluffs begin almost immediately below Clifton, where they rest against granite and basalt and continue for many miles. Excellent exposures are seen $1\frac{1}{2}$ miles below the new Shannon smelter, especially on the west side. The sandy river bottom is here from 300 to 600 feet wide; in several places there are narrow terraces of gravel, at most 100 feet above the creek. The bluffs, which in places are almost perpendicular, rise to a height of about 400 feet; the conglomerate is well cemented (railroad tunnels will stand in it without timbering) and is roughly stratified by small streaks of sand. On the whole, the deposit contains little sand and few indications of cross-bedding. The material consists of rhyolite, basalt, granite, and porphyry, all subangular, the fragments attaining a diameter of 2 feet, but averaging about 8 inches. Some of the material on top of the bluff seems better rounded than the rest. South of San Francisco River the same formation continues over the undulating foothills down to the Gila, but the conglomerate becomes distinctly finer in size of pebbles. At Gila River the formation rests against hills of basalt and other lavas.

Mode of deposition.—The Gila conglomerate is unquestionably of fluviatile origin. It was deposited during an epoch in which the lower reaches of the rivers gradually lost their eroding and transporting powers, while disintegration progressed rapidly in the mountains, especially in the loose masses of lava which then covered so much of this quadrangle, and intermittently torrential streams brought down vast masses of the crumbling rocks. The climatic conditions were then probably very similar to those of the present time.

The volcanic outbursts of the Tertiary took place under conditions of active erosion, the different flows being often deeply dissected before the eruption of the next mass. This epoch of erosion doubtless continued for a short time after the close of the igneous activity, for the Gila conglomerate was deposited on an uneven and in places deeply dissected surface. A deep and narrow canyon was cut corresponding to the present San Francisco River, with a course parallel, but about a mile farther west. This course is clearly marked by the bay of gravels now cut across by Chase Creek between Clifton and the Morenci foothills without exposing the bed rock. So far as known, the Gila conglomerate has not been warped or dislocated by faulting in this area; though studies extended over a wider field may possibly modify these conclusions. No volcanic tuffs are interbedded with the gravels in this quadrangle.

Age.—No fossils have been found in the formation. Mr. Gilbert, followed by Mr. Ransome, who has described its occurrence in the Globe quadrangle, assigns an early Quaternary age to it and no evidence from this region conflicts with that conclusion.

TERRACE GRAVELS.

Small benches of terrace gravels appear at intervals along San Francisco River and Eagle Creek, especially in the lower part of the stream courses. Such sandy gravels are found on Eagle Creek in small bodies, 100 or 200 feet above the creek in its lower course and 50 feet above the creek near the northern margin of the quadrangle. Similar benches are found along San Francisco River; the Shannon smelter is built on one of them, which is exposed 1 mile below Clifton, rising 60 to 100 feet above the water level. Several small remnants of these terrace gravels occur along the river between Clifton and Evans Point. These gravels, indicating a temporary check in the erosive power of the stream, are much more recent than the Gila conglomerate, and are referred to the late Quaternary.

ALLUVIUM.

The most recent Quaternary formation is the alluvium contained in San Francisco River and Eagle Creek. Both streams are well graded and occupy a continuous strip of sandy bottom land, in some places, however, only 100 or 200 feet wide. The alluvium along San Francisco River is ordinarily 400 feet wide, but increases to 2000 feet between Clifton and the mouth of Ward Canyon.

Cretaceous and Tertiary Igneous Rocks.

General statement.—Aside from the basal pre-Cambrian intrusive granite described above, there is a second and much younger series of igneous rocks which occur as stocks, dikes, sheets, and laccoliths in the lower Cretaceous, Paleozoic, and pre-Cambrian formations. The time of their intrusion falls between the middle Cretaceous and the middle Tertiary, but they antedate the Tertiary lavas, which are spread out over their eroded surface. Porphyries of granitic, monzonitic, or dioritic affiliations predominate; diabase occurs in subordinate amounts and would appear to be somewhat later than the porphyries. The great warpings and dislocations followed these intrusions.

INTRUSIVE ROCKS.

PORPHYRIES.

General character and distribution.—The porphyries form an almost continuous series of light-gray acidic or predominatingly feldspathic rocks, ranging from diorite-porphyry through monzonite-porphyry to granite-porphyry. Between the last two divisions no line can be drawn, but the diorite-porphyry occupies a somewhat more individual position.

The area covered by intrusive porphyry on the general map hardly amounts to 8 square miles. The rock is extensively developed in the Morenci hills between Eagle Creek and Chase Creek, but also reaches up from the canyon of the latter on the north and east flanks of Copper King Mountain.

The principal area forms a stock extending with jagged contacts for 7 miles in a northeast direction from the Eagle Creek foothills by Morenci to 1 mile north-northeast of Metcalf, where it splits up into very numerous dikes, all having a northerly or northeasterly trend. The northern half of this stock and its dikes chiefly break through granite, while the southern part is surrounded by Cretaceous shales and sandstones, Cambrian quartzites, or Ordovician limestones, and breaks up into a complicated mass of dikes and sheets near the point where the older rocks dip below the basalts which fill the valley of Eagle Creek. A narrow branch breaking through Cretaceous sediments connects this area with an oval mass of porphyry $1\frac{1}{2}$ square miles in extent and almost entirely surrounded by slightly upturned Cretaceous sediments. This mass is evidently a laccolith. Dikes and rounded masses of the same rock occur in the gently rolling Cretaceous area east of the laccolith.

At Shannon Mountain and Morenci, where the porphyry adjoins Paleozoic strata, the latter, close to the contact, contain a number of well-defined dikes. A persistent sheet of porphyry follows in places the division plane between the Coronado quartzite and the Longfellow limestone. Again, in the western portion of the great stock, the latter breaks up into a network of dikes and sheets, chiefly intercalated between the Ordovician strata. North of Metcalf, in Garfield Gulch and at the foot of the great lava masses of Malpais Mountain, are several smaller areas of porphyry, appearing as stock-like masses in granite, but frequently changing to sheet intrusions where in contact with limestone.

Summing up, it may be said that the porphyries usually occur in the granite as stocks and dikes, while in the Paleozoic sediments they are apt to take the form of sheets or sills. In the Cretaceous sediments again the tendency is to form laccolithic masses, probably because of the lighter load and greater flexibility of the covering sediments.

The northeastern half of the principal stock, from Morenci to Metcalf, consists of granite-porphyries marked by porphyritic quartz crystals. Many of the dikes, also, conform to this type. From Morenci nearly to the southwest end of the stock the prevailing rock consists of monzonite-porphyry, containing quartz in the groundmass only; the same is, as a rule, true of the dikes near Morenci, while the smaller areas inclosed in the mesh of altered sediments near the Eagle Creek basalts generally consist of diorite-porphyry. Diorite-porphyry also makes up the great laccolithic mass in the southwestern foothills and the dikes of that vicinity; it also appears in Garfield Gulch and near the head of Placer Gulch.

In short, it would seem that granite and monzonite-porphyry chiefly occur as stocks or dikes, while diorite-porphyry forms most of the sills, sheets, and laccoliths.

Near Metcalf porphyry breccias occur both in the mass of the rock and along the granitic contact. In the latter case the breccia often contains granite fragments and the contact becomes indistinct.

Petrography of the granite-porphyry.—As stated above, the north end of the great porphyry stock, from Morenci to beyond Metcalf, consists of granite-porphyry, forming a belt from 1 to 2 miles wide. Within this area the rocks are almost universally affected by the introduction of quartz, pyrite, and sericite. The yellowish or reddish-brown outcrops, tinted by oxidizing pyrite, are apt to appear in extremely rough topographic forms, as is well shown at Metcalf near the mouth of King Gulch. Fresh rock is almost impossible to obtain, the best being bleached and traversed by a network of quartz veinlets. Specimens from a railroad cut just south of King Gulch show on fresh fracture pale greenish-gray color and contain closely massed dull-white feldspar crystals, at most 2 or 3 mm. in length. There are also well-defined bipyramidal quartz crystals several millimeters in diameter, and sparingly represented biotite crystals converted into chlorite. The groundmass is fine grained, and now consists chiefly of sericite and quartz; sericite has also largely invaded the feldspar phenocrysts, especially the orthoclase. The feldspars consist partly of orthoclase and partly of sharply defined albite crystals. A partial analysis of this rock by Dr. W. F. Hillebrand gave the following percentages: SiO_2, 69.13; CaO, 0.22; Na_2O, 3.01; K_2O, 3.94.

Besides a large amount of quartz the rock would thus contain 23.5 per cent of the orthoclase molecule, 25.1 per cent of the albite molecule, and 1.1 per cent of the anorthite molecule. It is clearly a granite-porphyry, the large amount of individually developed albite being especially notable.

The stock at the head of Placer Creek is similar in character, but the rock is fresher and contains more biotite as well as a little secondary epidote, a mineral which is absent in the porphyries of the Metcalf basin. Its presence indicates an approach to monzonitic and dioritic modifications. Many of the dikes east and west of Metcalf also belong to the granite-porphyries, though quartz-monzonite facies are more common.

Petrography of the quartz-monzonite-porphyry.—The rocks of the great stock at Morenci and Gold Gulch basin, together with many dikes, belong to this type, which, as well as the preceding division, has a close structural and genetic connection with the ore deposits. Between Morenci and Metcalf quartz cementation and pyritic dissemination are generally present and are often accompanied by extensive sericitization. In this area the outcrops are reddish or yellowish red and weather in irregular, craggy form. The rock is most typically developed in the Gold Gulch basin, where mineralization is slight or absent, although weathering disintegrates it easily to a sandy yellowish soil and slightly rounded outcrops prevail. Entirely fresh rocks are not easily found. Specimens from the divide between Gold Gulch and Morenci Canyon are light colored, with fairly abundant greenish biotite foils up to 2 mm. in diameter; the feldspar prisms of light yellowish-gray color are closely massed and reach a length of 3 to 4 mm., while the quartz phenocrysts rarely attain 2 mm. in diameter and show no well-defined bipyramidal form.

Under the microscope orthoclase, albite, and oligoclase, with an occasional crystal of labradorite, are shown to be present. The plagioclastic feldspars often show fine zonal structure. The groundmass is coarsely microcrystalline, consisting of quartz and unstriated feldspar grains, with occasional octahedrons of magnetite. Sericite is present in the feldspars, while chlorite has formed from the biotite; a little secondary epidote also occurs. A partial analysis of this rock gave the following percentages: SiO_2, 69.30; CaO, 1.67; Na_2O, 5.56; K_2O, 2.39.

Similar porphyries make up the largest part of Copper Mountain and form the matrix of the chalcocite ore, but as a rule sericitization prevents exact determination.

One of the freshest porphyries obtainable in the mines at Morenci was collected in the first level of the Ryerson mine, in the crosscut to the Wellington vein, 100 feet north of the Ryerson stopes. The rock is similar to the one just described, though not quite so fresh. It shows the same closely massed, small, usually striated feldspar prisms; the greenish biotite foils are here rather scanty; individual quartz phenocrysts are seen, but the light greenish-gray flinty groundmass is more abundant. The feldspar phenocrysts consist of albite and oligoclase, with some orthoclase. The groundmass is fine grained and microcrystalline, with much quartz and orthoclase. Of secondary minerals sericite, chlorite, and pyrite are present in moderate amounts, but this does not seriously alter the composition of the rock. As this specimen would seem to most closely represent the prevailing rock of Copper Mountain, it was analyzed, with the following result:

Analysis of quartz-monzonite-porphyry from Ryerson mine, No. 211, Clifton collection.

[W. F. Hillebrand, analyst.]

	Per cent.
SiO_2	68.04
Al_2O_3	17.20
Fe_2O_3	.34
FeO	.67
MgO	1.05
CaO	2.21
Na_2O	5.33
K_2O	2.65
H_2O—100°	.60
H_2O+100°	1.23
TiO_2	.41
ZrO_2	.01
CO_2	None.
P_2O_5	.12
MnO	.06
BaO	.10
SrO	.03
Li_2O	Faint trace?
V_2O_3	Faint trace.
FeS_2 *	.24
Cu_2S?*	.02
ZnS?*	.03
MoO_3	None.
Total	100.34

* 0.14 per cent S; condition of zinc and copper problematical.

A fairly large amount of CaO and a strong preponderance of sodium distinguishes this porphyry from that of the Metcalf type. A rough calculation shows the rock to contain the following:

Proportion of minerals in quartz-monzonite-porphyry from Ryerson mine.

	Per cent.
Orthoclase molecule	16
Albite molecule	45
Anorthite molecule	10
Biotite	6
Quartz	22
Titanic iron ore	1
Total	100

While exact data can not be obtained, the rock probably contains equal quantities of orthoclase (mostly in groundmass) and albite, aggregating 38 per cent, against 24 per cent Ab_2An. It would thus represent an almost typical quartz-monzonite-porphyry, if the relation of granular rocks as defined by Professor Brögger is applied to their porphyries. Dikes of similar porphyries fresh enough to be determined were noted from the Longfellow mine and from the stope level of the Copper Mountain mine at the head of the incline.

A gradual increase in calcium, iron, and magnesium brings us to another series of quartz-monzonite-porphyries, similar in appearance to those just described except that hornblende sometimes occurs with the biotite and the fine-grained flinty groundmass is of a darker-greenish color. Quartz is not present as phenocrysts. This kind of porphyry is not represented in the great stock, nor in any other large areas, but is common among the dikes. To this class belong some dikes in the second level of the Arizona Central mine at Morenci, one occurring near the breast of the Hudson crosscut and the other on the northwest wall of the Arizona Central vein, 200 feet northeast of the shaft. Both are grayish-green porphyries with small and closely massed but inconspicuous feldspar crystals. The rectangular prisms consist chiefly of andesine; there are a few small quartz grains and fairly abundant prisms of hornblende; the groundmass is microcrystalline, fine grained, in places micropoikilitic, and evidently contains orthoclase. Of secondary minerals epidote and pyrite are the most prominent.

The long and prominent dike extending southward from Modoc Mountain consists of a similar rock. The abundant phenocrysts are andesine and oligoclase, with some orthoclase. The ferromagnesian silicates are mostly decomposed, one prism of hornblende, now converted to chlorite and epidote, being noted. The groundmass is microcrystalline, consisting of quartz and unstriated feldspar. Some sericite and much epidote are present, the latter here and there replacing whole feldspar crystals.

Many dikes east of Chase Creek also belong to this class—for instance, that which is followed by the Copper King vein.

Under this heading may also be described an unusually fresh dike rock from the Montezuma mine, Morenci, Waters shaft level, 135 feet northwest of the main vein. In thin section it shows well-defined and abundant phenocrysts of andesine up to 2 mm. in length, while there are few, if any, orthoclase crystals. Both hornblende and biotite, with a few grains of black iron ore, are present. The groundmass is microcrystalline, consisting of quartz and minute prismatic crystals of orthoclase, the latter irregularly distributed within the small quartz grains. As usual, the biotite is converted into chlorite and some epidote, the latter also replacing some of the andesine; some calcite is present in the groundmass and phenocrysts, but very little sericite was noted.

Petrography of the diorite-porphyry.—These rocks have usually a light-yellowish or greenish-gray color, weathering to dull brownish yellow; they form rounded outcrops in a sandy soil, the abundant detached fragments being generally also rounded, but rather by disintegration than by transportation. The Gila conglomerate below these porphyry hills consists nearly exclusively of cobbles of the same rock. The diorite-porphyry, as stated on page 6, in most cases forms laccolithic masses in Cretaceous sediments, or sheets or sills, more rarely dikes, in the Paleozoic strata. A common place of intrusion of these sills is between the Coronado and Longfellow formations. A specimen of this rock shows abundant prisms of white feldspar up to 4 mm. in length and of narrow dark-green hornblende up to 1 cm. in length, together with a few grains of black iron ore. These phenocrysts are embedded in a scant greenish groundmass. In thin section the beautifully developed feldspars prove to be a rather basic labradorite with zonal structure; the hornblende is of ordinary greenish-brown color, while the groundmass consists of small, thick, rectangular prisms, in part orthoclase; between these is a still finer microcrystalline mass of unstriated feldspar and quartz. Small amounts of chlorite and epidote are present, but no pyrite. A partial analysis gives the following percentages: SiO_2, 61.20; CaO, 5.11; Na_2O, 5.70; K_2O, 1.35.

Typical specimens of the porphyry from a point 1 mile north of the place where Gold Gulch enters the Eagle Creek basalt flows conform exactly to the above description. This porphyry forms a complicated stock-like intrusion in the Longfellow limestone. In reality it is probably a sheet with many intercalated and parallel strata of limestone. Entirely similar are the rocks from one of the small laccolithic masses in Cretaceous strata 2 miles southwest of Copper Mountain, and the large laccolith 3 miles south-southwest of Copper Mountain conforms to the same type.

The porphyry from the small stock on Garfield Gulch at the Mammoth mine is perhaps rather a monzonite-porphyry. It is slightly brownish in color and contains abundant small and well-defined crystals of a triclinic feldspar well filled with sericite and calcite, probably andesine, together with pseudomorphs of epidote and chlorite after hornblende in a microcrystalline groundmass of unstriated feldspar and quartz.

The porphyry stock on upper Silver Creek, northeast of Malpais Mountain, is a normal diorite-porphyry of light color and similar to the typical specimens described above.

Fine-grained dark-green (melanocratic) porphyries do not occupy large areas. A specimen collected 2 miles southwest of Copper Mountain, near the contact of the great stock with the Cretaceous rocks on the south side, is of this kind and contains many slender hornblende needles. Under the microscope these prove to be of pale-green color and partly altered to bastite, while the groundmass consists of long prisms of feldspar, probably labradorite, together with small needles of hornblende and a little magnetite. This type probably belongs to the dioritic lamprophyres.

The diorite-porphyries rarely contain copper ores and seldom pyrite; chlorite, much epidote, calcite, and a little sericite are the principal secondary minerals.

Age.—It is not possible to separate on the map the different classes of porphyry described above except by artificial lines. Beyond question they solidified from one magma, intruded about the same time. While it may not be advisable to draw too wide-reaching conclusions from the data, it would seem as if the deeper parts of the magma were the more acidic, while the upper and marginal parts more nearly approached dioritic types. The magma invaded the upper crust after the deposition of the Cretaceous beds (equivalent to the Benton), and the probably late Tertiary lavas flowed over their deeply eroded surface. Hence their eruption may be safely placed in the latest Cretaceous or in the earliest Tertiary. The magma invaded Cretaceous beds, and it seems certain that a considerable thickness of similar beds once covered the now exposed laccoliths—how much, it is impossible to say; the Cretaceous at the present time is only a few hundred feet thick, but as the Bisbee beds exceed 4000 feet in thickness the possibility of solidification at a considerable depth must be conceded.

Contact metamorphism.—At the contacts of the granitic, more rarely of the dioritic, porphyries, certain changes have taken place in the adjoining sedimentary rocks. Shales and limestones have suffered the greatest alteration, while sandstones and quartzites are but little altered. The granite is not affected. These changes are of the character usually described as contact metamorphism, and extend from a few feet to about 2000 feet from the contact. In limestones epidote, garnet, diopside, magnetite, chalcopyrite, pyrite, and zinc blende have developed, while in the shales tremolite and epidote are the principal minerals formed.

A great mass of diorite-porphyry, apparently a laccolith, 1$\frac{1}{2}$ miles by 1 mile in size, is intruded in the Cretaceous strata 3 miles southwest of Morenci. The sedimentary rocks are very little altered at the contact; at most a hardening and some development of epidote are noticeable. The same applies to the smaller areas of porphyry northeast of this mass. One of them, one-half mile south of Morenci, forms the top of a hill and apparently rests on Cretaceous sediments, shales, and sandstones, which are reddish and in places contain much epidote, but are otherwise not much altered. The metamorphism becomes more intense farther north, and appears to be due to the vicinity of the contact of the main stock. Along the Eagle Creek foothills north of Gold Creek diorite-porphyry again prevails and contains many slab-like inclusions of Ordovician limestone of various sizes, but at the contacts of these practically no alteration is visible. The same applies to the long sill of diorite-porphyry intruded all along the contact between the Coronado quartzite and the Longfellow limestone, and to the little stock of the same rock which occupies the basin of Garfield Gulch north of Metcalf.

From all this it appears that the diorite-porphyry exerts a very slight action on the surrounding sediments, whether they be limestone or shale.

Very different conditions obtain at the contacts of the quartz-bearing porphyries, mainly quartz-monzonite-porphyry and granite-porphyry. The Cretaceous strata which cross Gold Creek in irregular masses, deeply indented and torn by the porphyry, are decidedly altered. The shale and fine-grained sandstone are very much hardened, becoming sometimes even flinty and of black or dark-green color. They contain a little epidote, pyrrhotite, and pyrite, besides more or less green hornblende, which has developed in the mass of the shale and in the cement of the sandstones. In places the sandstone has acquired a quartzitic appearance, but withal the alteration does not compare in intensity with that suffered by the Paleozoic limestones.

At the mouth of Pinkard Gulch, where the Ordovician shaly limestone is greatly cut by dikes and masses of porphyry, some of the included masses are almost wholly converted to epidote, with magnetite and garnet; copper stains are abundant, and many small prospects have been opened. Between this place and the Soto mine, where Gold Creek crosses the Soto fault, which separates Ordovician limestone from granite, the same phenomena are repeated; garnet and epidote occur abundantly at the contacts and also along certain strata. But the alteration is not always extensive and some limestone masses seem to have escaped almost entirely.

For 1 mile northeast and southwest of Morenci the stock of quartzose porphyry abuts against the whole sedimentary series, which is less cut up by the intrusions than in the Gold Creek basin. Alteration has developed on a large scale; over an average distance of 1500 feet from the contact the sedimentary rocks are greatly transformed, in places to a width of even 2000 feet. There is very material difference in the manner of alteration of the various strata. Dikes both inside and outside of the altered zone are followed by bands of metamorphosed rocks. The alteration shows no dependence upon fissures or veins, the only factor which seems to have any influence being the proximity of intrusive bodies.

The Cretaceous sandstones and shales on Modoc Mountain and on the hills south and southwest of Morenci are altered to quartzites and epidote-amphibole schists, the latter of dark-green color and increasing size of grain as the porphyry is approached. The Modoc limestone, as well as the underlying dolomite, is most susceptible to change; a whole block of this formation extending from Modoc Mountain to the Copper Mountain fault has been almost bodily converted into a mass of calcium-iron garnet. The same applies to the exposure of the same formation in the next block between the Apache and the Copper Mountain fault exposed south of the smelter. It is entirely converted to garnet and epidote for 2000 feet from the contact, while the underlying shale and limestones remain almost entirely unaltered.

Next to the porphyry, bordering it for 1$\frac{1}{2}$ miles, lie more or less disturbed masses of Morenci shales and Longfellow limestone. The shale is converted to dense greenish rocks rich in epidote, amphibole, and pyrite, while the limestone contains garnet, epidote, pyroxene, amphibole, specularite, magnetite, pyrite, chalcopyrite, and zinc blende, all irregularly massed and distributed. Garnet, however, does not form large bodies, as in the Modoc limestone. Smaller, less altered masses of limestone are sometimes contained in these areas.

The almost entire absence of biotite, muscovite, and feldspars among the contact-metamorphic minerals is notable.

From Morenci to Metcalf the porphyry stock borders against granite, but at the latter place a small area of the Paleozoic series directly adjoins the granite-porphyry and is cut by several dikes projecting from it. The phenomena described at Morenci are here repeated. Practically the whole area is affected by the alteration. Chalcopyrite and pyrite form abundantly, together with garnet, pyroxene, and epidote. The small downfaulted limestone area at the mouth of Garfield Gulch is unaltered, except where a little epidote and magnetite appear in the immediate contact of the small dikes of diorite-porphyry traversing it.

The stock of quartzose porphyry at the head of Placer Gulch has exerted a somewhat capricious alteration. While the limestone adjoining on the north is not noticeably altered, the many small inclusions of the same rock in the southern part of the stock are partly converted to epidote and magnetite, and frequently show copper stains. The long dike traversing limestone near the head of Sycamore Gulch has changed the rock but little, epidote appearing only in places.

The stock at the head of Silver Creek, near the northern margin of the quadrangle, is composed of diorite-porphyry and has not changed the surrounding rock.

The general mode of occurrence of this peculiar alteration decidedly forbids its classification with either regional metamorphism, common hydrometamorphism, or hydrothermal metamorphism. The determining factor is evidently the presence of a quartz-bearing porphyry and there need be no hesitation in referring these changes to contact metamorphism.

DIABASE.

Distribution.—A dark-green medium-grained rock, which proves to be diabase, occurs at widely distant places in scant development as dikes and, more rarely, as sheets. Occasional dikes are found in the Gold Creek basin in monzonite-porphyry; at the Virginia, Trinidad, Brunswick, and Garfield mines, at or near Garfield, in granite; at the Coronado mine between granite and quartzite; and in the lower part of Sycamore Creek as an intrusive sheet or horizontal dike in granite. In no place are the dikes more than 100 feet wide, and usually they are much less. They are connected with a class of fissure veins carrying copper, but it is only a small division, containing as its most important representative the Coronado vein. In development and interest the diabase of the Clifton district is far inferior to that at Globe, Ariz., described by Mr. Ransome.

Petrography.—The freshest rock is exposed in Sycamore Gulch, where there are no copper deposits connected with it. The rock forms dark-gray rounded outcrops and is a typical medium-grained diabase, composed chiefly of labradorite and augite, with normal diabase structure.

The Coronado vein follows in part of its course a diabase dike up to 70 feet wide, but the rock is usually greatly altered. A specimen from a small vein 200 feet above the Horseshoe shaft and the same distance south of the main vein is fairly fresh and is a typical fine-grained diabase. Although much augite still remains between the feldspar prisms, most of it is converted into chlorite. The feldspar contains some sericite. A little pyrite is also present. Rocks from the dike along the main vein are dull dark green and very much altered, showing lath-like sericitic feldspars, chlorite replacing augite, and leucoxene replacing ilmenite.

The Black lode follows a diabase dike up to 40 feet wide, similarly altered; the other occurrences mentioned in the preceding section are also of the same type.

Age.—As a dike of diabase breaks through porphyry in Gold Creek basin, 2 miles due west of the railroad station at Morenci, it seems likely that the diabase is somewhat later than the porphyry, but it is not probable that the times of their eruption differed much.

RHYOLITE, BASALT, AND ANDESITE DIKES.

Dikes of rhyolite, basalt, and andesite are described with their effusive equivalents under the heading "Tertiary lavas," following.

TERTIARY LAVAS.

General statement.—North of Clifton the Tertiary lavas cover enormous areas. The southern edge of the great lava fields, which probably extend northward for 100 miles or more, is in the central part of the quadrangle, a few miles north of Metcalf. In addition, the same eruptive rocks practically cover the eastern side of the valley of San Francisco River down to the latitude of Clifton and almost the whole valley of Eagle Creek down to Gila River. Within the central parts of the mountains, where the copper deposits occur, they are almost absent. In some places erosion may have removed them, but it is not likely that they ever covered the domes of Coronado and Copper King mountains. Their age can not be determined with exactness, but many considerations point to the late Tertiary as their time of eruption. Copper deposits do not occur in them. They have suffered very little from the great faulting movements, which in the main must have preceded their eruption.

Succession.—A repeated series of deposits of rhyolite and basalt, with subordinate andesite, characterizes the Clifton volcanic series. The first eruptives were rhyolites, massive and tuffaceous, which now form the reddish bluffs on both sides of the town of Clifton. The rhyolite was covered with black, fine-grained basalts, over which poured out heavy sheets of gray or brown pyroxene-andesites, sometimes containing olivine. This is well exposed in the bluff northeast of Clifton. A few miles farther north, on the river, this is covered by thick flows of scoriaceous basalt, having their origin somewhere near Sunset Peak and thinning out very much along the river.

A second eruption of rhyolite took place, this time in the form of light-yellowish or brownish tuff breccias. Most of these seem to have flowed down from the upper river, 10 miles north of Clifton, but there was also one local eruption of massive rhyolite near the mouth of Hackberry Gulch, a few miles north of the town.

This eruption was succeeded by numerous basalt flows, aggregating 1500 or even 2000 feet in thickness, well exposed by the deep trench of Sardine Creek. These basalts also show in dark-brown outcrops on the north side of Garfield Gulch, though they are there only about 300 feet thick; they also form the basement of Malpais Mountain. To the same epoch belong probably also the basaltic flows which form the whole southern valley of Eagle Creek and the high ridges west of it. A considerable epoch of erosion followed the second great basaltic eruptions; Eagle Creek excavated its canyon to a depth at least as great as it has attained at present, and the northern basalt hills were deeply trenched.

After this came the third and last great rhyolite eruption, which appears to have originated from the high points near Malpais Mountain and the summits near the head of Whitewater Creek. The yellowish-gray masses of tuff breccia, similar to those of the second rhyolite eruption in San Francisco River, poured down westward, covering the upper basin of Eagle Creek, and, narrowing down to a thinner stream, filled the lower basalt canyon of Eagle Creek. Renewed Quaternary erosion has reexcavated the trench, but along its steep buttresses enough of the rhyolite tuff remains to show the former configuration of the canyon.

RHYOLITE.

Clifton flows.—The light-reddish or pink bluffs which rise to a height of 400 feet east and west of the river at Clifton consist of rhyolite which rests on granite and is covered by basalt, andesite, and the Gila conglomerate. The bluffs reveal at least two thick flows, which are gently inclined northward, but the difference between them is only slight. The rocks show a light-reddish groundmass with abundant small feldspar crystals and scattered biotite foils at most 3 mm. in diameter. The porphyritic feldspars, which are generally not well-developed crystals, are chiefly oligoclase. The felsophyric groundmass, banded or streaked and in part spherulitic, contains many small, irregular grains of quartz. A partial analysis by Mr. George Steiger of a rock collected near the railroad station at Clifton gave the following percentages: SiO_2, 67.38; CaO, 1.55; Na_2O, 2.16; K_2O, 5.96. This indicates that the rock is a rhyolite, although affiliated with the dacites and the trachytes.

So far as known this rhyolite, which covers comparatively small areas, is the oldest of the extrusive Tertiary lavas. Besides the bluffs mentioned above, the white tuffaceous flows which cover the limestone west and south of Mulligan Peak and which in turn are covered by basalt belong to this division. Thin flows of the same rhyolite are embedded in the superjacent basalt south of Mulligan Peak and north of Limestone Gulch.

San Francisco flows.—Rhyolitic flows appear again on San Francisco River north of Evans Point, where they cover the early basalt and andesite and are in turn covered by the thick basalt of the Prieto flows. Two smaller areas lie on the east side of the river, but the principal development is on the west side; the area gradually widens toward the north and near the boundary line of the quadrangle the rhyolite occupies the whole valley, extending from the foot of the Prieto escarpment across the river and for several miles eastward beyond the boundary. The thickness also increases from 100 or 200 feet at Evans Point to 1000 feet on lower Sardine Creek.

A prominent bluff on the north side of Hackberry Gulch consists in part of massive felsophyric and partly glassy rhyolite, and is evidently a local focus of eruption. Over the largest part of the area the rock is a light yellowish-gray tuff, with abundant small and angular fragments of felsophyric rhyolite and occasionally scoriaceous basalt. It is entirely similar to the later tuffs of the Malpais flows. The outcrops form yellowish-gray bluffy ridges, in which the several flows are often distinctly indicated. Toward the upper limit the basaltic detritus in the tuff increases rapidly, and the line of division between the two series of flows north of Sardine Creek can not be exactly drawn. The rhyolite tuff gradually changes into a basalt tuff or tuff-breccia, and at an elevation of 4500 or 5000 feet the massive basalt flows begin. Similar conditions exist on Pigeon Creek, along the northern boundary of the quadrangle, where 100 feet of mixed tuffs separate basalt and rhyolite at elevations of 5500 feet. The tuff flows have a dip of 7° to 10° NNW. or NW., changing in the southern part of the area, along San Francisco River, to WNW.

Malpais flows.—The most extensive rhyolitic flows of the quadrangle succeeded the principal eruption of basalt and covered its deeply eroded surface. The eruption of this rhyolite, which for convenience will be designated the Malpais flows, closed the Tertiary epoch of igneous activity. Several smaller areas occupy Malpais Mountain and the ridges west and north of it; the largest area lies in the northwestern part of the quadrangle and extends from Enebro Mountain westward down to Eagle Creek and for many miles west of the boundary. A partly eroded branch follows Eagle Creek Canyon down to the southern boundary of the quadrangle, and fills a trench deeply cut in the basalt flows. A small remnant of the rhyolitic flows covers Grey Peak, north of Whitewater Creek. The thickness of the flows amounts to 800 feet on Malpais Mountain and on lower Eagle Creek, while on Enebro Mountain it somewhat exceeds 1000 feet.

The Malpais flows form flat-topped ridges with yellowish-gray outcrops, often showing well-marked bedding and at a distance being easily mistaken for limestone beds. The slopes are almost invariably steep and bluffy, sometimes breaking into perpendicular cliffs. These characteristics are most pronounced along lower Eagle Creek, where bedding and vertical jointing combine to produce erosion forms of picturesque and striking appearance.

By far the larger part of the Malpais flows are composed of tuffaceous rocks in which the bedding is well marked, sometimes strikingly so, as along Eagle Creek, where the beds dip 7° to 9° E. West of Malpais Mountain the initial dip is 7° W., and in the main area north of Knight Creek the slope is 7° to 10° N. or NW.

The rock is soft, usually light reddish or pink, weathering to a pale yellowish brown, and contains in a porous and earthy matrix of rhyolitic character a great number of angular fragments of lithoidal, more rarely glassy, rhyolite. The fragments are seldom more than a few inches in diameter. In places, especially near the bottom of the series, basalt fragments become abundant, and actual transitions to basaltic tuffs may be thus formed. At many points normal felsophyric rhyolite in large irregular masses is mingled with the tuff and tuff-breccias—for instance, on the spurs of Malpais Mountain, on Enebro Mountain, and in Chase Creek 1½ miles southeast of the latter peak. Massive rhyolite, associated with tuffs, is also embedded as small individual flows in the basalt of Eagle Creek just south of Coronado Ridge. Large dark-gray masses of a pure rhyolite glass are found mingled with felsophyric rhyolite near the summit of Enebro Mountain and on the southwest slopes of Malpais Mountain. At Grey Peak 75 feet of basaltic breccia resting on basalt form the basement upon which lies a mixed breccia of basalt and rhyolite, which finally passes into normal banded and partly glassy rhyolite.

Well-defined dikes of rhyolite of moderate width cut the basalt ridges south of Malpais Mountain and the granite of Hickory, Colorado, and Dorsey gulches on the slope toward San Francisco River. Their direction is generally northwesterly. Another dike of rhyolite, 75 feet wide, extends northwestward from Grey Peak and breaks through the basaltic flows.

The lava probably issued from many points, Malpais and Enebro mountains being the most prominent loci of igneous activity. Enormous volumes of water must have accompanied the eruptions. The fragmental rocks caused by successive explosions mingled with the water, descended the flanks of Enebro Mountain, and filled the valley of Eagle Creek as a succession of mud flows. The domes of Coronado and Copper King mountains were clearly not covered by these eruptions, nor were the Morenci hills flooded by them.

BASALT.

Clifton flows.—At Clifton, as well as on the hills south of Mulligan Peak, the rhyolite is directly covered by flows of basalt, best exposed on the bluff at the junction between the river and Chase Creek. It rests upon the sloping surface of rhyolite, and is in turn covered by andesite. A thin bed of rhyolite tuff is intercalated in it south of Mulligan Peak, just as on Limestone Gulch a flow of basalt is contained in the upper part of the rhyolite. The greatest thickness of the Clifton flows of basalt is about 300 feet.

The rock is a compact, dull dark-gray to brownish-gray, fine-grained basalt containing in places large and well-developed crystals of olivine. In most of the outcrops a considerable amount of ferric oxide has developed.

Sunset flows.—The second outburst of basalt followed the andesite of Hackberry Gulch, and was in turn covered by the rhyolite of San Francisco River. Its flows, which have a maximum thickness of 500 or 600 feet, descend over the slopes of the andesite from the vicinity of the high volcanic point of Sunset Mountain (elevation, 6977 feet), 3 miles east of Harper ranch, and extend down to the river; the largest area lies between the river and the eastern margin of the quadrangle. It crosses the river at several places and forms a bluff a few hundred feet high on the west side, but is soon covered by the white tuffs of the rhyolite of San Francisco River.

The Sunset flows of basalt appear in flat-topped ridges, sloping eastward and bordered by steep bluffs in which several superimposed flows are discernible. The outcrops are black to reddish brown. The rock is very fine grained, dull black, and often extremely scoriaceous; the dark-brown olivine crystals are plainly visible. In the principal areas it forms a typical basalt, holocrystalline rather than glassy, but the lower flows sometimes present facies connecting them with the andesites, and the line between the two groups may be very difficult to draw.

Mulligan Peak, northeast of Clifton, is built up of flows which probably also belong to this division. Its black pyramid rises conspicuously 500 feet above the plateau of andesite and doubtless represents a local eruptive vent. It is built up of many northward-sloping flows, beginning with dark, fine-grained, vesicular basalts with intercalated beds of black or dark-brown agglomerates, and is capped by a black flow of olivine-basalt related to olivine-andesite, containing many phenocrysts of plagioclase 1 cm. long.

Under this heading may also be mentioned a very straight and conspicuous dike which, with an east-west direction, cuts across the granite on the northwest side of Limestone Gulch. It consists of a dark-gray, medium-grained olivine-basalt with holocrystalline diabasic structure.

Prieto flows.—The latest eruptions of basalt have been comprised under the general name of the Prieto flows, named after the Prieto Plateau, north of Sardine Creek. They cover two large areas, the first occupying the whole of the most northern part of the quadrangle and extending down to Malpais Mountain and Garfield Gulch. Minor areas are exposed below the rhyolite north of Knight Creek. The second area, which in all probability is of contemporaneous origin, covers the whole southwest corner of the quadrangle to the foot of the Coronado Ridge and the Morenci hills. A maximum thickness of 2000 feet is observed on Sardine Creek and the southwestern mass of basalt is probably equally thick. Toward Malpais Mountain and Knight Creek the thickness diminishes to a few hundred feet. Wherever not too deeply modified by denudation, the later basalt tends to form level or sloping ridges bounded by steep erosion slopes upon which the individual flows are distinctly outlined. The color of the outcrops is characteristically black, contrasting strongly with the light-buff colors of the rhyolitic tuffs, and changes to dark brown or reddish brown only where agglomerates or very vesicular rocks form a part of the series, as commonly happens near Malpais Mountain, or in the narrow strip exposed below the rhyolite north of Knight Creek.

Massive flows predominate; volcanic tuff-breccias or agglomerates are present, however, in the lower part of the series near the underlying rhyolite tuff of lower Sardine Creek and Pigeon Creek, at the western base of the Coronado Ridge and the Morenci hills, and at a few other places as subordinate intercalated flows. The thickness of individual basalt flows averages about 30 feet, although some may greatly exceed this figure. In the northwest corner of the quadrangle, on the abrupt slopes of a flat ridge toward Eagle Creek, fourteen individual flows may be counted, and many more are exposed in the prominent escarpment north of Sardine Creek. The individual flows may show a rudely columnar jointing, rarely, however, of striking regularity. Excellent instances of curved and twisted joint planes, such as are often seen near loci of volcanic eruptions, were observed along Eagle Creek, 1½ miles north of the pump station. Smaller flows of rhyolite are sometimes intercalated in the basalt, as shown, for instance, along Eagle Creek south of the west end of the Coronado Ridge. Thin basalt flows are intercalated in the later rhyolite tuff on Whitewater Creek, 2 to 4 miles west of Granville.

As revealed by the microscope the structure of the basalts of the Prieto flows is monotonous and offers few points of interest. They are almost without exception normal olivine-plagioclase-basalts of fine grain, with a strong tendency to holocrystalline diabasic-granular structure. A little glass is, however, very commonly present, pressed in between the pyroxene grains and feldspar laths, producing what is known as intersertal structure. Many of the rocks from the northwest corner of the quadrangle are, however, rather coarse and entirely holocrystalline. Basaltic glasses are very rarely observed. In the southwest corner of the quadrangle normal basalts likewise prevail, but transition forms to andesite with phenocrysts of feldspar are also present. The points of eruption from which these enormous masses of basalt issued are not definitely located.

ANDESITE.

There were two distinct eruptions of andesite within this quadrangle. The earlier andesite occupies an area of about 6 square miles, which extends from Clifton beneath Mulligan Peak northward along the river up to a point northeast of Harper ranch. It covers the Clifton flows of basalt and is in turn overlain by the basalt of the Sunset flows. The andesite forms sloping ridges, of dark-brown, sometimes dark-gray, color, in which individual thin flows are much more rarely observed than in the basalt. The exposed thickness of the flows is probably not over 600 feet, and their general slope is westward. North of Limestone Gulch a subordinate flow of rhyolite is intercalated in the andesite.

In many parts of the area the rocks exhibit a close affiliation with basalts and occupy in fact an intermediate position. The color in specimens is reddish or reddish gray and small phenocrysts of feldspar crystals up to 5 mm. long are usually visible in the dense groundmass. Pyroxene-andesites predominate and some contain olivine, although in the extreme northern part of the area there are biotite-andesites, in which the feldspar crystals attain a length of 8 mm. The groundmass is hypocrystalline, with relatively small amounts of glass and a predominance of feldspar laths and small grains of pyroxene. At many places it shows a distinct basaltic character.

The later andesite is of a more distinctive type and occurs as dikes and smaller intrusive bodies in the Prieto flows of basalt northwest and southeast of Tule Creek. One of the dikes, which is 20 feet wide, straight, and very sharply defined, is continuous for 1½ miles west-northwest of Tule Creek. It intersects basalt and Tule Spring limestone, but is overlain by rhyolite.

The rocks are very similar in all exposures and show a black to dark-gray, very fine-grained groundmass, in which lie embedded scattered phenocrysts of small, fresh feldspar laths and slender hornblende needles. The microscope shows phenocrysts of labradorite and long prisms of dark-brown hornblende, more rarely hypersthene, in a hypocrystalline trachytic groundmass, chiefly consisting of slender laths of andesine or labradorite and often showing fluidal structure.

GEOLOGICAL STRUCTURE.

GENERAL CHARACTERIZATION.

Under the designation "structure" are described those changes of position which sedimentary or igneous rocks have suffered by the intrusion of magmas or by more gradual earth movements, including warping, doming, folding, and faulting.

The movements of this order which have taken place in the Clifton quadrangle may be divided as follows:

(1) The pre-Cambrian folding, probably accompanied by faulting.

(2) The pre-Cambrian disturbance of sediments due to granitic intrusions.

(3) The late Cretaceous or early Tertiary disturbance of sediments, due to intrusions of granitic and dioritic porphyries.

(4) The late Cretaceous or early Tertiary doming and faulting.

(5) The late Tertiary warping and faulting.

Of these the fourth is of preeminent importance, owing to its profound influence on the present configuration of the region and the distribution of the several formations. The resulting structures are shown graphically in the structure sections.

THE PRE-CAMBRIAN MOVEMENTS.

After the sediments which now constitute the Pinal formation were deposited and before the irruption of the granitic magmas these sediments were closely folded and converted to schists by regional metamorphism. Regarding the general result of this movement, with which faulting was probably associated, we have little information, owing to the fact that the bedding is largely obliterated. It is certain, however, that it affected a considerable part of Arizona, for similar schists are found at the Grand Canyon, at Globe, and at Bisbee. In the area at the head of Chase Creek stratification is fairly well preserved, and the strata stand usually at steep angles, with a northeasterly strike. The superimposed schistosity, which is more clearly indicated than the bedding, is also steep, but its strike diverges decidedly from that of the bedding. It is worthy of note that at no later period have any of the rocks of the quadrangle been affected by regional metamorphism producing schistosity on a large scale.

The intrusion of granitic magmas into the sediments was undoubtedly accompanied by violent ruptures, and the contact lines of schist and granite are probably determined by these dislocations. In the present case the schists may very likely occupy a large area in the northern part of the quadrangle underneath the volcanic flows.

MOVEMENTS DUE TO THE INTRUSION OF THE PORPHYRIES.

During the unbroken period of sedimentation from the Cambrian to the Carboniferous the strata remained horizontal. The unconformity between Cretaceous and Carboniferous is not strongly marked and, during the deposition of the former, the older strata preserved an approximately horizontal position. The first marked disruption of the stratified formations, which were at least 1500 feet thick and probably much more, for the original thickness of Cretaceous sediments is in doubt, occurred at the intrusion of the porphyry. That this movement was most violent can not be doubted, for a body of magma 7 miles long by 2 miles wide could not be intruded in the basement granite and overlying sediments without seriously affecting the position of the latter. The magma, which probably did not reach the surface, must have bulged the uppermost Cretaceous strata; it certainly dislocated the Paleozoic rocks extensively, injected itself between the beds, and tore large parts away from the edges of the fractured masses. A most important structural line was determined by this intrusion. The direction of the stock was northeast and the dike system at its north end, as well as the mineral lodes formed later, followed the same strike. Certain prominent fissures with northeast strike, soon to be filled with cupriferous minerals, were opened shortly after the intrusion. Somewhat later began the principal faulting movements, the general results of which consist in a settling and breaking down of the edge of the mountains toward the Gila Valley.

Fragments of granite engulfed in the porphyry are seen near Metcalf, both east and west of Chase Creek. Similar partly or wholly isolated fragments of the Paleozoic series are found at the contacts at Metcalf and at Morenci. In Gold Gulch irregular masses of both Cretaceous and Paleozoic rocks are in like manner embedded in the intrusive rock, which had a tendency to inject itself between the planes of stratification and form sills and laccoliths. Near the foothills of the Eagle Creek basalts several parallel thin slabs of limestone up to one-fourth mile long lie inclosed in diorite-porphyry and dip 20° W. Within the Cretaceous area the tendency of the porphyry to form laccoliths is more marked than in the Paleozoic rocks. The Cretaceous strata dip gently away from the western side of the large laccolith 2 miles south-southwest of Morenci, and appear to dip underneath it on the eastern side. The bulging of the pliable sediments under the influence of the intrusion of a large mass of porphyry which did not find outlet to the surface is believed to have been the cause of these disturbances.

PRINCIPAL EPOCH OF DOMING AND FAULTING.

General features.—After the irruption of the porphyry, but before the epoch of the great lava flows, occurred important earth movements during which the horizontal strata were deformed so as to acquire gentle dips, and profoundly faulted into a series of blocks which descend toward the south or southeast. This epoch of important disturbances occurred during the latest Cretaceous or perhaps rather during the earlier Tertiary. In fact, the movements continued, but with greatly lessened intensity, after the outbursts of the Tertiary lavas. The influence of this epoch upon the topography of the region is very strikingly marked.

Dips and strikes of the beds.—Gentle westerly, northwesterly, or northerly dips averaging 15° prevail over practically the whole quadrangle in the Paleozoic beds. In the northerly area on Tule and Whitewater creeks dips range from 10° to 15° NW., changing about Granville to almost due north. South of Enebro Mountain they are 14° to 20° NW. On Coronado Mountain they trend west, northwest, or north and amount to from 8° to 20°. The large blocks between the Coronado fault and the porphyry stock show dips averaging 17° due west, although local irregularities occur, in

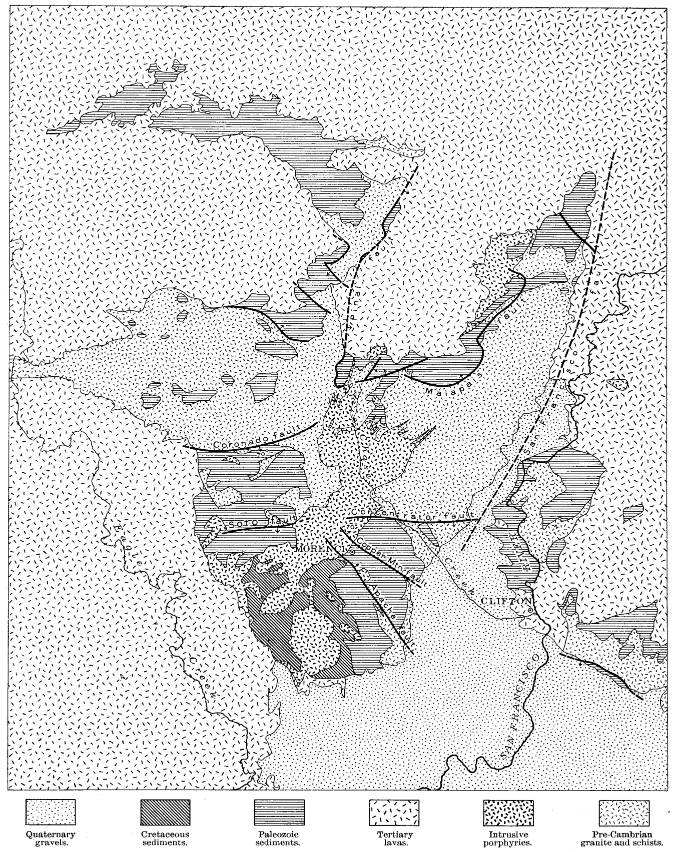


FIG. 2.—Generalized geologic map of Clifton quadrangle, showing the major faults.
Arrows show dip and downthrown side of faults.
Scale, approximately, 1 inch=2 miles.

part probably produced by the intrusion of porphyry. Exceptional westerly dips of 37° were noted in the Devonian at the extreme west end of the Coronado fault. Blocks south of Morenci dip 8° to 20° WSW. or more rarely SW.

Along the eastern side of the quadrangle similar relations prevail. South of Sardine Creek the dips are 10° to 30° NW. or N., and the same applies to the areas farther south, at Hackberry Gulch, Limestone Gulch, and south of Mulligan Peak, while the limestone north of Clifton and west of the river dips 25° to 30° W., similarly to the Morenci blocks. An exceptional dip of 55° NNW. was observed in the Ordovician limestone 1 mile northeast of Clifton.

Distribution of faults.—Faults belonging to this epoch are extremely common in the prevolcanic areas of the quadrangle, and the minor ones, at least, appear most abundant in the sedimentary areas, partly because more easily identified here by the aid of a comparatively thin series of beds. The fault planes divide the rocks into blocks of variable extent and shape (see fig. 2). They are, however, nearly always monoclinal, the beds dipping to the west and north at gentle angles, as has been stated.

The two most important blocks in the northwestern part of the quadrangle culminate in the Coronado Mountain and Pinal Point. In the Pinal block the base of the Coronado quartzite lies at an elevation of 7200 feet, and the strata dip away gently to the northwest, so that in the limestone area on Tule Creek the elevation of the lower part of the Tule Spring limestone is 5000 feet; this would correspond to an average dip of 6° or 7° NW. The block is broken by several small dislocations, but probably none of large size.

The Coronado block slopes gently westward. At the eastern side of Coronado Mountain the base of the Cambrian quartzite is at an elevation of 7000 feet, while 6 miles farther west, just outside of the quadrangle, the same contact is at an elevation of about 4300 feet, giving again a dip of 6° or 7° W. On the northern and southern slopes of Coronado Mountain small patches of quartzite lie on the curved surface of the granite, with divergent dips up to 20° (see areal geology map), showing that the granite itself, the fundamental rock of the block, has been deformed in dome-like shape.

Between the two blocks is a structural depression in which several smaller blocks of the Paleozoic sediments have sunk from 1000 to 2000 feet below the general elevation. On the north side these smaller blocks are separated from the Pinal schists by a displacement of nearly 2000 feet, divided into at least two probably nearly vertical faults. On the south side they are limited by a curved fault plane which evidently has a decided northward dip and is excellently exposed in Knight Creek.

On the south and east the Coronado and Pinal blocks are bordered by two dislocations of the first importance, indicated in fig. 2 as the Coronado and Pinal faults. Probably the two are practically continuous, though the direction swings from nearly due east in the former to north-northeast in the latter. Along the Coronado fault a large block to the south, including the whole of the Morenci hills, has sunk from 1000 to 2000 feet, the smaller figure occurring at the Coronado mine and the larger at the point in Horseshoe Gulch where the dislocation is covered by Tertiary lavas. The fault plane is well exposed in the Coronado mine and is, in fact, followed by the Coronado copper vein. It dips 70° S. and is accompanied by a zone of friction breccia at most 200 feet wide. Irregular masses of diabase lie along the fault plane.

Steep granite bluffs with very well-defined jointing and sheeting, striking north-northeast and dipping 70° ESE., border Coronado Mountain on the east and indicate that the fault line has swung around and here follows a north-northeast strike. The dislocation is splendidly shown near the mouth of Garfield Gulch, where a sunken limestone block lies at the foot of an imposing scarp, and the sharply defined fault plane dips about 50° ESE. From this point northward it is partly hidden under the lavas which fill the bottom of the canyon, but the bold bluff of the escarpment continues on the west side up to the head of the south fork of Sardine Creek, where the vertical throw is again measured to 2000 feet and the fault plane also has a decided eastward dip.

The Copper King block, to the east of the Coronado block, has a similar elevated position. Both may indeed be considered as "horsts," or isolated masses bordered by fault lines and surrounded by sunken crust fragments. The Copper King block, which culminates in the mountain of the same name, extends in a north-northeast direction along the west side of San Francisco River from Chase Creek to Sardine Creek. Its highest elevation is 6825 feet, and as its granitic dome is not covered by quartzite beds except at the north end its exact relative height can not be determined, though it is probable that the now eroded quartzite once covered its summit at an elevation of about 7000 feet. The dip of the block is evidently gently north or northwest, for near its north end at Silver Creek the Coronado quartzite caps the granite at an elevation of 5000 feet. On the north side the block dips below the lavas at Sardine Creek. On the west, separating it from the Coronado block, lies a structural depression, or "graben," the lowest portion of which is marked by the Paleozoic series on Shannon Mountain and at the mouth of Garfield Gulch, referred to above. The dislocation which separates Shannon Mountain from the Copper King block probably consists of a series of northeast-trending faults between Placer Gulch and Markeen Mountain, but these faults are not distinctly traceable and therefore are not shown on the map. The downthrow on the northwest side of Markeen Mountain is at least 2000 feet. Farther northeast the throw on the west side of Copper King block diminishes, but is more clearly marked along the Malpais fault zone; the fault plane probably dips northwest at moderate angles. At the south end of the Malpais fault the drop is only a few hundred feet, and it diminishes still further up toward Silver Creek.

On the south side the Copper King block is separated from the depressed area of the Morenci hills by the steep Concentrator fault, along the south side of which a drop of at least 2000 feet has taken place. The throw diminishes greatly west of Chase Creek. On the east side the Copper King block is limited by the San Francisco fault, which is the greatest dislocation in the quadrangle and extends parallel to the Pinal fault. The total dislocation as measured at Evans Point is at least 3500 feet, although it is probable that this amount is to some extent distributed on subordinate faults and joint planes not easily traceable in the granite. The throw diminishes considerably northward, and at the point where the canyon of Silver Creek breaks through the fault block the actual composite nature of the fault is discernible. The dislocation finds topographic expression in the imposing dark-red granite bluffs which for several miles follow the river on the west side. The actual fault plane is all along hidden by lavas or gravels and since it can not be definitely located it has not been shown on the geologic map, but is shown in the structure sections. At Evans Point the plane lies only a short distance west of the exposures of Longfellow limestone, which dip 20° W. or NW. along the west bank of the river.

Topographically as well as structurally, the lowest exposed block in the quadrangle is that on the west side of the river from Evans Point to Clifton; this may be called the Clifton block. The base of the Coronado quartzite is calculated to lie at an elevation of about 2300 feet, or 3800 feet below its position on Coronado Mountain.

On the east side of San Francisco River lies what may be termed the Nortiz block; the contact of Coronado quartzite and granite has here elevations of from 4000 to 4500 feet, and the block has thus about the same elevation as those near Morenci. Three smaller areas of Longfellow limestone just east of the boundary of the quadrangle and north of Limestone Gulch indicate that the Nortiz block continues for some distance eastward with gentle rise.

The Nortiz block is separated from the narrow Clifton block by a dislocation with a throw of 800 or 900 feet, which follows approximately the trend of the river between Evans Point and Clifton. As seen from the map and the sections it has peculiar characteristics. The fault plane is here evidently a curved surface, beginning parallel to a plane of stratification in the Longfellow limestone, cutting obliquely across the Coronado quartzite, and entering the granite just below the base of the quartzite. The effect has been to draw the Longfellow limestone down over a granite surface gently sloping westward at an angle of about 20°. The surface of the broad granite salient on the east side of the river just south of Evans Point practically coincides with the fault plane. The contact of limestone and granite is well exposed on the west side of the river at Evans Point. It dips here gently northwest and the granite and limestone are separated by a layer of very soft granite, 1 foot thick, containing well-rolled cobbles of hard granite, evidently produced by the friction. Eight feet above the contact the limestone contains a streak of granitic sand, which again incloses granite cobbles up to 10 inches in diameter. On the south the Nortiz block is bounded by an extremely well-marked fault which follows Ward Canyon with an east-southeast trend. The fault plane dips 60° or 70° S. and small masses of downfaulted limestone may be seen along the bottom of the canyon. As far as can be made out on account of covering gravels, the vertical throw is about 600 feet.

The region south of the Coronado fault and west of Chase Creek is cut up into five large and many smaller blocks (see fig. 3), the strata of practically all of which dip west or southwest at angles ranging from 10° to 20°. The first large fault south of the Coronado is the Soto (fig. 2), along which a further drop of from 400 to 800 feet has taken place. The throw diminishes toward the western end of the fault. The nearly vertical fault plane, striking east-west, is exposed in the Soto tunnel in Pinkard Gulch.

The Concentrator fault is almost an eastern continuation of the Soto, and may be studied along the slopes of Chase Creek Canyon 1 mile northeast of Morenci. Granite and Coronado quartzite have been brought into juxtaposition from the bottom of Chase Creek Canyon to the summit of the hill at the Arizona Copper Company's concentrating plant, a vertical distance of 1000 feet. A narrow block just south of the main fault plane has suffered the greatest dislocation, for immediately to the south lie several parallel step faults along which the contact of granite and quartzite gradually rises until it occupies its normal elevation in this block—about 4500 feet. The Concentrator fault continues across Chase Creek, rapidly gaining in vertical throw as it approaches Markeen Mountain. At the southern foot of this mountain the downthrown quartzite block is exposed and has evidently suffered a dislocation of at least 2000 feet. The throw continues to increase until the Concentrator fault reaches the San Francisco fault.

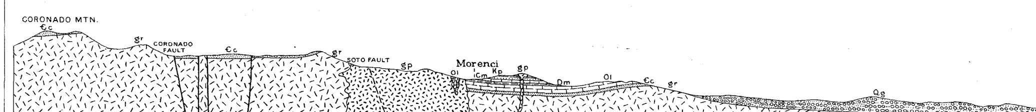


FIG. 3.—Cross section along line E–E on areal geology map.

Qg, Gila conglomerate; Kp, Pinkard formation; Cm, Modoc limestone; Dm, Morenci formation; Ol, Longfellow formation; €c, Coronado quartzite; gp, granite-porphyry; gr, pre-Cambrian granite.
Vertical and horizontal scale, approximately, 1 inch=1 mile.

South of the Soto and Concentrator faults the Paleozoic series is broken by three principal northwestward-trending faults. The first one is the Copper Mountain fault, which follows the course of Morenci Canyon and along which the northeasterly block has moved down 225 feet vertically and 70 to 90 feet horizontally toward the southeast. The fault plane dips 60° or 70° NE. and is well exposed in the Morenci mines, as well as along Morenci Canyon, where it is followed, in the quartzite, by thin sheets of friction breccia. The second dislocation is called the Apache fault zone, and along it the east side has dropped about 800 feet, the throw probably diminishing to the north, at the point where it crosses the extreme western head of Morenci Gulch.

Parallel to this fault and half a mile west is the fault along the east side of Silver Basin, which shows a downthrow on the west side of about 200 feet.

There are many other faults of minor importance which can not be described here in full. One of these is parallel to Chase Creek south of the Concentrator fault, and is indicated by the fact that the quartzite beds on the east side of the creek lie several hundred feet lower than on the west side. At the point in Chase Creek where the Morenci road turns up the hillside the breaking up of the strata into small blocks is excellently illustrated. A small area of Coronado quartzite has here become detached from the main mass and settled along fault planes almost to the level of Chase Creek.

Summary.—Faulting has taken place along two principal directions, (1) east-west and (2) north-northeast to south-southwest, and in each case the blocks to the south and east are those which occupy the relatively depressed position. This general statement finds corroboration in the Coronado east-west fault, continued in the Pinal fault trending north-northeast, and, a few miles farther south and east, in the Soto and Concentrator east-west faults, continued in the San Francisco fault, trending north-northeast. Many minor faults trending northwest or northeast divide the larger blocks. The principal fault planes are not vertical, but dip south or east at angles ranging from 45° to 70°. The minor faults near Morenci, of which the Copper Mountain fault is an example, dip 60° or 70° NE. Still flatter fault planes are exemplified by that south of Evans Point, where the dip is only 20° and where the Longfellow limestone over a large area has been drawn down over the granite.

The faults are in all cases normal, accompanied by a relative depression of the hanging wall. The greatest depression has usually taken place immediately along the fault plane; a little farther away the thrown block is very apt to rise gradually or by step faulting. The greatest vertical throws are those of the Pinal fault (2000 feet) and the San Francisco fault (over 3000 feet).

Unequal settling is of common occurrence; the difference in throw for points 2 miles apart along the fault may reach 1000 feet. In some cases this involves considerable changes of dip of the strata.

Faulting shows decided influence on topography. All of the principal faults are strikingly marked by prominent scarps. This is especially emphasized in the Pinal, Coronado, San Francisco, and Ward Canyon faults, the height of the fault scarp being in all cases about the same as the vertical throw. No doubt this remarkable preservation of fault scarps was aided by the lava floods which soon covered the broken blocks and which have been only comparatively recently removed by erosion.

The drainage is very decidedly influenced by the faulting. The course of San Francisco River north of Oroville follows the fault line; other instances are furnished by Chase Creek above Metcalf, Horseshoe Gulch, Morenci Gulch, Apache Gulch, and Ward Canyon.

A doming or bending of the crust, including the granite, either preceded or accompanied the faulting. This is best shown by the exposures of quartzite on Coronado Mountain. Whether the granite was actually somewhat plastic or was deformed along joint planes is left undecided. Possibly both kinds of movement took place.

Age of the faulting.—The dislocations took place after the intrusion of the granite- and diorite-porphyries, but before the eruption of the principal lava flows. An epoch of erosion of considerable length intervened between these two events and laid bare the central masses of the porphyry stock. On the other hand, the faults do not continue into the capping lavas. The main period of faulting, then, falls between the latest Cretaceous and the middle Tertiary.

Minor faults north of Malpais Mountain and on Whitewater Creek show, however, that small dislocations have occurred subsequent to the eruptions of Tertiary lavas, and in the eastward extension of the Prieto Plateau beyond the boundary of the quadrangle a fault was observed in a rhyolite bed inclosed in basalt; its vertical throw is about 200 feet. It is possible that movement has taken place on some of the older fault lines subsequent to the Tertiary eruptions. The persistent but gentle dip of the rhyolite tuff toward the fault plane along the San Francisco River north of Harper ranch suggests this possibility, as does also the basaltic escarpment rising above Prieto Plateau between Sardine and Pigeon creeks. It is certain that the main faulting preceded the volcanic flows, but on the other hand the freshness of the fault escarpments, wherever exposed by erosion of the lavas, indicates that one event followed the other very closely. All these facts tend to place the epoch of faulting well into the Tertiary period.

At Globe, in central Arizona, where similar extensive shattering has taken place, Mr. Ransome (Geologic Atlas U. S., folio 111) finds that the principal faulting has taken place after the eruption of certain dacitic surface lavas, but before the deposition of the Gila conglomerate and certain associated basalts. The time of this faulting is tentatively placed in the middle of the Tertiary period.

Origin of the faulting.—The difficult question of the origin of the crust movements described in the above paragraphs remains unanswered. It is held by many that such phenomena are due to the breaking and settling of the crust due to gravity, and the fact that all of the faults are normal tends to confirm this. On the other hand, several of the most important fault planes have dips of from 60° to 45°, and many of the minor ones are still flatter. In such cases it would seem that gravity opposed by friction could not have accomplished the results observed, but rather that actual stretching movements have taken place and that these were aided by gravity.

GEOLOGICAL HISTORY.

SEDIMENTARY RECORD.

The oldest records are less well preserved in the Clifton quadrangle than in any other parts of Arizona, but still reach back to pre-Cambrian time, when a low, gently undulating land area of red, coarse granite, with more prominent points of harder quartzitic schists, was spread out where the hills of Morenci and Coronado now lift their summits high above the sea level. Dim indications hint at a far older basement on which these quartzite schists were deposited, at mountain-building forces which compressed the sediments between them and made them schistose, at an intrusion of red granite which almost engulfed the sediments, and at a long period of erosion which planed down the rough topography produced by the orogenic forces to the smooth outlines of the plain referred to above. Animal and vegetable life probably did not grace that barren land, but the rains and the storms beat on its surface then, as now, for underneath the covering sediments is clear evidence of weathering, disintegration, and oxidation.

At first streams flowed over its surface, accumulating in their beds pebbles of resistant quartzite from neighboring areas. The uneven distribution of this basal conglomerate proves that the land area was accentuated, while the fairly even thickness of the covering quartzite shows that the topography was not of a rough character. Intimate mingling of sandy conglomerates with sandy disintegrated rock also indicates an epoch when the sea had not yet invaded this land, though the invasion was not distant and the waves soon covered the low hills. Abrasion by the sea and erosion by the streams soon accumulated the Coronado sandstones, in the uppermost part of which scant shell remains point to a Cambrian age. Submersion and deposition continued unbroken during the Ordovician period, but the sediments soon became prevailingly calcareous. The Silurian seems to be absent, though no unconformity can be observed between the Ordovician Longfellow limestone and the covering rock, which is probably Devonian. The sea again grew more shallow, but no granite or quartzite remained above water to supply quartzose sediments; these came from more distant quarters. The limestones became argillaceous and soon changed into clay shales. Both of these terranes have been referred to the Devonian on rather scant evidence from the meager fauna.

Above the Morenci shales, in a deepening sea, was deposited a series of limestones, first dolomitic, then remarkably pure and rather coarse, the Modoc and Tule Spring limestones of the Mississippian and Pennsylvanian epochs. Throughout the whole of the Carboniferous animal life was abundant and rich faunas may now be collected in many places.

The time interval between the Carboniferous and the middle Cretaceous is not represented by any sediments; there is, on the contrary, evidence of an epoch of erosion, for the Cretaceous rests unconformably on the Mississippian at Morenci, where the Pennsylvanian is not present. The disturbance was, however, not great and the Cretaceous strata were deposited on the nearly horizontal, partly eroded Carboniferous. During the last subsidence under the Cretaceous sea the sediments deposited consisted of coarse sandstones and carbonaceous shales, indicating moderate depth and clearly not derived from the granite of this vicinity, but rather from somewhat distant land areas. The total thickness of the Cretaceous is unknown; the larger part of the series may, in fact, have been removed by erosion.

This long era of deposition without far-reaching orogenic disturbances was followed by intense intrusive activity, beginning in the earliest Tertiary or in the latest Cretaceous. Masses of acidic porphyries, with some diorite-porphyries, broke through the crust, filled great spaces made for them by gradual or violent dislocations, and congealed to stocks, sheets, dikes, and laccoliths in the disrupted granite and sediment. These intrusions practically form one connected mass, extending from Eagle Creek to Copper King Mountain, and have been exposed only by erosion.

The intrusive bodies were thus consolidated far below the surface at that time; just how far below is doubtful, but at any rate the distance can not well have been more than a few thousand feet for their upper portions, and it may have been less.

The porphyries in cooling produced far-reaching metamorphism of such of the adjacent sediments as were susceptible of this alteration, and the introduction of sulphides of various kinds accompanied the contact metamorphism. Shortly after the consolidation fissures broke open, following the general northeast direction of the stock and dikes, and became filled with cupriferous pyrite, zinc blende, and other minerals. Soon after this intrusion a great uplift must have taken place, raising the heavily sediment-laden crust to high elevations and producing in it, as well as in the underlying partly plastic granite, gentle dome-shaped swells or anticlines. The uplifted area later broke into fragments, which gradually settled down, forming monoclinal blocks around the more resistant buttresses of Coronado and Copper King mountains and fracturing still further as they settled.

The country was now a land area with rough topographic features, to which the faulting contributed important elements. Active erosion following the epoch of faulting has not entirely effaced this influence, and, though obscured by the Tertiary lava flows, the fault scarps are still dominant features, visible in the granite bluffs of Coronado and Copper mountains and the downthrown valley between them. During this epoch of erosion the principal valleys, like those of Chase Creek and San Francisco River, were carved. The valley of the latter is, however, primarily of structural origin, being determined by the great San Francisco fault.

Volcanic eruptions of great volume took place in the later part of the Tertiary period. They consisted of thrice-repeated flows of rhyolite and of basalt, with subordinate flows of andesite. In places they are 2000 feet thick and practically surround the old granitic buttresses.

Next followed a second epoch of erosion, accompanied by the deposition of thick detritus in front of the mountains—the coarse accumulations which have been called the Gila conglomerate; much material for this was supplied by the enormous volcanic masses north of the plains. This epoch is referred to the early Quaternary.

Renewed activity of the streams took place during the late Quaternary and on the sloping plains of the Gila conglomerate the abrupt little canyons of the present day were excavated.

Lastly must be mentioned the gradual changes which have been going on since the mineral deposits were first exposed by erosion—a continuous oxidation, solution, and redeposition of minerals, among these the copper ores, within the zone easily accessible to surface waters. Inconspicuous and slow as these processes are, they have resulted in the transformation of poor primary ores into the rich and extensive bodies which have placed the Clifton-Morenci district among the first ranks of copper producers.

PHYSIOGRAPHIC RECORD.

Under this heading it is proposed to discuss briefly the origin of the present topographic forms. The subject has already been referred to briefly in the section on topography.

The present surface forms are influenced by (1) the eruption of lavas, (2) sedimentation, (3) faulting and doming, and (4) erosion.

The first agency has determined the roughly plateau-like form of the northern, eastern, and western lava fields, which, however, the fourth agency (erosion) has greatly modified. The second agency has determined the sloping plain of the Gila conglomerate at the foot of the mountains. The third agency has outlined the two principal blocks of Coronado Mountain and Copper King Ridge, caused the step-like lowering of the areas of older rocks south of the Coronado fault, and determined the course of San Francisco Valley. Owing to the protective influence of the covering lavas this factor has been far more important in shaping the great features of this region than of areas where erosion has had full sway in its work of destroying the topographic evidences of dislocation. As shown above, under the heading "Geological structure," faulting has influenced stream courses in a remarkable degree.

The fourth and by far the most important agency, as far as the details of topography are concerned, is erosion. Several epochs of erosion can be distinguished:

(1) The pre-Cambrian land and marine erosion which modified the surface of the granite and schists before the deposition of the Coronado quartzite.

(2) The post-Carboniferous to Upper Cretaceous erosion which slightly modified the monotonous land surface before the deposition of the Pinkard formation.

(3) The post-Cretaceous erosion.

The last epoch is the only one that is important in connection with a discussion of the present surface forms. Erosion began after the great uplift which followed the intrusion of the granitic and dioritic porphyries, probably during the earlier part of the Tertiary, and had accomplished a considerable amount of work, the details of which are unknown, when its whole system of attack was profoundly changed by the great dislocations which took place and which outlined a very different plan of drainage.

Very shortly afterwards the lava flows overwhelmed the country and previous topographic forms were to a great extent blotted out.

Before the lava flows the structural depression of San Francisco Valley existed, but whether it was occupied by a river of the same size as the present stream is very doubtful. The depressions now covered by the Gila conglomerate also existed then, but Chase Creek probably did not. Instead, there was a very pronounced depression beginning near the head of the present Chase Creek, extending in a northerly direction across the present Sardine Creek, and probably also draining northward. The lava contacts show that the country over which the fiery streams poured out was deeply eroded and had, in fact, a topography almost as pronounced as the present. As now, the Coronado and Pinal blocks drained westward.

During the maximum stage of volcanic activity, perhaps just after the Prieto flows of basalt, the most prominent topographic forms consisted of broad, monotonous lava plateaus, which rested against the central area of older rocks, without, however, fully covering them. San Francisco Valley still existed, though partially filled by flows coming down from the east. The plateau was most strongly developed in the northern part of the quadrangle, where the Prieto Plateau extended across the present Sardine Creek toward Malpais Mountain. The high basaltic escarpment west of the Prieto Plateau has been referred to under the heading "Geological structure;" its origin is not satisfactorily explained. A thin débris cover of rhyolite was distributed over the surface of the Prieto Plateau from the succeeding rhyolite eruption, before the Sardine Creek drainage had been fully established.

After the basalt eruptions erosion was extremely active. The present general course of Eagle Creek was laid out in the depression between the southwestern basalt dome and the Coronado and Morenci hills, and was excavated as a narrow canyon to practically its present depth. The last eruptions of the rhyolite tuff of Enebro Mountain then followed as thick mud flows, filled the depression between Coronado Mountain and the basalt ridge north of Tule Creek, and poured down the narrow canyon of Eagle Creek, filling it to a level of 4500 feet, as is well shown by the remnants of tuff along its present course. Over the constructive surface of this tuff the present course was then established, and the creek has again reached its former depth by erosion through tuff and the covering Gila conglomerate.

At this time a general consequent drainage was laid out over the sloping volcanic tables. As shown by Sardine, Whitewater, Tule, and Knight creeks, it was very irregular and probably followed chance inequalities of the surface. Sardine Creek is distinguished by the deepest and most sharply incised canyon.

San Francisco River, which previous to the volcanic epoch found its outlet by way of Limestone Gulch and Clifton, was by the eruption crowded toward the fault scarp and flowed in the narrow channel now filled with Gila conglomerate just south of Rocky Gulch. The course of Chase Creek was determined by the filling of the deep depressions near Sardine Creek and Malpais Mountain, referred to above, and the drainage was forced southward.

This most important epoch of erosion, during which all the principal present features of the mountain mass became established, began in the latter part of the Tertiary during and shortly after the volcanic activity, and has in fact continued until the present day, although at one time the erosive power was checked by the rising of the level of deposition in the valleys and the formation of the Gila conglomerate. When these detrital rocks were spread like a sloping plateau in front of the mountain area to a marginal elevation of 4500 feet the principal drainage lines of the higher part of the quadrangle were the same as those of to-day, but when in the latter part of the Quaternary the rivers began to attack and erode the detrital material the lower stream courses were established along new lines on the gravel table. San Francisco River deviated from its old course at Rocky Gulch and turned almost due south for several miles and then to the southwest. Likewise were established lower Chase Creek and the many long consequent gulches which traverse the constructive mesa of the Gila conglomerate to join San Francisco River. The river deepened its box-like canyon rapidly and north of Clifton soon began to erode the older rocks underneath the gravels. With shorter interruptions, accompanied by the formation of gravel terraces along the canyons, this deepening process continued, until now the river is 600 feet below the general level of the gravel plateau.

ECONOMIC GEOLOGY.

MINERAL RESOURCES.

COPPER.

The Clifton quadrangle contains many copper deposits. This is, in fact, the only metal produced in large amounts, and the deposits of copper ores at Morenci and Metcalf are among the most important in Arizona.

Only a brief description of these is here given, for the subject has been treated in detail in Professional Paper No. 43, United States Geological Survey, to which the reader is referred for additional information.

PRODUCTION AND DEVELOPMENT.

The ore deposits were discovered in 1872, but for many years their development was slow, as only rich ores could be utilized and as the district was far distant from established lines of communication. Since 1890, however, the progress has been rapid and at the present time, when large bodies of low-grade ore are utilized, the production has reached high figures. Two strong companies, the Detroit Copper Company and the Arizona Copper Company, have contributed by far the greatest part of the production since 1882, and since 1902 a third, the Shannon Copper Company, has been added. The mines of the Detroit Company are located at Morenci, those of the Arizona Company at Morenci and Metcalf, and those of the Shannon Company at Metcalf.

In 1902 the total production rose to 49,500,000 pounds of copper and in 1903 it had attained 53,400,000 pounds, with a value of about $7,400,000. Of the production in 1903 the Arizona Company contributed 30,228,000 pounds, the Detroit Company 16,558,232 pounds, and the Shannon Company 6,600,000 pounds. The ores mined average 3 to 4 per cent of copper. The monthly output of ore in 1902 was about 60,000 short tons. Of this, 47,000 tons were classed as concentrating ore and 12,000 tons as higher-grade smelting ore with 6 to 10 per cent copper. The Arizona Company smelted the lowest grade of ore, while the Detroit Company averaged somewhat higher. The ores of the Shannon Company were in 1902 exclusively oxidized ores containing about 8 per cent copper, but since then this company has also begun the mining of concentrating ore. By far the larger percentage of ore mined in 1902 consisted of sulphide ore containing pyrite and chalcocite. Of oxidized ores about 13,000 tons per month were mined at Metcalf and a steadily diminishing amount of 1500 tons per month at Morenci, making a total of 14,500 tons, or about one-fourth the total production. The output of oxidized ore at Metcalf will continue for a number of years and possibly increase. The oxidized ore mined by the Arizona Copper Company at Metcalf is the lowest grade utilized in the district and probably contains on an average less than 3 per cent.

The total output of the district to the end of 1903 is estimated to be about 201,600 short tons of copper, having a value of approximately $60,500,000.

Clifton is second in importance in Arizona as a copper-producing camp. In 1903 Bisbee produced 62,500,000 pounds of copper, Clifton 53,400,000, and United Verde 28,600. The production of Arizona is at present a little more than one-fifth of the total production of the United States.

The Morenci and Metcalf districts are not distinguished by the great depth attained in mining. At Metcalf all of the deposits are worked by open cuts or tunnels, as they occur near the surface of Shannon Mountain. At Morenci, where the more important deposits underlie Copper Mountain, two of the largest mines, the Copper Mountain and the Humboldt, are still worked by tunnels, while others, like the Arizona Central and the Ryerson, are opened by shafts less than 400 feet in depth. The celebrated Longfellow deposit was mined from four tunnel levels, the Manganese Blue by a shaft 400 feet deep, and the Detroit by a shaft about 300 feet deep.

OCCURRENCE AND GENERAL FEATURES OF ORE DEPOSITS.

The geographical distribution of the copper deposits is practically coextensive with the great porphyry stock and its dike systems. The deposits occur either in the porphyry or close to its contacts, or along dikes of porphyry in some other rock. Areas in which no intrusions have taken place are practically barren. This intimate connection with the porphyry is certainly a most important fact. There is only one small division of deposits—namely, that connected with the diabase dikes—which deviates from this rule.

Practically all types of deposits contain copper as the most valuable metal. Gold and silver occur, as a rule, only in minute quantities, except in some of the outlying districts, where they become more important. The two principal mining centers, Morenci and Metcalf, which are 3 miles apart, are both situated at the main contact of the porphyry stock and the series of Paleozoic limestones. Elsewhere the intrusive rock generally adjoins granite or Cretaceous sediments.

The ores consist of chalcocite, chalcopyrite, malachite, azurite, chrysocolla, brochantite, cuprite, and native copper. Covellite and bornite are practically absent. Brochantite, the basic copper sulphate, is very commonly present, especially in oxidized veins in porphyry, and, in fact, constitutes in places an important ore. On account of its similarity to and intimate intergrowth with malachite it has usually been overlooked.

The following-named minerals have been found in the district: Native copper, native gold, quartz, chalcedony, rutile, magnetite, hematite, limonite, pyrolusite, coronadite (a new mineral, chiefly PbO and MnO_2), cuprite, pyrite, chalcopyrite, zinc blende, galena, molybdenite, chalcocite, diopside, tremolite, garnet, epidote, muscovite, chlorite, serpentine, asbestos, kaolin, willemite, calamine, dioptase, chrysocolla, copper-pitch ore, morencite (a new mineral, chiefly a ferric silicate), calcite, dolomite, zinc carbonate, malachite, azurite, libethenite (copper phosphate, not previously found in the United States), brochantite, alunite, gypsum, spangolite (basic chlorosulphate of copper and aluminum), chalcanthite, goslarite, epsomite, and gerhardtite (basic copper nitrate forming green crusts on weathered surfaces of porphyry and associated with a copper chloride, possibly atacamite).

The deposits containing payable copper ore take many widely differing forms, as follows:

- Deposits in limestone and shale, not connected wit'. fissure veins, all carrying oxidized ores almost exclusively; rarely chalcocite:
  - Irregular bodies near contacts of main stock or dikes.
  - Tabular bodies near contacts of main stock or dikes, following stratification.
  - Tabular bodies following contacts of porphyry dikes.
- Fissure veins:
  - Normal veins in porphyry or in any of the other rocks near porphyry contacts. Include central veins and surrounding partly replaced porphyry, forming together a lode. Carry chalcocite as the important ore; in upper levels also sometimes oxidized ores.
  - Normal veins following porphyry dikes in granite. Chalcocite and oxidized copper ores.
  - Normal veins following diabase dikes. Chalcocite and oxidized copper ores.
- Stockworks. Irregular disseminations in porphyry, quartzite, and other rocks. Contain chalcocite and oxidized copper ores.

The above classification is based on the occurrence and form; a more general genetic system, including the unpayable pyritic deposits, would show a somewhat different arrangement.

Native copper, all of the oxysalts of copper, and chalcocite are wholly secondary minerals produced by direct or indirect oxidation from primary pyritic ores. In all of the divisions given above, this primary ore consists of pyrite and chalcopyrite, with some zinc blende and molybdenite. The scant gangue of the veins consists of quartz, while the deposits in the first division are usually accompanied by garnet, epidote, magnetite, diopside, or by their products of oxidation.

Contact-metamorphic deposits.—There is no evidence that ore deposits were formed in this region before the intrusion of porphyry. This event appears to have had most intimate connection with the origin of all the copper deposits in the region. Wherever the porphyry came into contact with the granite or the quartzite little alteration can be observed; but wherever the porphyry adjoins the limestones or the shales of the Paleozoic series the sedimentary rocks have undergone very extensive contact metamorphism, resulting in the formation of large masses of garnet and epidote. This alteration is particularly observable at Morenci. The whole Paleozoic series is affected, but more particularly the pure limestone of the Mississippian, which for a distance of several hundred feet from the contact has been converted into an almost solid mass of garnet. The shales have suffered less from this metamorphism, but near the porphyry are apt to contain epidote and other minerals. This metamorphism appears not only at the contact of the main mass of porphyry forming the southern slope of Copper Mountain, but also in the hills between Morenci and the Longfellow mine, in which dikes have produced contact-metamorphic minerals along their sides. Wherever alteration has not masked the phenomena magnetite, pyrite, chalcopyrite, and zinc blende accompany in various proportions the contact-metamorphic minerals and are intergrown with them in such a way that the contact-metamorphic origin of these ores appears beyond doubt. In many places the ores have accumulated along certain horizons in the sedimentary series, evidently more suitable than others to the processes of alteration which produced the deposits. These contact-metamorphic deposits, it is believed, were derived from the water and the metallic substances which were originally contained in the magma of the porphyry, and which were released by decreasing pressure at the time of the intrusion of the rock into higher levels of the earth's crust. We may thus speak of these deposits as contemporaneous with the cooling and solidification of the porphyry.

As to form, the ore deposits in limestone are often wholly irregular, but more frequently, perhaps, tabular in shape, because of the accumulation of the minerals along certain planes of stratification.

Oxidizing waters have very greatly altered the deposits in limestone. The sulphides have been converted into carbonates, and malachite and azurite are the most common ores. Cuprite also occurs extensively, and seems to form as a rule in the Devonian shale. Chalcocite and other sulphides are almost entirely absent. The zinc blende has been carried away as sulphate of zinc, which is frequently found in efflorescence on the walls of the tunnels. The magnetite and garnet which originally formed a part of these deposits have also undergone decomposition, the resulting minerals being silica and limonite.

The celebrated Longfellow mine is worked on one of these deposits, occurring as, roughly speaking, a funnel-shaped mass in the Ordovician limestone, between two large porphyry dikes. Farther west along the main porphyry contact is the Montezuma mine, and still farther the Detroit and the Manganese Blue mines. Both of the latter mines were worked on several tabular ore bodies, three or more in number, occurring in horizons ranging from the Ordovician to the Pennsylvanian. All of these deposits are now almost exhausted. They contained a large quantity of very rich carbonate and oxide ore. These ore bodies were, however, much smaller in extent than the large masses of chalcocite ore which now form the main support of the camp.

The Shannon mine at Metcalf contains several ore bodies of similar origin. A fragment of the Paleozoic series outcrops on Shannon Mountain, and is cut by an extensive system of porphyry dikes, which in the lower part of the mountain join the main part of a large intrusive body of porphyry. At several horizons the limestones are greatly altered, the final product generally being copper carbonates and limonite, with some quartz. In some places the ore bodies are less affected by oxidation, and their original character of garnet, epidote, magnetite, and sulphides may be plainly seen.

Oxidation by surface waters, as at the Shannon mine, also diffused much copper as chalcocite in some of the porphyry dikes, and the Metcalf mine, on a lower spur of the same hill, consists chiefly of a body of extremely decomposed porphyry containing chalcocite and carbonates. Very probably this copper has migrated into the decomposing porphyry from bodies of contact-metamorphic rock at higher elevation, parts of which are probably now eroded.

Fissure veins.—At many places in the district the copper deposits consist of fissure veins, cutting alike porphyry, granite, and sedimentary rocks. From the available evidence it would seem as if these veins had been formed a short time after the consolidation of the porphyry. In lower levels the veins consist of pyrite, chalcopyrite, and zinc blende, magnetite being noticeably absent. At the surface many of the veins have been completely leached, and now show nothing but limonite and silicified porphyry. This rule is, however, not a general one, as, especially in porphyry, oxidized ores are sometimes found in the outcrops of the deposits. Between the leached outcrops and the deep ores of pyrite and chalcopyrite is a more or less extensive zone of chalcocite or copper glance, deposited by secondary processes and replacing the pyrite.

The most important vein system is that which, under the general name of the Humboldt lode, extends from northeast to southwest through Copper Mountain at Morenci. The outcrops of this vein are practically barren, but at the depth of about 200 feet the deposit becomes productive and contains chalcocite associated with pyrite. There are usually one or more central seams of massive chalcocite, some of which are fairly persistent. These seams are ordinarily adjoined by decomposed porphyry, now consisting chiefly of sericite and quartz, together with pyrite and chalcocite. These extensive impregnations of the country rock are rarely confined by distinct walls, but gradually fade into the surrounding porphyry. That these deposits are genetically connected with fissure veins, however, can not be doubted. In lower levels the ore is apt to change to pyrite and chalcopyrite. Both the Arizona Copper Company and the Detroit Copper Company are now working the low-grade bodies of chalcocite ore accompanying the veins. The reserves thus far opened assure a high production for many years to come.

Parallel veins, somewhat narrower, but similar in character, are opened by the Arizona Central mine, also at Morenci. These veins are partly in porphyry, partly in contact-metamorphosed limestone. While malachite and azurite sometimes occur, they are by no means as prominent as in the limestone deposits, and frequently the leached surface zone is immediately adjoined by the chalcocite ore.

The Coronado mine represents a different type of deposits, formed on a fault fissure between granite and quartzite, indicating a throw of at least 1000 feet. The fissure is followed in places by a diabase dike, which shows some effect of crushing and movement on the vein. The outcrops contain copper carbonates and silicate, but these minerals change at slight depth to chalcocite, and it is believed that the ore minerals still farther down consist chiefly of pyrite and chalcopyrite.

Somewhat different again are the fissure veins on Markeen and Copper King mountains. The granite of this complex of hills is cut by a great number of porphyry dikes, which generally have a northeasterly direction. Along many of these dikes movement and fissuring have taken place, and varying amounts of copper ores have been deposited. The veins contain comparatively little gangue, the copper minerals being chiefly distributed through the altered porphyry or through the granite adjoining the dike. At the surface a small amount of carbonates may be found, but they change at slight depth, sometimes only a few feet from the surface, into an ore composed of chalcocite and pyrite, which still farther down appears to change into pyrite and chalcopyrite. The most prominent deposit on this system of veins is in the Copper King mine, which is situated only a few hundred feet below the summit of Copper King Mountain. The main mass of porphyry between Morenci and Metcalf shows evidence of very strong mineralization throughout. A great number of fissure veins have been encountered in it, although most of them are neither persistent nor strong. Close to the surface the ores are apt to spread through a considerable mass of rock, and in some cases important bodies of chalcocite, due to secondary deposition on pyrite from solutions containing copper, have resulted.

The granite adjoining this porphyry is sometimes also thoroughly altered and impregnated with pyrite and chalcopyrite. This may be seen in the narrow canyons of Chase Creek for a mile above the Longfellow incline. While a number of more or less well-defined veins have been opened here, the results have not been encouraging.

Several smaller deposits of oxidized copper ores are found near Garfield Gulch and along Placer Creek.

CONDITIONS OF GROUND WATER.

Permanent water has not thus far been encountered in any of the mines in this district. Morenci is situated on the hills, from 800 to 1500 feet above the principal streams, Chase and Eagle creeks, and the deepest workings in no place reach farther than 600 feet below the surface. A little seepage from the surface takes place in case of heavy rains, or from the local water supply, and some drifts and crosscuts underneath the town are somewhat damp, especially in the Manganese Blue and Arizona Central mines. The mines at Metcalf are situated on Shannon Mountain, from 500 to 1200 feet above Chase Creek, and here, too, the workings are dry, except at one place in the Shirley tunnel, where a winze struck some standing water. The few shafts and prospects sunk in the bottom of Chase Creek are the only places containing permanent water. The Copper King mine, situated a few hundred feet below the summit of Copper King Mountain, has a shaft 600 feet deep, and in it some crevices containing water have been found, but this soon drained out and no more has since come in.

The present stand of the water level, except along the creeks, is practically unknown. It probably rises as a slightly curved surface from the creek levels toward the high hills. The total amount of water stored below this water level is likely to be small.

DEPTH OF OXIDIZED ZONE.

The presence of products of direct or indirect oxidation shows the depth to which the oxidizing waters or the sulphate solutions have penetrated. In that part of the porphyry area of Copper Mountain which has been explored the average depth of the lower limit of the chalcocite zone is 400 feet, but it increases in places to 500 or even 600 feet. The sulphate solutions descended to this depth from the surface, and along important fissures they may have gone somewhat farther. They not only followed fissures, but penetrated the porous, sericitized porphyry with considerable ease. On the other hand, the altered limestones and shales are very compact, nonporous, and impervious. Where circulation was facilitated by fissures, as in the Manganese Blue and Joy mines, the rocks may be partly oxidized to a depth of 400 feet, but this is generally a maximum. There is no well-defined plane expressing the depth of oxidation; on the contrary, it proceeds in an extremely capricious manner, entirely fresh pyritic ores being frequently found very close to the surface.

SUMMARY OF GENESIS.

It has been shown that the intrusions of stocks and dikes of granite-porphyry and quartz-monzonite-porphyry, which took place in late Cretaceous or early Tertiary time, produced an important contact metamorphism in adjoining shales and limestones of Paleozoic age. This metamorphism resulted in metasomatic development of garnet, epidote, diopside, and other silicates, accompanied by pyrite, magnetite, chalcopyrite, and zinc blende. The sulphides are not later introductions, but are contemporaneous with the other contact minerals.

The contact zone received very substantial additions of oxides of iron, silica, sulphur, copper, and zinc—enough to form good-sized deposits of pure magnetite and very low-grade deposits of chalcopyrite and zinc blende, all of which are entirely unknown in the sedimentary series away from the porphyry.

The porphyry magma, as shown by the character of the fluid inclusions in its quartz crystals, contained much water which held dissolved various salts, among them some of the heavy metals. Sodic chloride and ferric oxide probably predominated. It is believed that it contained all of the substances mentioned above, and that large quantities of this gaseous solution (for the critical temperature must have been exceeded) dissolved in the magma were suddenly released by diminution of pressure as the magma reached higher levels and forced their way through the adjoining sedimentary beds, the purest and most granular limestones suffering the most far-reaching alteration and receiving the greatest additions of substance. It is thus held that a direct transfer of material from cooling magma to adjacent sediments took place. The formation of garnet indicates large gains of ferric oxide and silica. These contact-metamorphic deposits often occur at the immediate contact of the main porphyry stock and the limestones, but more commonly they seem to be connected with dikes of the same porphyry close to the principal mass, these dikes being probably more highly charged with magmatic waters.

It is shown that fissures and extensive shattering developed both in porphyry and in altered sediments after the congealing of the magma, and that these fissures and seams were cemented by quartz, pyrite, chalcopyrite, and zinc blende, forming normal veins, largely of the type of replacement veins. The amount of copper contained in these is usually small, though in places possibly large enough to form pay ore. The bulk of the veins consists of pyrite. Two classes of veins may be distinguished. The usual type is practically always connected with granite-porphyry or quartz-monzonite-porphyry, occurring in these rocks or along dikes of the same. The smaller class consists of those connected in their occurrence with diabase dikes. The genesis of the former type will be discussed first.

As far as the metallic minerals are concerned there is a striking similarity between the veins connected with porphyry and the contact-metamorphic deposits, the principal difference being in the magnetite, which is not found in the veins proper and occurs only subordinately in certain of the altered wall rocks. A relationship is also clearly seen in the remarkable action of the vein solutions on the adjoining wall rock wherever this is limestone, tremolite and diopside being formed in it by replacement. On the whole, iron and silica are the main substances added during the vein formation, as well as during contact metamorphism.

A study of the fluid inclusions in the vein quartz proves conclusively that the veins were formed in the presence of aqueous solutions and that these solutions were at a high temperature, for they contained various salts—in part those of heavy metals, probably iron—which have been separated during the cooling of the crystallized quartz. This eliminates entirely the possibility that the veins were deposited by cold surface waters and points to three possible methods of deposition: (1) By atmospheric waters heated by contact with the cooling porphyry, (2) by ascending magmatic waters, or (3) by a mixture of both. In any case the metals must have been derived from the porphyry, or from deep-seated sources below the porphyry, for, as stated above, the presence of porphyry is the only common factor in all occurrences. In view of the evidence of the fluid inclusions in the quartz, together with the similarity of the products of the vein-forming processes to those of contact metamorphism, it is reasonably certain that parts of the mineral solutions were derived directly from and formed part of the porphyry magma, and probably they were derived entirely from this source. It seems likely that the fissuring which took place after the cooling opened vents of escape for magmatic waters under heavy pressure at lower levels, and that they ascended in these fissures, depositing the heavy metals and the silica and acquiring at the same time carbon dioxide from the sediments which they traversed. It remained for the surface waters, as erosion gradually exposed the deposits, to alter and enrich them in manifold forms.

From the evidence presented above, it must be concluded that some of the deposits, especially the fissure veins, were laid bare by erosion and attacked by surface waters at an early date, probably before the principal faulting movement and certainly before the eruption of the Tertiary basalts and rhyolites. Oxidation has thus acted on them for a very long period.

The irregular and tabular deposits in limestone and shale have obtained their present form partly by direct oxidation and partly by the influence of sulphate solutions derived from the disseminated chalcopyrite due to contact metamorphism. A great enrichment has taken place, due to decrease of volume and addition of copper from the circulating sulphate solutions. Some of the oxidized deposits in shale, however, may be due wholly to adsorption exerted by the kaolin in the shale on these sulphate solutions.

The history of the veins, especially those which traverse the porphyry stock or follow porphyry dikes, is more complicated. It has been shown that oxidation dates back to Tertiary time, and that the water level was then considerably higher than it is at present. By the action of descending sulphate solutions on pyrite, chalcocite was deposited very extensively, and very likely the great vertical extent of the chalcocite zone, ordinarily from 200 to 500 feet, is due to slow and gradual changes in the water level. Disintegration and erosion removed the iron cap (the product of direct oxidation of the primary vein) and began to oxidize the exposed chalcocite zone. In practically all the veins the surface zone of poor ore is due to the direct oxidation of chalcocite. The solutions from this part descend and add richness to the upper part of the remaining chalcocite zone.

MINOR METALS.

Iron.—Both at Morenci and at Metcalf the sedimentary contact-metamorphosed rocks contain irregular bodies of magnetite, which near the surface is usually partly or wholly changed to limonite. The largest mass of magnetite was found in the Arizona Central mine and was about 150 feet long, 40 feet wide, and 80 feet thick. Other large masses were mined in the Manganese Blue mine. Both magnetite and limonite are used for fluxing purposes by the smelting works and a varying but not very large amount is mined each year.

Considerable amounts of massive pyrite are found on the lower levels of some of the veins at Morenci, especially in the Joy and Montezuma mines, where the bodies attain 20 and even 40 feet in thickness. In 1903, 420 tons of pyrite were mined per month in the Joy mine and utilized at Clifton to manufacture sulphuric acid for the purpose of leaching copper ores from Metcalf, the total amount of sulphuric acid produced in that year being 3471 tons.

Zinc.—The veins of Morenci contain, in their lower levels, a notable amount of zinc blende. The same mineral is usually present in the contact-metamorphosed limestones at Morenci and Metcalf, and the oxidized ores of this kind are apt to contain even more. Zinc appears to be concentrated in the partly oxidized "iron cap" of Shannon Mountain, representing the metamorphosed Modoc limestones. It is not probable that the metal is present in economically important quantities.

Lead.—No important lead deposits have been discovered in the quadrangle, though the Paleozoic limestones in some places contain small bodies of lead ore. Several of these small deposits, usually of irregular form, are included in the Longfellow limestone south and southwest of Morenci. The Hormeyer vein, which is located 1½ miles east-southeast of Morenci, carries some oxidized lead ores, as well as gold. Small amounts of oxidized lead ores occur in the Stevens prospects in limestone near the mouth of Garfield Gulch and also in the veins of the Polaris Company on Dorsey Gulch. An irregular deposit of yellowish oxidized lead ores has been worked in the Longfellow limestone 1½ miles south-southeast of Enebro Mountain, or 2 miles north-northeast of the mouth of Garfield Gulch. Some ore had evidently been shipped from this prospect, and a sample assayed 24 per cent lead, with traces of gold and silver. In the mines of Morenci and Metcalf lead minerals are almost unknown.

Silver.—The ordinary copper ores of Morenci and Metcalf contain only traces or very small amounts of silver. Even the copper bullion rarely carries more than 4 or 5 ounces of silver per ton. Ore from the Stevens properties, near Garfield Gulch, carried a little silver, and the same is true of the veins on Dorsey Gulch. Narrow silver-bearing veins were at one time prospected at Granville, in the northern part of the quadrangle.

Gold.—The gravels of the Gila conglomerate, resting in front of the older rocks on lower San Francisco River and Eagle Creek, are sometimes gold bearing, although the metal usually occurs only as very fine flakes. The late Quaternary bench gravels along the San Francisco above Clifton contain gold in a somewhat more concentrated form, and at Oroville attempts have been made to work them by the hydraulic method, but the results were not encouraging. This gold is probably derived from a system of veins outcropping on lower Dorsey and Colorado gulches, a few miles north of Clifton on the west side of San Francisco River. Work has occasionally been done on these veins and at one time a stamp mill was erected at Evans Point. Lately the Polaris Company has been actively prospecting the veins.

Another gold-bearing district is that of Gold Gulch, 2 or 3 miles west of Morenci. The diorite-porphyry here contains many included masses of limestone and other sediments. Many narrow and irregular veins cut these rocks, and pockets of gold associated with limonite have been found in several places. The veins are small, no great depth has been attained by the workings, and the deposits, which farther down will doubtless contain sulphide ore, have not yet proved to be of much value. About twenty years ago the gulch was worked for placer gold and the ruins of several arrastres are still visible near the foothills of Eagle Creek between Gold and Horseshoe gulches.

The copper ores of Morenci and Metcalf, whether occurring as contact deposits or as fissure veins, contain only traces of gold. At the Copper King mine, however, a certain amount of gold—perhaps $8 per ton—is found in the ore, and from this point northeastward, as noted above, this tenor in gold increases.

NONMETALLIC MINERAL RESOURCES.

Coal.—No coal is found in the Carboniferous beds of this quadrangle, but the Cretaceous strata (Pinkard formation) contain much carbonaceous shale, and in one place, at least, material has been found deserving the name of coal. The locality is about 2½ miles south of Morenci, in a tributary to Silver Basin Creek one-half mile southeast of bench mark 5175, near the place where Cretaceous fossils have been found. The beds of coaly shale dip gently southwest. The percentage of ash is very high and the value of the coal is very problematical. The beds were discovered in 1903 or 1904, after the geological work on the quadrangle had been completed.

Limestone.—The purest limestone in this region is that of the upper 100 feet of the Modoc formation, which is exposed on Modoc Mountain and at other places near Morenci, on Shannon Mountain near Garfield Gulch, and at several other localities. It often contains 94 to 96 per cent of calcium carbonate. Two quarries are located on Modoc Mountain and one on Shannon Mountain; these supply the the needs of the three smelting works of the district. Near Morenci an almost pure dolomite underlies the pure limestone. The Longfellow and Morenci formations contain chiefly impure and more or less siliceous limestone.

Quartzite.—Near the foot of the Longfellow incline and in the Lone Star tunnel at Morenci quartzite is mined for the purpose of lining copper converters. The total amount needed is not large. At the former locality the quartzite contains some pyrite and one-half of 1 per cent of copper. At both places the quartzite is taken from the Coronado formation.

Kaolin.—For the local requirements of the smelting works kaolin has been mined at the Longfellow and East Yankie mines, where it occurs in great purity associated with limonite and derived partly from porphyry, partly from clay shale.

Building stone.—Among the materials available for building stones the dark-brown, banded quartzite of the Coronado formation should receive first mention. It forms excellent and easily dressed material and has been used in the construction of large buildings at Morenci, the quarry being located along the road in the gulch three-fourths of a mile south of the town. Many beds of the Longfellow limestone also furnish good building stone. In Clifton the rhyolite occurring in a large bluff on the west side of the river has been used to advantage. With this exception, the volcanic formations are not well adapted for building purposes.

WATER SUPPLY.

STREAMS.

San Francisco River forms the principal source of water supply, ample at all times for the requirements of town and smelter and for some irrigation. No detailed measurements of its volume have been made. The quantity of water carried varies considerably and is subject to very sudden increase by heavy freshets. The water a few miles north of Clifton is of excellent quality, but near that town it becomes more saline on account of the numerous salt springs which discharge their contents into it. Some of these are found 1 mile north of Clifton; others carrying a large volume of water containing much sodium chloride enter 2 miles below the town and at other places. Samples of the normal river water from the dam a short distance north of Clifton show, according to Mr. J. Colquhoun, the following composition: Sodium chloride, 4.1 to 6.9 grains per gallon; carbonate of lime, 5 to 5.3 grains per gallon; total salts, 14.05 to 20.3 grains per gallon. Below Clifton the increase in salts, chiefly chloride of sodium, becomes very noticeable. The Shannon smelter, 1 mile below Clifton, experienced at first considerable difficulty in procuring a supply of sufficiently fresh water.

Several hundred miner's inches are taken out just above Limestone Gulch and conducted in a flume to the Arizona Copper Company's smelter. A plan to supply the town of Clifton with water taken out at a point farther up has recently been executed. A pipe line from Clifton supplies the mines and concentrators of the Arizona Copper Company at Morenci. Four miles below Clifton is another pump station from which the necessary amount is forced up to supply the Detroit Copper Company's works at Morenci, the total head being approximately 1700 feet.

Eagle Creek carries a fair stream of water, which gets rather low during the dry season. The sandy bed contains, however, a large amount of excellent ground water. At the station 4 miles west-southwest of Morenci from 30 to 40 gallons per minute of this ground water is pumped up against a head of .1500 feet to supply that town for domestic purposes.

The small amount of water in Sardine Creek is not utilized.

SPRINGS.

In the southern part of the quadrangle permanent springs are rare. A small spring is located a little north of Gold Gulch. Another, which has a volume of several miner's inches, issues among the desolate ravines in the basalt area a short distance west of Eagle Creek and is utilized for irrigation. A third, also of fairly large volume, is found in the upper part of Limestone Gulch. Very little water issues along the southern base of Coronado Mountain, but ordinarily a limited supply may be found in a shallow well where the trail crosses Horseshoe Gulch. North of Coronado Mountain the water is a little more abundant. In addition to the two springs noted on the map along Tule Creek and north of it, permanent water may be found on at least the two northern branches of Whitewater Creek near its head, and also in the middle part of Knight Creek. Along Chase Creek springs appear at several places between Metcalf and the head of the creek; also on Garfield Gulch. The headwaters of Sardine Creek, HL Canyon, and Pigeon Creek also contain permanent flowing water.

Along the foot of the Copper King Ridge many springs occur—for instance, at Hickory Gulch, Dorsey Gulch, Sycamore Gulch, Quail Spring, and Silver Creek. The water sinks as soon as it reaches the volcanic formations at the base of the ridge. A large spring issues near Sardine Creek just below the limestone canyon, and small streams of water trickle from the volcanic rocks at the base of Malpais Mountain.

Mineral springs.—The salt springs along San Francisco River south of Clifton, referred to above, are the only strong mineral springs known; their temperature ranges from tepid to hot.

One of these spring issues near the river 300 feet south of the Clifton railroad station and has a temperature of 160° F. An analysis made for the Arizona Copper Company by Mr. J. D. Audley Smith gave the following result:

Analysis of spring water from San Francisco River near Clifton.

	Grains per United States gallon.
Sodium chloride	301.54
Potassium chloride	28.90
Magnesium chloride	7.11
Calcium chloride	78.99
Calcium sulphate	4.76
Calcium carbonate	22.05
Silica	4.37
Oxide of iron and alumina	.43
Organic matter	2.75
Total solids	450.90

Wells in the bottom lands opposite the Shannon smelter contained 200 to 300 grains of sodium chloride per gallon.

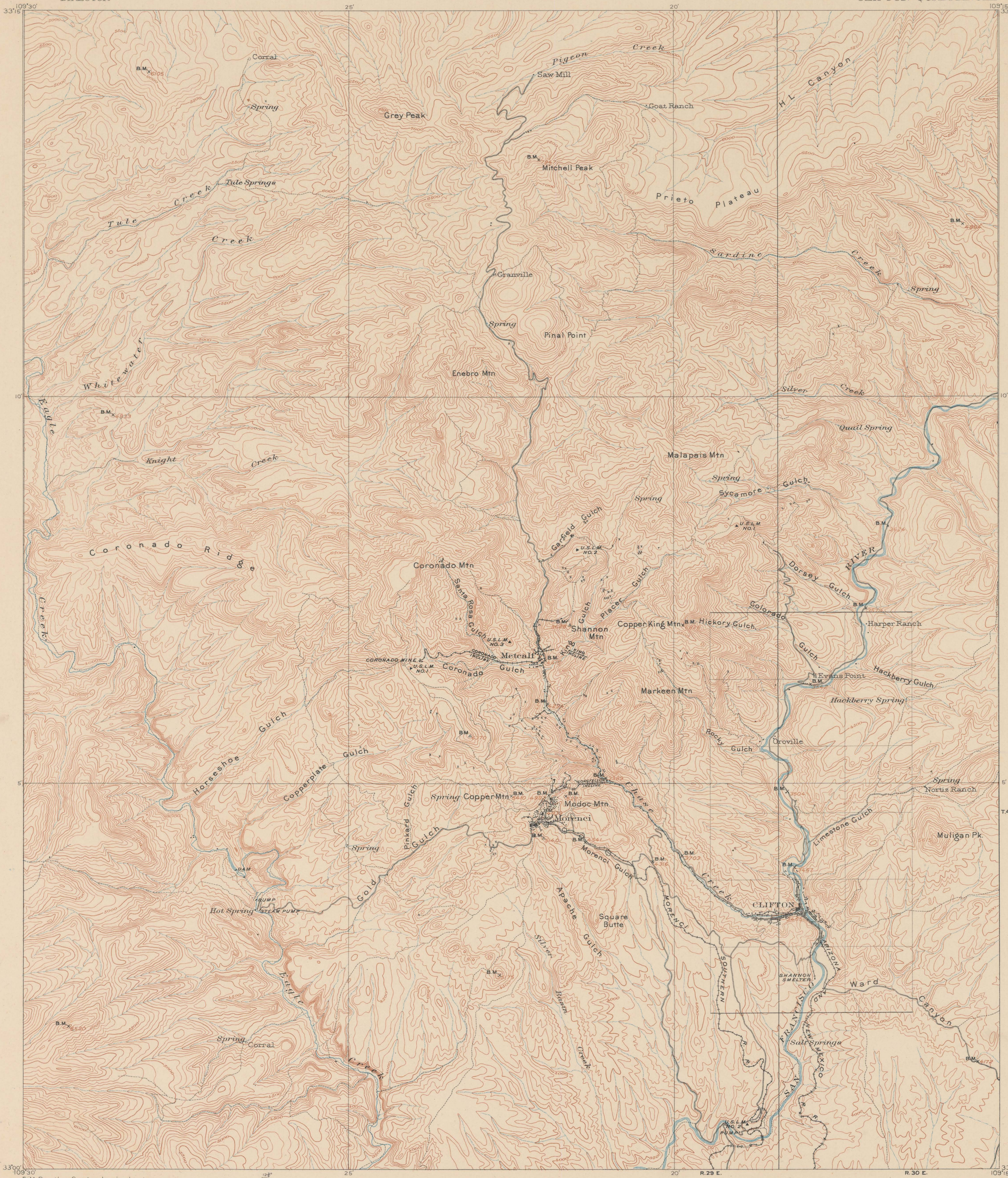
A hot spring with a small volume of weak mineral water issues near the bed of Eagle Creek, at the pump station.

June, 1905.

U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT
DIRECTOR

TOPOGRAPHY

ARIZONA
(GRAHAM COUNTY)
CLIFTON QUADRANGLE



E. M. Douglas, Geographer in charge.
Triangulation and topography by Jeremiah Ahern.
Surveyed in 1900-1901.

APPROXIMATE MEAN DECLINATION 1901.

Scale 1/62500

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 100 feet.
Datum is mean sea level.

DIAGRAM OF TOWNSHIP

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
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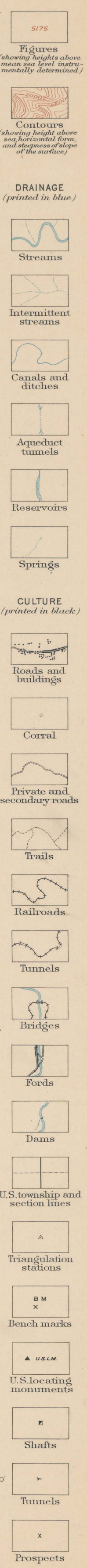
Edition of Sept. 1902, reprinted July 1905.

LEGEND



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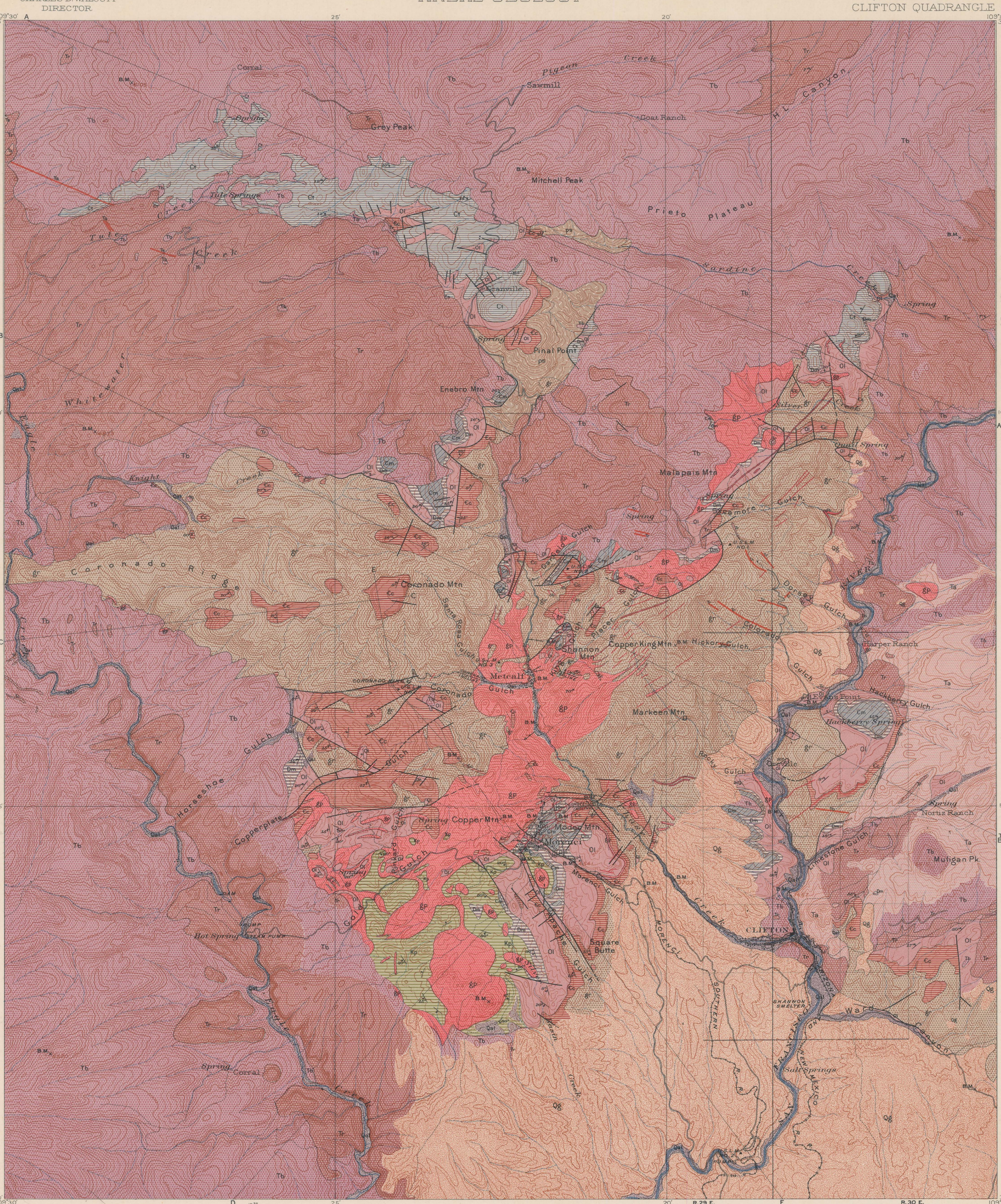
AREAL GEOLOGY

ARIZONA
(GRAHAM COUNTY)
CLIFTON QUADRANGLE



LEGEND

SEDIMENTARY ROCKS

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

QUATERNARY

Qal — **Alluvium** (sand and gravel along present valleys, and local talus accumulations)

Qg — **Gila conglomerate** (thick fluviatile deposits of irregularly bedded conglomerate and sand, locally consolidated)

CRETACEOUS — Benton group

Kp — **Pinkard formation** (alternating brown sandstone and black shale; hardened and metamorphosed near porphyry contacts)

Modoc, Morenci, and Longfellow formations locally metamorphosed near porphyry contacts

CARBONIFEROUS

Ct — **Tule Spring limestone** (heavy-bedded bluish-gray limestone in northern part of quadrangle; contains Mississippian and Pennsylvanian fossils)

Cm — **Modoc limestone** (heavy-bedded gray limestone, sometimes magnesian in lower part; contains Mississippian fossils)

DEVONIAN ?

Dm — **Morenci formation** (black clay shale with argillaceous limestone locally in lower part)

ORDOVICIAN

Ol — **Longfellow formation** (heavy-bedded brown limestone, shaly and siliceous in lower part; usually cherty and sometimes magnesian)

CAMBRIAN ?

€c — **Coronado quartzite** (brown and red quartzitic sandstone, usually with basal conglomerate)

PRE-CAMBRIAN — Metamorphic

ps — **Pinal schist** (sericite-quartz-schist containing small masses of amphibolite)

IGNEOUS ROCKS

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

TERTIARY

Ta — **Andesite** (surface flows and dikes, representing two epochs of eruption)

Tb — **Basalt** (thick, dark-colored surface flows, rarely tuffaceous; represents two epochs of eruption)

Tr — **Rhyolite** (thick, light-colored surface flows with much tuff and breccia; represents three epochs of eruption)

Tr, Tb, Ta — **Dikes of rhyolite, basalt, and andesite**

LATE CRETACEOUS OR EARLY TERTIARY

gp, db — **Granite-porphyry, quartz-monzonite-porphyry, and diorite-porphyry** (with transition phases; occur in dikes, stocks, and laccoliths; also dikes of diabase, db)

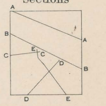
PRE-CAMBRIAN

gr — **Granite** (intrusive masses in Pinal schist)

Known faults

Concealed faults (covered by younger deposits)

Sections



E. M. Douglas, Geographer in charge.
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Geology by W. Lindgren and J. M. Boutwell.
Surveyed in 1902.

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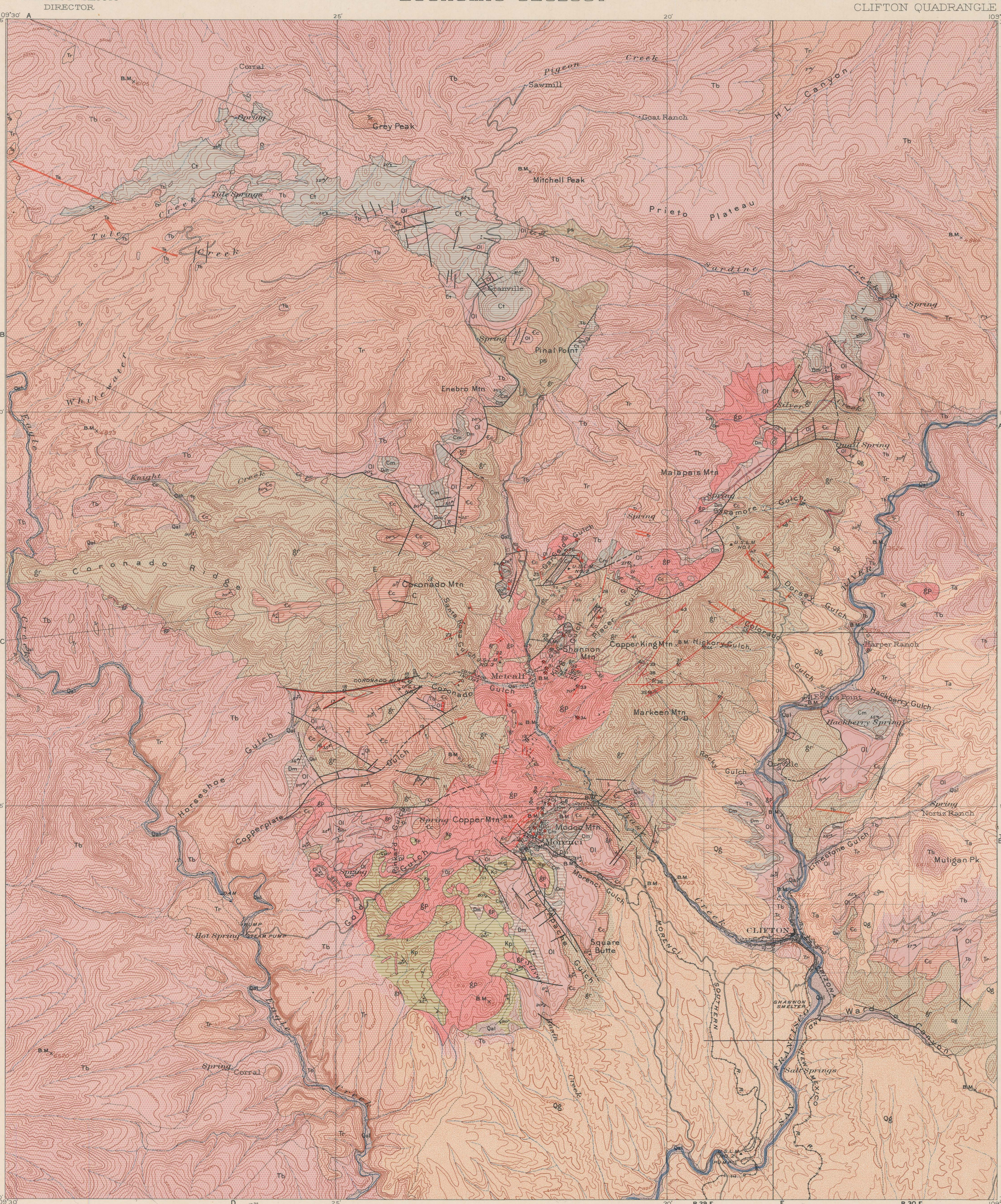
ECONOMIC GEOLOGY

ARIZONA
(GRAHAM COUNTY)
CLIFTON QUADRANGLE



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- Tr Tb Ta — **Dikes of rhyolite, basalt, and andesite**

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- gp, db — **Granite-porphyry, quartz-monzonite-porphyry, and diorite-porphyry** (with transition phases; occur in dikes, stocks, and laccoliths; also dikes of diabase, db)

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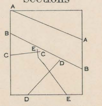

20° Strike and dip of stratified rocks
80° Strike and dip of schistose cleavage
Mineral veins, chiefly copper, showing strike and dip
Mineral deposits, other than veins
Mines, chiefly copper
Prospect pits
Tunnels

MINING PROPERTIES.

Location indicated on the map by numbers.

1. Arizona Central.
2. Copper Mountain.
3. Humboldt.
4. Hormeyer.
5. Liverpool.
6. Yavapai.
7. West Yankie.
8. Longfellow
9. Clay.
10. Caynga.
11. Producer.
12. Fairbanks.
13. Copper Queen.
14. Mexican.
15. Las Terasses.
16. Copper Plate.
17. Keating.
18. Coronado (2 shafts).
19. Las Trajas.
20. Emerald.
21. Pyramid.
22. Ida.
23. Miza.
24. Stevens Group
25. Brunswick.
26. Mammoth.
27. Iolanthe.
28. Antietam.
29. Shannon (2 shafts)
30. Shirley.
31. Metcalf Mines.
32. Jameson.
33. King.
34. Standard.
35. Markeen.
36. Olivette.
37. Copper King.
38. Virginia.
39. Delaware.
40. Raton.
41. Veiled Prophet.
42. Trilby.
43. Mansfield.
44. Clifton Consol.
45. Colorado.
46. Golden Eagle.
47. Black Prince.
48. Poland.
49. Fischer.

E. M. Douglas, Geographer in charge.
Triangulation and topography by Jeremiah Ahern.
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Geology by W. Lindgren and J. M. Boutwell.
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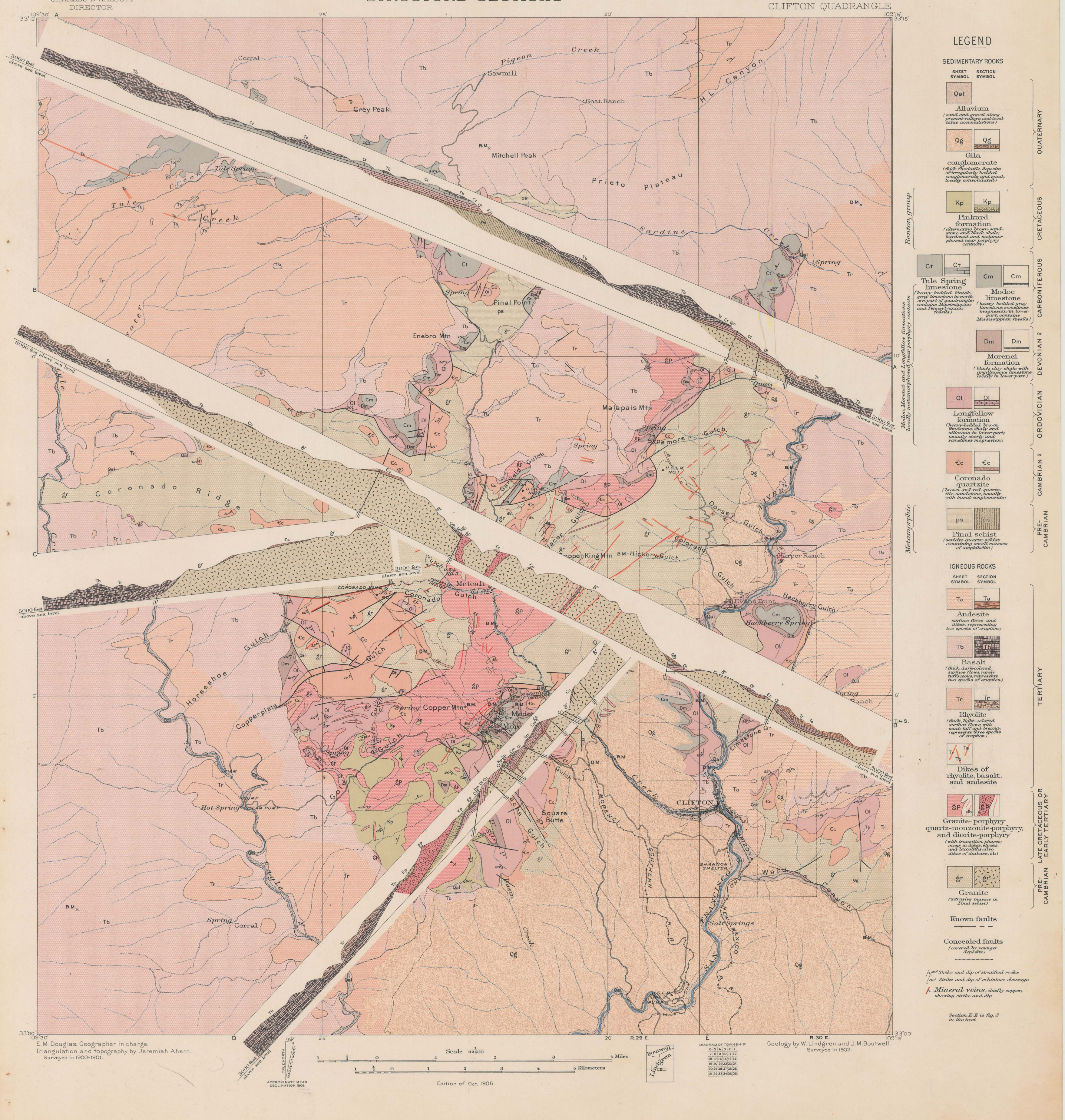
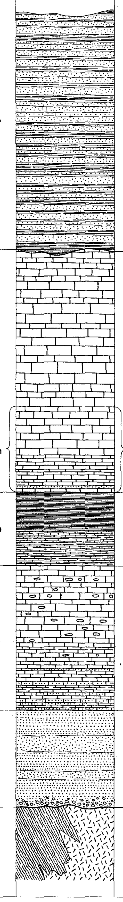
STRUCTURE SECTIONS

ARIZONA
(GRAHAM COUNTY)
CLIFTON QUADRANGLE



COLUMNAR SECTION

GENERALIZED SECTION FOR THE CLIFTON QUADRANGLE.
SCALE: 1 INCH = 200 FEET.

System.	Formation Name.	Symbol.	Columnar Section.	Thickness in Feet.	Character and Distribution of Formations.
CRETACEOUS BENTON GROUP	Pinkard formation.	Kp		500+	Alternating black shale and yellow or brown sandstone. Total thickness unknown.
	UNCONFORMITY				
CARBONIFEROUS PENNSYLVANIAN SERIES	Tule Spring limestone.	Ct		500	In northern part of quadrangle, heavy-bedded blue limestone containing Mississippian and Pennsylvanian fossils.
MISSISSIPPIAN SERIES	Modoc limestone.	Cm		180	In southern part of quadrangle, upper 100 feet heavy-bedded pure limestone, lower 80 feet dolomite and limestone with one stratum of sandstone; contains Mississippian fossils.
DEVONIAN?	Morenci formation.	Dm		150	Black clay shale. Argillaceous limestone.
ORDOVICIAN	Longfellow formation.	Ol		200–400	Cherty limestone, locally dolomitic, shaly and more siliceous toward the base.
CAMBRIAN?	Coronado quartzite.	Ꞓc		200	Brown and red quartzitic sandstone with local conglomerate.
	UNCONFORMITY				
PRE-CAMBRIAN	Pinal schist and intrusive granite.	ps			Sericite-quartz-schists, containing small masses of amphibolite, and intrusive granite.

WALDEMAR LINDGREN,
Geologist.

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35	Gadsden	Alabama	25
36	Pueblo	Colorado	50
37	Downieville	California	25
38	Butte Special	Montana	50
39	Truckee	California	25
40	Wartburg	Tennessee	25
41	Sonora	California	25
42	Nueces	Texas	25
43	Bidwell Bar	California	25
44	Tazewell	Virginia-West Virginia	25
45	Boise	Idaho	25
46	Richmond	Kentucky	25
47	London	Kentucky	25
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49	Roseburg	Oregon	25
50	Holyoke	Massachusetts-Connecticut	50
51	Big Trees	California	25
52	Absaroka	Wyoming	25
53	Standingstone	Tennessee	25
54	Tacoma	Washington	25
55	Fort Benton	Montana	25
56	Little Belt Mountains	Montana	25
57	Telluride	Colorado	25
58	Elmoro	Colorado	25
59	Bristol	Virginia-Tennessee	25
60	La Plata	Colorado	25
61	Monterey	Virginia-West Virginia	25
62	Menominee Special	Michigan	25
63	Mother Lode District	California	50
64	Uvalde	Texas	25
65	Tintic Special	Utah	25
66	Colfax	California	25
67	Danville	Illinois-Indiana	25
68	Walsenburg	Colorado	25
69	Huntington	West Virginia-Ohio	25
70	Washington	D. C.-Va.-Md.	50
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78	Rome	Georgia-Alabama	25
79	Atoka	Indian Territory	25
80	Norfolk	Virginia-North Carolina	25
81	Chicago	Illinois-Indiana	50
82	Masontown-Uniontown	Pennsylvania	25
83	New York City	New York-New Jersey	50
84	Ditney	Indiana	25
85	Oelrichs	South Dakota-Nebraska	25
86	Ellensburg	Washington	25
87	Camp Clarke	Nebraska	25
88	Scotts Bluff	Nebraska	25
89	Port Orford	Oregon	25
90	Cranberry	North Carolina-Tennessee	25
91	Hartville	Wyoming	25
92	Gaines	Pennsylvania-New York	25
93	Elkland-Tioga	Pennsylvania	25
94	Brownsville-Connellsville	Pennsylvania	25
95	Columbia	Tennessee	25
96	Olivet	South Dakota	25
97	Parker	South Dakota	25
98	Tishomingo	Indian Territory	25
99	Mitchell	South Dakota	25
100	Alexandria	South Dakota	25
101	San Luis	California	25
102	Indiana	Pennsylvania	25
103	Nampa	Idaho-Oregon	25
104	Silver City	Idaho	25
105	Patoka	Indiana-Illinois	25
106	Mount Stuart	Washington	25
107	Newcastle	Wyoming-South Dakota	25
108	Edgemont	South Dakota-Nebraska	25
109	Cottonwood Falls	Kansas	25
110	Latrobe	Pennsylvania	25
111	Globe	Arizona	25
112	Bisbee	Arizona	25
113	Huron	South Dakota	25
114	De Smet	South Dakota	25
115	Kittanning	Pennsylvania	25
116	Asheville	North Carolina-Tennessee	25
117	Casselton-Fargo	North Dakota-Minnesota	25
118	Greeneville	Tennessee-North Carolina	25
119	Fayetteville	Arkansas-Missouri	25
120	Silverton	Colorado	25
121	Waynesburg	Pennsylvania	25
122	Tahlequah	Indian Territory-Arkansas	25
123	Elders Ridge	Pennsylvania	25
124	Mount Mitchell	North Carolina-Tennessee	25
125	Rural Valley	Pennsylvania	25
126	Bradshaw Mountains	Arizona	25
127	Sundance	Wyoming-South Dakota	25
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