RAY FOLIO
NO. 217

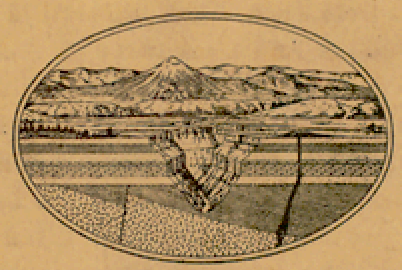
DEPARTMENT OF THE INTERIOR
HUBERT WORK, SECRETARY
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

GEOLOGIC ATLAS
OF THE
UNITED STATES

RAY FOLIO
ARIZONA

BY

F. L. RANSOME



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RAY FOLIO
NO. 217

GEOLOGIC ATLAS OF THE UNITED STATES.

UNITS OF SURVEY AND OF PUBLICATION.

The Geological Survey is making a topographic and a geologic atlas of the United States. The topographic atlas will consist of maps called *atlas sheets*, and the geologic atlas will consist of parts called *folios*. Each folio includes topographic and geologic maps of a certain four-sided area, called a *quadrangle*, or of more than one such area, and a text describing its topographic and geologic features. A quadrangle is limited by parallels and meridians, not by political boundary lines, such as those of States, counties, and townships. Each quadrangle is named from a town or a natural feature within it, and at the sides and corners of each map are printed the names of adjacent quadrangles.

SCALES OF THE MAPS.

On a map drawn to the scale of 1 inch to the mile a linear mile on the ground would be represented by a linear inch on the map, and each square mile of the ground would be represented by a square inch of the map. The scale may be expressed also by a fraction, of which the numerator represents a unit of linear measure on the map and the denominator the corresponding number of like units on the ground. Thus, as there are 63,360 inches in a mile, the scale 1 inch to the mile is expressed by the fraction $\frac{1}{63,360}$, or the ratio 1:63,360.

The three scales used on the standard maps of the Geological Survey are 1:62,500, 1:125,000, and 1:250,000, 1 inch on the map corresponding approximately to 1 mile, 2 miles, and 4 miles on the ground. On the scale of 1:62,500 a square inch of map surface represents about 1 square mile of earth surface; on the scale of 1:125,000, about 4 square miles; and on the scale of 1:250,000, about 16 square miles. In general a standard map on the scale of 1:250,000 represents a "square degree"—that is, an area measuring 1 degree of latitude by 1 degree of longitude; one on the scale of 1:125,000 represents one-fourth of a "square degree"; and one on the scale of 1:62,500 represents one-sixteenth of a "square degree." The areas of the corresponding quadrangles are about 4,000, 1,000, and 250 square miles, though they vary with the latitude, a "square degree" in the latitude of Boston, for example, being only 3,525 square miles and one in the latitude of Galveston being 4,150 square miles.

GENERAL FEATURES SHOWN ON THE MAPS.

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

Relief.—All altitudes are measured from mean sea level. The heights of many points have been accurately determined, and those of some are given on the map in figures. It is desirable, however, to show the altitude of all parts of the area mapped, the form of the surface, and the grade of all slopes. This is done by contour lines, printed in brown, each representing a certain height above sea level. A contour on the ground passes through points that have the same altitude. One who follows a contour will go neither uphill nor downhill but on a level. The manner in which contour lines express altitude, form, and slope is shown in figure 1.

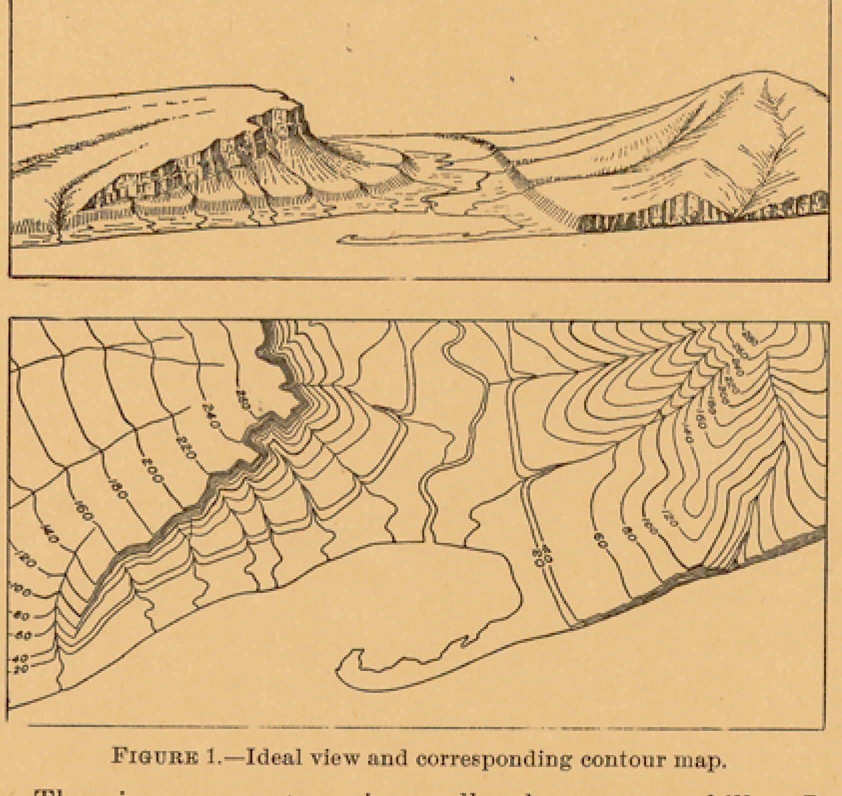

FIGURE 1.—Ideal view and corresponding contour map.

The view represents a river valley between two hills. In the foreground is the sea, with a bay that is partly inclosed by a hooked sand bar. On each side of the valley is a terrace. The terrace on the right merges into a gentle upward slope; that on the left merges into a steep slope that passes upward to a cliff, or scarp, which contrasts with the gradual slope back from its crest. In the map each of these features is indicated, directly beneath its position in the view, by contour lines. The map does not include the distant part of the view.

As contours are continuous horizontal lines they wind smoothly about smooth surfaces, recede into ravines, and project around spurs or prominences. The relations of contour curves and angles to the form of the land can be seen from the map and sketch. The contour lines show not only the shape of the hills and valleys but their altitude, as well as the steepness or grade of all slopes.

The vertical distance represented by the space between two successive contour lines—the contour interval—is the same, whether the contours lie along a cliff or on a gentle slope; but to reach 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 slopes.

The contour interval is generally uniform throughout a single map. The relief of a flat or gently undulating country can be adequately represented only by the use of a small contour interval; that of a steep or mountainous country can generally be adequately represented on the same scale by the use of a larger interval. The smallest interval commonly used on the atlas sheets of the Geological Survey is 5 feet, which is used for regions like the Mississippi Delta and the Dismal Swamp. An interval of 1 foot has been used on some large-scale maps of very flat areas. On maps of more rugged country contour intervals of 10, 20, 25, 50, and 100 feet are used, and on maps of great mountain masses like those in Colorado the interval may be 250 feet.

In figure 1 the contour interval is 20 feet, and the contour lines therefore represent contours at 20, 40, 60, and 80 feet, and so on, above mean sea level. Along the contour at 200 feet lie all points that are 200 feet above the sea—that is, this contour would be the shore line if the sea were to rise 200 feet; along the contour at 100 feet are all points that are 100 feet above the sea; and so on. In the space between any two contours are all points whose altitudes are above the lower and below the higher contour. Thus the contour at 40 feet falls just below the edge of the terrace, and that at 60 feet lies above the terrace; therefore all points on the terrace are shown to be more than 40 but less than 60 feet above the sea. In this illustration all the contour lines are numbered, but on most of the Geological Survey's maps all the contour lines are not numbered; only certain of them—say every fifth one, which is made slightly heavier—are numbered, for the heights shown by the others may be learned by counting up or down from these. More exact altitudes for many points are given in bulletins published by the Geological Survey.

Drainage.—Watercourses are indicated by blue lines. The line for a perennial stream is unbroken; that for an intermittent stream is dotted; and that for a stream which sinks and reappears is broken. Lakes and other bodies of water and the several types of marshy areas are also represented in blue.

Culture.—Symbols for the works of man, including public-land lines and other boundary lines, as well as all the lettering, are printed in black.

GEOLOGIC FEATURES SHOWN ON THE MAPS.

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

KINDS OF ROCKS.

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

Igneous rocks.—Rocks that have cooled and consolidated from a state of fusion are known as *igneous*. Molten material has from time to time been forced upward in fissures or channels of various shapes and sizes through rocks of all ages to or nearly to the surface. Rocks formed by the consolidation of molten material, or *magma*, within these channels—that is, below the surface—are called *intrusive*. An intrusive mass that occupies a nearly vertical fissure which has approximately parallel walls is called a *dike;* one that fills a large and irregular conduit is termed a *stock*. Molten material that traverses stratified rocks may be intruded along bedding planes, forming masses called *sills* or *sheets* if they are relatively thin and *laccoliths* if they are large lenticular bodies. Molten material that is inclosed by rock cools slowly, and its component minerals crystallize when they solidify, so that intrusive rocks are generally crystalline. Molten material that is poured out through channels that reach the surface is called *lava*, and lava may build up volcanic mountains. Igneous rocks that have solidified at the surface are called *extrusive* or *effusive*. Lavas generally cool more rapidly than intrusive rocks and contain, especially in their outer parts, more or less volcanic glass, produced by rapid chilling. The outer parts of lava flows are also usually made porous by the expansion of the gases in the magma. Explosions due to these gases may accompany volcanic eruptions, causing the ejection of dust, ash, lapilli, and larger fragments. These materials, when consolidated, constitute breccias, agglomerates, and tuffs.

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

The chief agent in the transportation of rock débris is water in motion, including rain, streams, and the water of lakes and of the sea. The materials are in large part carried as solid particles, and the deposits they form are called mechanical. Such deposits are gravel, sand, and clay, which are later consolidated into conglomerate, sandstone, and shale. Some of the materials are carried in solution, and deposits composed of these materials are called organic if formed with the aid of life or chemical if formed without the aid of life. The more common rocks of chemical and organic origin are limestone, chert, gypsum, salt, certain iron ores, peat, lignite, and coal. Any one of the kinds of deposits named may be formed separately, 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 the glacial deposits is *till*, a heterogeneous mixture of boulders and pebbles with clay or sand.

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

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

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

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

From time to time during geologic ages rocks that have been deeply buried and have been subjected to enormous pressure, to slow movement, and to igneous intrusion have been afterward raised and later exposed by erosion. In such rocks the original structural features may have been lost entirely and new ones substituted. A system of parallel planes along which the rock can be split most readily may have been developed. This acquired quality gives rise to *cleavage*, and the cleavage planes may cross the original bedding planes at any angle. Rocks characterized by cleavage are called *slates*. Crystals of mica or other minerals may have grown in a rock in parallel arrangement, causing lamination or foliation and producing what is known as *schistosity*. Rocks characterized by schistosity are called *schists*.

As a rule, the older rocks are most altered and the younger are least altered, but to this rule there are many exceptions, especially in regions of igneous activity and complex structure.

GEOLOGIC FORMATIONS.

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

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

DESCRIPTION OF THE RAY QUADRANGLE.

By F. L. Ransome.

INTRODUCTION.

SITUATION AND ACCESS.

The Ray quadrangle (see Figs. 1 and 2) is in southeast-central Arizona, in the belt of generally linear ranges and valleys that, except for a stretch of about 75 miles in the northwestern part of the State, separates the Plateau Province (Colorado Plateaus) on the northeast from the Plains Region (Sonoran Desert) on the southwest and that from its present diversified relief has been called the Mountain Region (Mexican Highland).[1] The Mountain Region and the Plains Region are here regarded as divisions of the Basin and Range Province, which extends from Arizona into Nevada, California, and Mexico. The quadrangle lies between meridians 110° 45′ and 111° and parallels 33° and 33° 15′. Its area, which is 249.76 square miles, is nearly equally divided between Gila and Pinal counties.

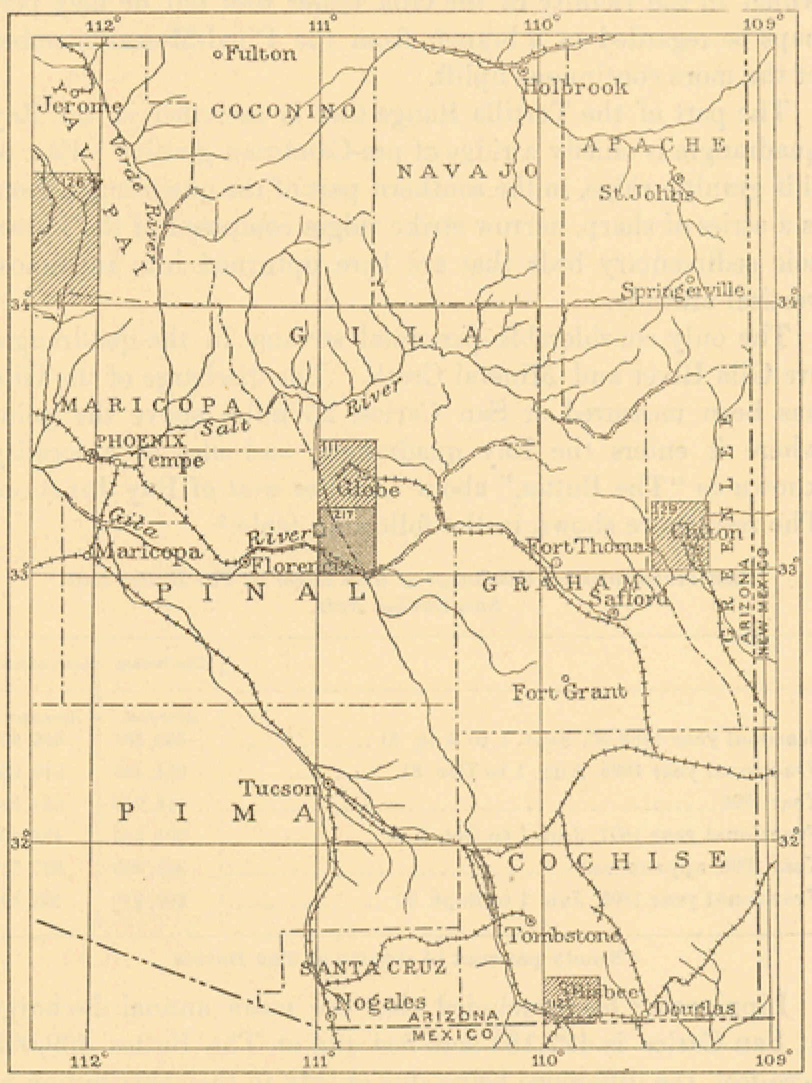

FIGURE 1.—Index map of southeastern Arizona.

The location of the area described in the Ray folio (No. 217) is shown by the darker ruling. Published folios describing other quadrangles, indicated by lighter ruling, are 111, Globe; 112, Bisbee; 126, Bradshaw Mountains; 129, Clifton.

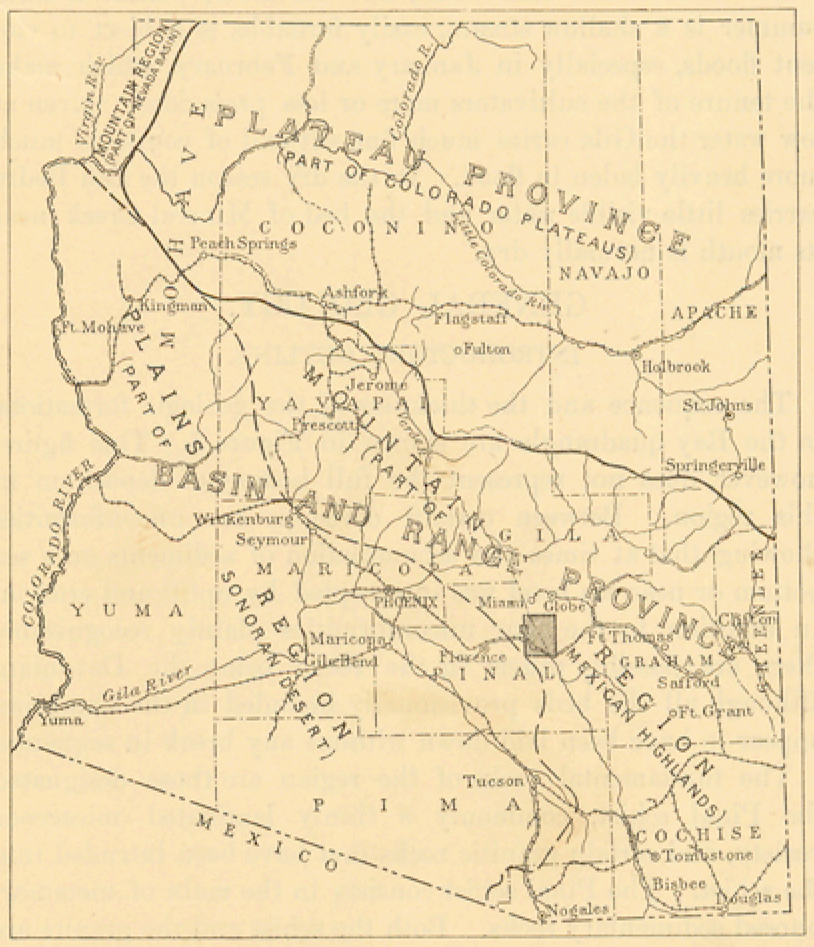

FIGURE 2.—Map of Arizona showing the principal physiographic divisions of the State.

The Ray quadrangle is shown by shading.

The main route of access to the Ray quadrangle is that by way of the Hayden division of the Arizona Eastern Railroad. This branch leaves the main line at Tempe, 8 miles southeast of Phoenix, runs southeastward to Florence across the plain that here separates Salt and Gila rivers, and then follows the Gila up to Ray Junction, the station near Kelvin, in the western part of the quadrangle. The distance from Tempe to Ray Junction is 72.8 miles. From Ray Junction the railroad continues up the Gila for 22 miles to its present terminus near Christmas. Ultimately this road will probably be continued eastward to connect at San Carlos with the Bowie-Globe-Miami branch of the Arizona Eastern Railroad. From Ray Junction the railroad of the Ray Consolidated Copper Co. provides communication with the mines near Ray, about 7 miles north of the Gila.

The quadrangle may also be entered from the north by stage from Globe over the Pinal Range by way of Pioneer, a distance of about 35 miles, or, less conveniently, by stage from Tucson by way of Mammoth and down San Pedro River to its confluence with the Gila near Winkelman, just south of the quadrangle. The distance from Tucson to Winkelman by this route is about 71 miles.

SETTLEMENT AND INDUSTRIES.

The principal industries in the Ray quadrangle are the mining, milling, and smelting of copper ore, particularly that from the mines in the vicinity of Ray. This town and the adjacent settlements, including the large Mexican village of Sonora, probably contain about 7,200 people. Hayden, a town built up near the concentrating mill of the Ray Consolidated Copper Co. and the smelter of the American Smelting & Refining Co., had a population of 2,508 in 1920. Winkelman, a smaller and older settlement a few miles south of Hayden on the Gila, opposite the mouth of the San Pedro, is in the Winkelman quadrangle, which adjoins the Ray quadrangle on the south. Christmas, a still smaller place, is in the quadrangle of that name, about half a mile east of the Ray quadrangle, nearly in the latitude of Tornado Peak. Kelvin, founded by the Ray Copper Mines (Ltd.), an English company, at the confluence of Mineral Creek and the Gila, was a place of some importance in 1900, but after the failure of the company the population dwindled, and in 1920 it was only 300. As a consequence of the construction of the concentrating mill of the Ray Hercules Copper Co. near Kelvin, that place may regain some of its former prosperity, although a new settlement, known as Belgravia, appears to have been established still nearer to the mill.

Outside of the settlements mentioned, the quadrangle is inhabited only by a few prospectors and ranchmen. Much of it is a lonely wilderness, whose only obvious usefulness to man is to supply scanty grass at certain seasons to wide-roaming cattle. There is some arable land along the Gila and a few small patches along Mineral Creek. A large part of the best land near the river, however, has been turned into dumping ground for the tailings from the Hayden concentrator.

CLIMATE AND VEGETATION.

The climate of the Ray quadrangle closely resembles that of the adjoining Globe quadrangle, to the north, but as the region here described is generally lower than that adjacent to Globe the mean annual temperature is higher. The town of Ray, hemmed in by hills, is decidedly hotter in summer than Globe or Miami.

So far as known, no continuous weather records have been kept within the Ray quadrangle, but the conditions at the Weather Bureau station 8 miles south of Dudleyville, on the San Pedro, are fairly representative of those at Hayden, Kelvin, and Ray. According to records,[2] between 1891 and 1903 the annual mean temperature at Dudleyville is 65°, the absolute maximum 114°, and the absolute minimum 14°. June is usually the hottest month. The annual mean precipitation is 12 inches. The precipitation in the driest year within the period of record was 8.4 inches and of the wettest year 15.9 inches. May and June are the driest months and are followed by the principal rainy season, in July and August, but part of the rain comes in winter. Much of the rain falls in violent local showers, which in a few minutes change dry arroyos into torrents.

In consequence of the dryness of the air and the rapidity of evaporation the great heat of summer is less oppressive than much lower temperatures in the Eastern States, especially if some protection can be had from the direct rays of the sun, and in winter the clear skies and cool nights are thoroughly delightful, although a change in temperature of 30° or 40° may take place between midnight and noon.

The vegetation is that which is generally found in a climate like that just described throughout this part of the arid Southwest. The higher, forested part of the Pinal Range lies almost entirely in the Globe quadrangle, and the area here described is generally treeless. A few pines grow, however, on the steep north slope of El Capitan, in the Mescal Range, and sycamores, cottonwoods, and walnuts grow along the larger streamways and about some of the springs. Scrubby, bushlike oaks, the alligator juniper (*Juniperus pachyphloea* Torrey) and possibly the western juniper (*Juniperus occidentalis monosperma* Engelmann), the sotol (*Dasylirion wheeleri* S. Watson), the datil (*Yucca baccata* Torrey) and probably other yuccas, the century plant or maguey (probably *Agave parryi* Engelmann), a leafless broomlike shrub (*Canotia holacantha* Torrey), and the deer nut (*Simondsia californica* Nuttall) are among the common larger plants on the higher hills. On lower slopes and on the gravelly mesas of Gila conglomerate are found the green-barked palo verde (*Parkinsonia microphylla*), the ocotillo (*Fouquieria splendens* Engelmann), a notable plant at any time and when decked with its scarlet blossoms well deserving its specific designation, the imposing giant cactus or sahuaro (*Carnegiea gigantea*), suggestive of huge candelabra, the barrel cactus or bisnaga (*Echinocactus wislizeni* Engelmann), the prickly pear (*Opuntia*, several species), the formidable cholla (*Opuntia mammillata*), amid whose keen, glistening, thickset spines the little cactus wren nests in security, the cane cactus (*Opuntia arborescens* Engelmann), and many smaller members of the cactus family.

Mesquite (*Prosopis glandulosa* Torrey), the catclaw[3] (*Acacia greggii* A. Gray), which makes amends for the sharpness of its curved spines by the delicious perfume of its small yellow blossoms, and the palma (*Yucca macrocarpa* (Torrey) Engelmann) are common along some of the dry bottom lands, as in Dripping Spring Valley.

Although the vegetation is of the desert type it has a distinctive beauty that is no less real because it is totally different from that of the more humid regions in which most of us live. Grasses spring up after the rains, and in the spring nearly all the cactuses bear flowers of clear and brilliant color. Many of the shrubs also are flowering and when in bloom brighten the landscape with their massed color and exhale their delicate perfumes into the desert air.

SURFACE FORMS AND DRAINAGE.

The most prominent features of the surface of the Ray quadrangle are three mountain ranges that trend generally southeastward and two intervening broad, gravel-filled valleys. These features, enumerated from northeast to southwest, are (1) the Mescal Range; (2) the Dripping Spring (or Disappointment) Valley; (3) the Dripping Spring Range; (4) the valley of the Gila, and (5) the Tortilla Range. The valleys are similar in their topography and in the general character of their filling, which consists of the Gila conglomerate. Though all these mountain ranges are carved from materials that are in large part identical, each displays distinctive features of structure and topography.

The elevation of the quadrangle ranges from 1,750 feet in the gorge of the Gila west of Ray Junction to 6,564 feet on the summit of El Capitan, in the Mescal Range. The bottom lands along the Gila attain an elevation of 1,900 feet above sea level in the southeast corner of the quadrangle, and those in Dripping Spring Valley reach about 3,000 feet between Troy and Walnut Spring. The mountain ranges rise in general from 1,500 to 4,200 feet above the bottoms of the main valleys. As a whole the surface of the quadrangle slopes from northeast to southwest.

The Mescal Range, which occupies the northeast corner of the quadrangle, in spite of having a local name of its own, is in a broad topographic sense merely the southeastern continuation of the Pinal Range, which is the principal orographic feature of the Globe quadrangle. There are, however, both topographic and geologic reasons for a distinction, inasmuch as the loftier part of the range, to which the name Pinal is usually applied, consists chiefly of pre-Cambrian crystalline rocks from which the Paleozoic sediments have been stripped

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[1] The names in parentheses are those adopted by the committee on physiography of the United States Geological Survey for physiographic divisions of which the Arizona units are respectively parts.

[2] Henry, A. J., Climatology of the United States: U. S. Weather Bureau Bull. Q, p. 910, 1906.

[3] The common name also for species of *Mimosa*, especially *biuncifera*.

back by erosion, whereas the Mescal Range is composed principally of these Paleozoic beds and intruded diabase. In structure and in topographic expression the Pinal and Mescal ranges are in decided contrast.

The two ranges overlap and merge along the northern border of the quadrangle, the ridges of sedimentary rock decreasing in height and finally disappearing to the northwest under the younger deposits of Dripping Spring Valley, while northeast of these ridges the bold heights of the Pinal Range are succeeded on the southeast by a lowland, which is overlooked by the quartzite cliffs of El Capitan.

The traveler who follows the road from Globe to Troy has ample leisure, as his vehicle climbs the long grade up Pinal Creek, to note the rugged and irregular topography that is characteristic of a youthful stage in the erosion of an intricate complex of schist and granitic rocks. He sees the dominant peaks buttressed by sharp, uneven, branching spurs, with rough pinnacles of schist or rounded masses of granite jutting from the vegetation along their crests. Between the spurs lie narrow ravines where, under the shadow of pines, tiny streams murmur through the fierce heat of an Arizona summer. As he gains the summit of the pass a different scene is suddenly spread before him. He looks down over a broad conglomerate-filled valley, backed by the treeless slopes and uneven crest of the Dripping Spring Range. Beyond is the valley of the Gila, the river flashing here and there like a glint of steel, and still farther beyond lies a succession of desolate ridges and barren valleys, which fade away into the quivering haze on the southwestern horizon. The splendid sweep of the distant view holds the gaze of one who sees it for the first time, but as his vehicle rolls down the slope of the range he can not fail to have his attention attracted by the dominating profile of El Capitan, on his left, and to observe with interest that Old Baldy, Pioneer Mountain, and other peaks of the Mescal Range are all much alike in form but are very different from the mountains through which he has just passed. Structurally they are uniformly tilted or homoclinal[4] blocks of bedded rock. Topographically they are cuestas, whose broad, flat backs, with a dip of about 20°, rise like inclined planes from the southwest to the crests of abrupt scarps of limestone or quartzite that overlook the pre-Cambrian rocks to the northeast. Even from a distance the topography appears as the accurate, emphatic expression of structure, but, as will be seen later, there is really less structural regularity than is suggested by the uniformity of dip as seen in any general view of the range from a commanding outlook.

That part of the Mescal Range which lies north of the Gila culminates at 6,564 feet in El Capitan, the highest point in the Ray quadrangle, although just north of that area the Pinal Range attains an altitude of 7,850 feet.

Within the quadrangle the Mescal Range is intersected by four lines of transverse drainage. These are Silver and El Capitan creeks southeast of Pioneer and two smaller unnamed arroyos northwest of that station. These streams head in the pre-Cambrian rocks and have cut deep and very narrow gorges through the Paleozoic ridges. In summer the gravelly reaches of their channels are ordinarily dry, although as a rule a little water generally comes to the surface in the gorges and wherever the arroyos are floored with hard rock. Southeast of El Capitan the range continues as an unbroken rampart to the Gila, and the same general belt of uplift that in the Ray quadrangle is represented by the Pinal, Mescal, and Dripping Spring ranges may be traced southward along the east side of San Pedro River through the Caliuro and Dragoon ranges to the Mexican border.

Dripping Spring Valley (also known as Disappointment Valley) has an average width, as defined by its filling of Gila conglomerate, of about 4 miles. It opens to the southeast on Gila River and heads to the northwest in the Globe quadrangle, about 5 miles north of the area here described. Its total length is about 30 miles. Although the valley as a whole opens to the southeast it does not all drain in that direction. A low divide in the Gila conglomerate near Walnut Spring diverts some of the intermittent streams northward into Mineral Creek, which after skirting the north end of the Dripping Spring Range flows southward past Ray and joins the Gila at Ray Junction.

The topography of the floor of this depression (Pl. I) is that characteristic of the Gila formation throughout most of this region. There is a main line of axial drainage, defined by broad strips of sandy wash, from which branch countless lateral arroyos that divide toward their heads into dendritic ramifications. The conglomerate is correspondingly dissected into long, generally even-topped ridges, whose summits give gradual ascents from the middle of the valley to its bounding mountain ranges.

These spurs generally descend from the mountains in a direction nearly at right angles to the main axis of the valley or curve near their distal ends into the direction of the trunk drainage. In the vicinity of Walnut Spring the development of the low divide mentioned has led to a fanlike divergence of the conglomerate spurs on the eastern side of the valley.

Some of the spurs are fairly simple in contour, others are elaborately scalloped and are furrowed by steep secondary gullies. The typical conglomerate spur has a narrow flat crest and its sides at first slope gently toward the neighboring arroyos but steepen rather abruptly downward and finally turn into nearly vertical bluffs. At some places, especially in the part of the valley southeast of Dripping Spring ranch, where the Gila formation contains much fine silty material, the topography is of the typical badland type. The arroyos, which carry no water except for a short time after rain, are floored with sand and gravel and maintain a regular grade from the middle of the valley into the mountains. Progress along the main spurs or streamways presents no difficulties, but attempts to travel in directions across their trend are likely to be regretted, and a horseman who enters one of the narrow, steep-walled arroyos may have to follow it for miles before he can find a place of egress.

The Dripping Spring Range, which stretches diagonally across the quadrangle from the northwest to the southeast corner, varies in width in this part of its course from 3 to 4 miles, being definitely bounded on the northeast by the Gila conglomerate of Dripping Spring Valley and along most of its southwest flank by the similar material that fills the valley of the Gila. On the north the range ends at Mineral Creek, less than a mile beyond the boundary of the Ray quadrangle.

Notwithstanding the uniform width and the rectilinear trend of this range its topography is without recognizable system and shows none of that obvious relation to geologic structure that is so evident in the Mescal Range. Nevertheless, a general view of the mountains suggests that the broken, irregular topography corresponds to an equally intricate and unsystematic structure, in which faulting is the essential feature. If, for example, an attempt is made to trace an easily recognizable, conspicuous formation, like the Carboniferous limestone, from one exposure to another along the range, it soon becomes evident that the formation occurs in disjointed blocks that show much diversity of dip and many sharp contrasts in elevation. At one place, perhaps, the limestone may appear low down along the edge of the valley, while close behind it and 1,500 feet or more above it the bold cliffs encircling the summit of some peak are carved from another block of the same beds. If, again, the nearly horizontal strata of these cliffs are sought at the same elevation on the opposite side of a near-by ravine, that side may show, instead of the white or gray limestone, the buff or rusty tint of one of the quartzite formations or the characteristic olive-green of the diabase. Clearly the range has been carved from an almost chaotic assemblage of small fault blocks. Under the searching action of erosion large blocks have proved more resistant than many small blocks of the same materials. Consequently, in the Dripping Spring Range the higher peaks mark in general those areas where fissures are least numerous. The presence of an easily erodible mass of granodiorite and the prevalence of an extraordinarily minute dissection of the rocks by faulting furnish conditions that have favored the construction of the one wagon route across the range—the road by way of Troy.

The valley in which the Gila flows for most of its course through the quadrangle heads in the vicinity of Ray and expands southward to a width of nearly 8 miles in the neighborhood of Branaman. Southeast of Branaman it is narrowed to about 5 miles by some hills composed of Paleozoic and older rocks cut by diabase, that project into the valley on the southern edge of the quadrangle, west of Burns; but as the valley of the San Pedro, a tributary of the Gila, it continues with gently ascending grade southeastward for at least 120 miles, past Benson, to the Mexican border near Naco. Concerning much of this great linear depression little topographic or geologic information is available. Seen from high points in the Dripping Spring Range, such as Tornado Peak, the valley, with its long lateral slopes and spurs of conglomerate rising gently from the river to the mountains, stretches away to the southeast as far as the eye can see. Farther south it may open here and there into broad desert embayments, but the San Pedro throughout its course from Mexico to its confluence with the Gila appears to follow a remarkably straight and persistent structural trough, which is filled more or less deeply with Gila conglomerate and later deposits. The present Gila River apparently had nothing to do with the formation of this long valley. It enters the valley on the east near Winkelman, after having traversed the Mescal and Dripping Spring ranges through deep gorges, flows northwestward for 14 miles, and then, turning west, finds outlet through another gorge across the Tortilla Range. It is not unlikely that this gorge is of comparatively late development and that the river at one time found its way across the Tortilla Range south of the Ray quadrangle. This, however, is little more than a conjecture suggested by what could be seen of the country south of the quadrangle in distant views and by general maps of the region.

The Tortilla Range is generally lower and more irregular in plan than the Mescal and Dripping Spring ranges. Distant views indicate that as a definite range it loses its identity a short distance south of the Ray quadrangle, being separated by irregularly hilly but comparatively low ground from the Santa Catalina Mountains, which continue southeast past Tucson to the line of the Southern Pacific near Benson. To the north the Tortilla and Dripping Spring ranges come together in the vicinity of Ray and continue northward to Salt River as an irregular mountain complex that includes the Superstition Mountains, of rather intricate geologic structure. North of Salt River a well defined range, the Mazatzal, between Tonto Creek and Verde River, prolongs the general line of uplift to the edge of the Colorado Plateaus. The rectilinear chain make up of the Mazatzal, Dripping Spring, Pinal, Mescal, Caliuro, Dragoon, and Mule ranges has a length of about 250 miles and is one of the most notable features in the physiography of Arizona. Nearly parallel with this chain on the east is the line of the Chiricahua, and Pinaleno ranges, which in the vicinity of the Gila either dies out or may perhaps be regarded as a branch from the Pinal-Mescal member of the more continuous uplift.

The part of the Tortilla Range that is included in the Ray quadrangle is chiefly a ridge of pre-Cambrian granite. East of this granitic ridge, in the southern part of the quadrangle, there is a series of sharp, narrow strike ridges composed of the Paleozoic sedimentary beds that are here upturned into an almost vertical attitude.

The only considerable perennial streams in the quadrangle are Gila River and Mineral Creek. The discharge of the Gila has been measured at San Carlos, 25 miles above the point where it enters the Ray quadrangle, and also at a locality known as "The Buttes," about 12 miles west of Ray Junction. The results are shown in the following table:[5]

Estimated annual discharge of Gila River at The Buttes and San Carlos, Ariz.

	The Buttes.	San Carlos.[a]
	Acre-feet.	*Acre-feet.*
Seasonal year 1889–90, Sept. 1 to Aug. 31	366, 561	329, 905
Fractional year 1895, Aug. 1 to Dec. 31	354, 429	318, 986
Year 1896	616, 206	554, 585
Fractional year 1897, Jan. 1 to Oct. 3	503, 585	453, 227
Year 1898, approximate	363, 902	327, 512
Fractional year 1899, Jan. 1 to Sept. 30	203, 910	183, 519

[a] Ninety per cent of volume at The Buttes.

Lippincott[6] has concluded that the mean annual discharge at San Carlos is 422,184 acre-feet and at The Buttes 469,093 acre-feet, the difference being due chiefly to the contribution of the San Pedro near Winkelman, just south of the quadrangle, although Mineral Creek at certain seasons is also a considerable affluent. An annual discharge of 469,093 acre-feet is equivalent to an average flow of approximately 4,850 gallons per second.

The river where it crosses obliquely the valley between Dripping Spring and Tortilla ranges is bordered by an irregular flood plain having a maximum width of 1¼ miles. Some of this land is under cultivation, but the river, which in midsummer is a shallow stream, easily fordable, is subject to violent floods, especially in January and February, which make the tenure of the cultivators more or less precarious. Even at low water the Gila caries much fine silt and of course is much more heavily laden in flood. In the dry season the San Pedro carries little visible water and the bed of Mineral Creek near its mouth is normally dry.

GENERAL GEOLOGY.

INTRODUCTORY OUTLINE.

The sequence and the thickness of the geologic formations in the Ray quadrangle are shown in Figure 3. This figure, however, does not represent the full history of deposition in this region. Between certain divisions are unconformities showing that at times the accumulation of sediments on a sea bottom or near sea level was interrupted by uplift and erosion. In addition to the four unconformities plainly recognizable there are possibly others in the rocks below the Devonian, although all the beds provisionally included in the Cambrian appear to have been laid down without any break in sequence.

The fundamental rocks of the region are those designated the Pinal schist, commonly a thinly laminated micaceous variety, and certain granitic rocks that have been intruded into the schist. The Pinal schist consists in the main of metamorphosed sedimentary rocks. Both the schist and the granite are pre-Cambrian and were subjected to long erosion before the deposition of the succeeding formations.

Resting as a rule directly on the worn surface of the pre-Cambrian crystalline rocks is the Scanlan conglomerate. This formation differs in character and thickness from place to place. Generally in the Ray quadrangle it is about 15 feet thick and contains abundant well-rounded pebbles, some of which are

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[4] A homocline is a block of bedded rocks all dipping in the same direction. See Daly, R. A., A geological reconnaissance between Golden and Kamloops, B. C., along the Canadian Pacific Railway: Canada Geol. Survey Mem. 68, p. 53, 1915.

[5] Lippincott, J. B., Storage of water on Gila River: U. S. Geol. Survey Water-Supply Paper 33, p. 29, 1900.

[6] Op. cit., p. 30.

composed of quartzite. In some places weathered, disintegrated, and recemented granitic detritus, or arkose, lies between the conglomerate and the pre-Cambrian granite.

The Scanlan conglomerate is overlain conformably by the Pioneer shale. As a rule this formation consists of dark reddish-brown, more or less arenaceous shale composed largely of fine granitic detritus with little or no calcareous material. At many places the shale grades downward into arkosic sandstone. Abundant round or elliptical spots of light-buff or greenish color are highly characteristic of the shale.

Next above in the stratigraphic series is the Barnes conglomerate, which in its typical development consists of smooth pebbles of white quartz and of hard vitreous quartzite in an arkosic matrix. The pebbles are generally less than 6 inches in diameter. Small fragments or pebbles of bright-red jasper, although nowhere abundant, are a very characteristic and constant feature of this conglomerate, which in the Ray quadrangle is from 10 to 40 feet thick.

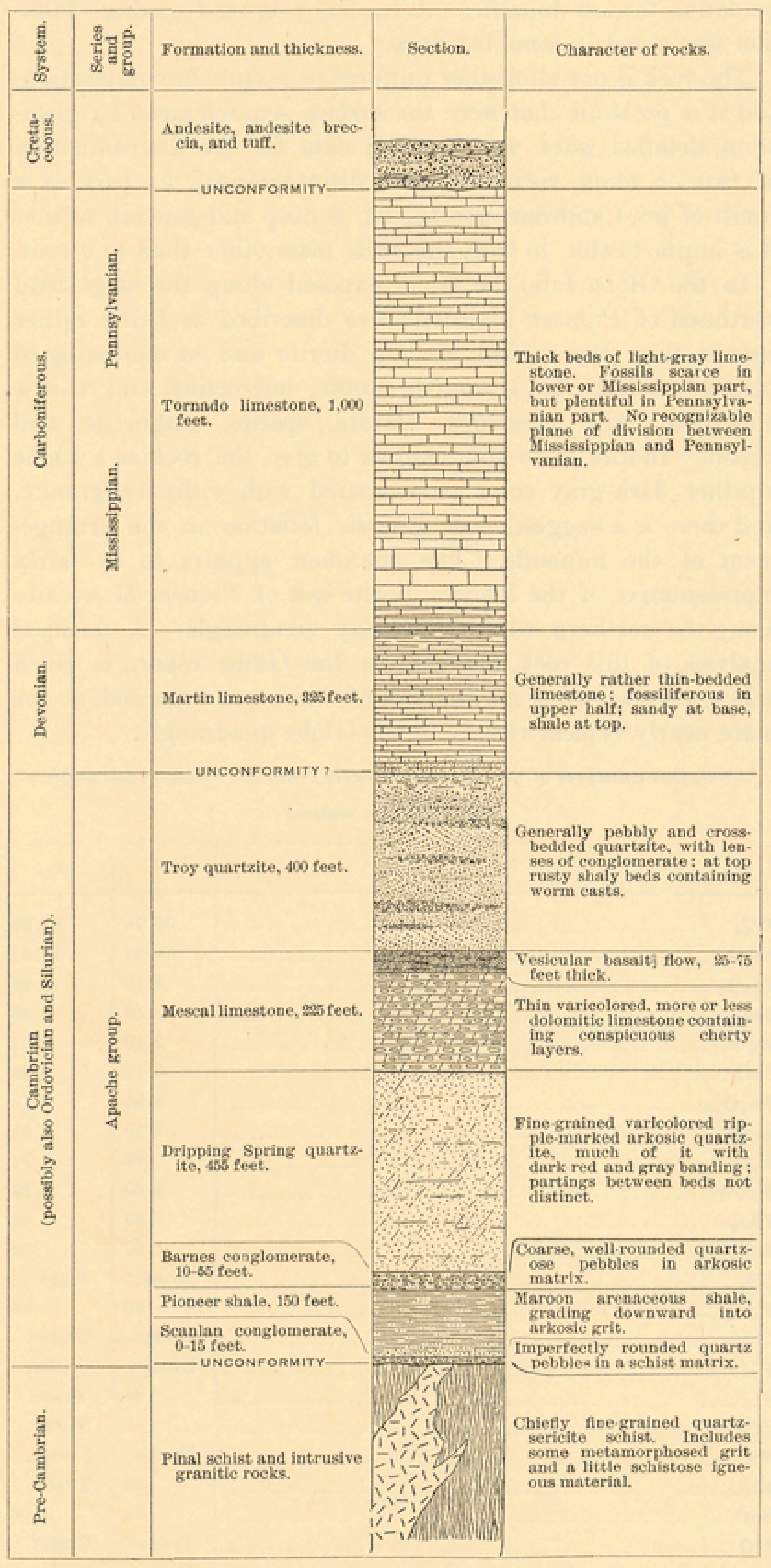

FIGURE 3.—Generalized columnar section of the rocks that crop out in the Ray quadrangle.

Scale: 1 inch=400 feet.

Conformably overlying the Barnes conglomerate is a formation of quartzite and quartzitic sandstone from 400 to 500 feet thick, the Dripping Spring quartzite. In most localities in the Globe, Ray, Florence, and Roosevelt quadrangles this formation is closely associated with thick intrusive masses of diabase. The diabase occurs chiefly as sheets following the bedding planes but also as crosscutting bodies connected with the sheets.

The Mescal limestone conformably overlies the Dripping Spring quartzite. It is composed of thin beds that have a varied range of color but are persistently cherty. The siliceous segregations as a rule form irregular layers parallel with the bedding planes, and on weathered surfaces these layers stand out in relief and give the limestone the rough, gnarled banding that is its most characteristic feature. The average thickness of the Mescal limestone in the Ray quadrangle is about 225 feet. At the time of the diabase intrusions the Mescal offered less resistance to the advance of the magma than the other formations, and it has been much broken and displaced by the force of the igneous invasion. In places it is represented only by fragments included in the diabase. Between the limestone and the overlying formation is a layer of decomposed vesicular basalt whose maximum observed thickness is from 75 to 100 feet. Although the basalt in places is much thinner than this, the flow was apparently coextensive with the Mescal limestone throughout the Ray and Globe quadrangles and has been recognized as far north as Roosevelt. This basalt, owing to its small thickness, has been mapped with the Mescal limestone in the Ray quadrangle, although it is not included in the definition of that formation.

The succeeding formation is the Troy quartzite, about 400 feet thick. Everywhere in this region it is separated from the Mescal limestone by the basalt flow, and this may possibly indicate some unconformity. No evidence of erosion, however, has been detected either below or above the basalt, which may have flowed over the sea bottom.

All the beds thus far described as above the great unconformity at the base of the Scanlan conglomerate constitute the Apache group and, although no fossils have been found in them, are believed, for reasons presented on pages 9–10, to be of Cambrian age. It is possible that some of the beds near the top of the group may represent Ordovician and Silurian time, but there is no fossil evidence for this nor has any unconformity been detected to account for the apparent lack of representation of these two great periods.

Conformably above the Troy quartzite is the Martin limestone, which is about 325 feet thick in the Ray quadrangle. This formation is divisible into upper and lower portions of nearly equal thickness. The upper portion carries characteristic Devonian fossils, but no identifiable fossils have been found in the lower portion, which consequently can not be regarded as unequivocally Devonian.

The Martin limestone is conformably overlain by a thick-bedded light-gray limestone that is nearly everywhere a prominent cliff maker. This is the Tornado limestone. As exposed in the Ray quadrangle it has a maximum thickness of at least 1,000 feet. As its upper limit is a surface of erosion dating in part from early Mesozoic time, the limestone was probably once much thicker. It is of Carboniferous age.

After the deposition of the Tornado limestone the region was uplifted above sea level and underwent erosion, probably until Cretaceous sedimentation began. The diabase is thought to have been intruded when this uplift occurred, in late Paleozoic or early Mesozoic time. Intrusive relations show very clearly that the diabase is younger than the Troy quartzite. The Martin and Tornado limestones have been cut only here and there by small bodies of diabase that are supposed to represent parts of the same magma that solidified in larger masses at lower stratigraphic horizons.

In the southern part of the Ray quadrangle and stretching southward across the Gila is a broad belt of andesitic tuff and breccia associated with some andesitic lava flows and cut by many porphyry dikes of andesitic to dioritic or monzonitic character. In places the andesite is separated from the eroded surface of the underlying Tornado limestone by a few feet of angular cherty detritus, clay, or fine, soft tuff. Along the Gila, however, and according to Campbell[7] south of that stream, a coarse conglomerate lies at the base of the volcanic series. Walcott[8] and Campbell both refer to the andesite as overlying Cretaceous sediments and connected with them by the intercalation of sedimentary layers containing a little coal. Presumably, therefore, the andesite, like the coal, is Cretaceous.

The eruption of the andesitic rocks was followed by the intrusion, in the general order enumerated, of (1) quartz diorite in small irregular masses and a few dikes of considerable size; (2) granite, quartz monzonite porphyry, and granodiorite in masses, some of which, as the Schultze granite, are several miles in diameter; and (3) quartz diorite porphyry in dikes, sills, and small rotund masses. The rocks of the second group are closely related to the copper deposits. The time of intrusion of all the rocks mentioned is not definitely known. They are provisionally considered early or middle Tertiary.

The intrusion of these rocks was followed by a period of erosion during which was deposited in parts of the region the Whitetail formation, of very irregular thickness, consisting chiefly of coarse angular or only slightly waterworn land detritus.

The next rock in order of time is dacite, which was poured out as a thick lava flow, or possibly as a series of flows. Although the continuity of this lava cover has been much broken by faulting and erosion the dacite still occupies a large portion of the area. The former maximum thickness is unknown, but existing remnants show that it must have exceeded 1,000 feet. The age of the dacite is not closely determinable, but the lava is supposed to have been erupted in the later half of Tertiary time.

The outpouring of the dacite was followed by extensive faulting and vigorous erosion. During the period of erosion, probably in early Quaternary time, the Gila formation accumulated in the valleys. This is a fluviolacustrine deposit ranging from very roughly bedded coarse angular detritus near the mountains to well-bedded silts and layers of gypsum in the middle of the broader valleys. The Gila formation has been deformed by faulting and in general has been deeply cut by erosion.

PRE-CAMBRIAN ROCKS.

PINAL SCHIST.

Definition.—The name Pinal schist was applied in 1903 to the pre-Cambrian schistose terrane of the Globe quadrangle, the geographic term of the designation being derived from the Pinal Mountains, on whose slopes the schists are extensively exposed.[9] As was then pointed out, these rocks probably correspond to those which Blake[10] 20 years earlier had called the "Arizonian slates"; but as the geographic term of his name does not accord with the rules of nomenclature followed by the United States Geological Survey and as the lithologic term is not appropriate for crystalline schists, Blake's designation has not been retained. Since the publication of the Globe report the name Pinal schist has been applied to the pre-Cambrian crystalline schists of the Clifton-Morenci[11] and Bisbee[12] districts. The Pinal schist has of late years attained prominence as the principal country rock of the disseminated copper deposits at Ray and Miami.

Distribution.—In the Globe quadrangle the Pinal schist constitutes an extensive formation, but in the Ray quadrangle, although it doubtless underlies a large portion of the area, it is covered for the most part by Paleozoic and younger formations, and only in the northwest corner of the quadrangle does it appear at the surface, in a number of comparatively small exposures which stretch northeastward from the vicinity of Ray past Walnut Spring.

Lithologic character.—Like most crystalline metamorphic formations, the Pinal schist is not uniform in appearance. The divergencies from what may be considered the typical schist are mainly of two kinds—those due to differences in the original materials from which the schists were formed and those dependent upon local variations in the intensity of the metamorphism. As examples of the first kind may be mentioned certain subordinate bands of amphibolite schist in the Globe quadrangle and some irregular bands of an unusual variety southwest of Ray, which has been fully described elsewhere[13] and is an altered rhyolite. The second kind of variation is illustrated by the increase of the crystallinity of the schists and the development of additional minerals in them near the contact with intrusive masses, such as the pre-Cambrian quartz-mica diorite (Madera diorite) of the Pinal Range or the quartz monzonite porphyry of Granite Mountain, southwest of Ray. (See the geologic map of the Ray district.) On the whole, within the Globe-Ray region variations dependent upon degree of metamorphism are more conspicuous than those dependent upon differences in composition.

In general the Pinal schist is light gray to blue-gray, with a more or less satiny luster on cleavage surfaces. In texture the varieties range from very fine grained slaty sericitic schist to imperfectly cleavable, coarsely crystalline quartz-muscovite schist carrying locally andalusite or sillimanite. The coarsely crystalline varieties occur chiefly in the Globe quadrangle, in the vicinity of the Madera diorite in the Pinal Mountains, and grade into the less metamorphosed kinds that make up the bulk of the formation and are characteristic of most of the exposures in the Ray quadrangle.

In the areas of schist exposed from the town of Ray northeastward to the south border of the Globe quadrangle the prevalent variety is an almost slaty blue-gray rock that disintegrates readily so that slopes on the schist present a characteristic glistening blue surface distinguishable at a distance from the detritus into which other formations break down by weathering. Small, ill-defined dark spots, due to the local segregation of some of the deeper-colored constituents especially biotite or chlorite, are common in certain bands, and some rather conspicuously spotted schist occurs in the contact zone of the granite porphyry on Granite Mountain, near Ray.

Microscopic sections show that the principal constituent minerals of the typical fine-grained fissile schist are quartz and sericite. The quartz occurs in part as grains of irregular outline as much as 0.5 millimeter in diameter in a finely granular groundmass of quartz and sericite with many dust-like particles of magnetite. Small, short prisms of tourmaline are fairly abundant, and minute rounded crystals of zircon are sparsely disseminated through the rock. The fissility of the schist is determined by the general parallel arrangement of the sericite flakes and by a tendency of this mineral to form thin layers separated by correspondingly thin layers of quartz granules.

A specimen collected in the Globe quadrangle 2 miles northeast of Pinal Peak, a few hundred feet from the Madera diorite, may be taken as typical of the coarser mica schist. This is a

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[7] Campbell, M. R., The Deer Creek coal field, Ariz.: U. S. Geol. Survey Bull. 225, p. 247, 1904.

[8] Walcott, C. D., Description of the Deer Creek coal field: 48th Cong., 2d sess., S. Ex. Doc. 20, Appendix I, pp. 5–7, 1885.

[9] Ransome, F. L., Geology of the Globe copper district, Ariz.: U. S. Geol. Survey Prof. Paper 12, p. 23, 1903.

[10] Blake, W. P., Geology of the Silver King mine: Eng. and Min. Jour., vol. 35, pp. 238–239, 1883.

[11] Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Ariz.: U. S. Geol. Survey Prof. Paper 43, 1905.

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

[13] Ransome, F. L., The copper deposits of Ray and Miami, Ariz.: U. S. Geol. Survey Prof. Paper 115, pp. 33–34, 36–37, 1919.

silvery-gray rock of imperfect cleavage and on surfaces of fresh fracture flashes with irregular plates of white mica, generally about half a centimeter across. Under the microscope the principal constituents are seen to be quartz and muscovite in very irregularly bounded crystal grains. The muscovite occurs both in comparatively large plates, many of which inclose grains of quartz, and as the small-leaved variety known as sericite. The subordinate minerals are magnesite, plagioclase, sillimanite, rutile, and chlorite. Similar varieties of the schist near the quartz diorite contain abundant andalusite.

Chemical composition of Pinal schist and sedimentary rocks.

	1	2	3	4	5
SiO_2	61.62	65.58	66.84	60.15	60.49
TiO_2	.56	.83	.67	.76	.73
Al_2O_3	19.98	16.47	17.46	16.45	17.56
Fe_2O_3	3.46	4.19	4.88	4.04	2.74
FeO	2.57	2.25	.74	2.90	4.61
MnO		.06	.02	Trace.	
CaO	.62	1.29	.37	1.41	1.26
SrO				None.	
BaO				.04	
MgO	1.24	1.29	1.14	2.32	2.51
K_2O	5.35	4.58	4.65	3.60	3.31
Na_2O	1.78	1.42	.53	1.01	1.32
Li_2O	Trace.			Trace.	
H_2O-	.21	.22	.17	.89	.31
H_2O+	2.23	2.27	2.61	3.82	3.61
P_2O_5		.06	.03	.15	
CO_2				1.46	1.11
SO_3				.58	
Carbon (organic)				.88	
	99.62	100.51	100.11	100.46	99.56

1. Pinal schist (Ry 348). Ravine half a mile southwest of Vitoria, close to contact with granite porphyry mass of Granite Mountain, Ray district. R. C. Wells, analyst.
2. Pinal schist (Ry 332). South slope of Red Hills, Ray district. George Steiger, analyst.
3. Pinal schist (M 3). Dump of prospecting shaft 1,500 feet west of the office of the Warrior mine, on north side of Webster Gulch, Miami district. George Steiger, analyst.
4. Composite analysis of 51 Paleozoic shales. H. N. Stokes, analyst. U. S. Geol. Survey Bull. 419, p. 10, 1910.
5. Average of 79 slates and phyllites, mostly roofing slates, compiled by E. S. Bastin. (Chemical composition as a criterion in identifying metamorphosed sediments: Jour. Geology, vol. 17, p. 456, 1909.)

In the vicinity of Ray and west of that town a considerable part of the schist is a gray, fine-granular, moderately fissile rock with the unmistakable aspect of a squeezed and metamorphosed sandstone. Thin sections of this variety under the microscope show rotund but irregular grains of quartz up to 5 millimeters in diameter in a groundmass that consists chiefly of quartz and sericite. The large quartz grains show the effects of granulation with more or less recrystallization under pressure. Some consist of many small interlocking crystal grains; others are crystallographic units but show by their shadowy extinctions that the quartz has undergone molecular readjustment under the stresses accompanying metamorphism.

Other varieties, not very different from the foregoing in general appearance, contain a little plagioclase and some greenish biotite associated with the sericite. These are probably metamorphosed feldspathic sandstones or graywackes.

Southwest of Ray, in the vicinity of the intrusive quartz monzonite porphyry of Granite Mountain, the Pinal schists have been clearly modified by the igneous rock, as shown near the contact by an increase in crystallinity, by a pronounced tendency of the mica to segregate so as to give the schists a spotted appearance, and by the development of andalusite. Although this metamorphism was imposed upon rocks long previously rendered schistose the two epochs of alteration are not sharply distinguishable in their results.

Origin and metamorphism.—The foregoing description has given anticipatory suggestions of the conclusion that the Pinal schist is, in the main, a series of metamorphosed sediments. The evidence in support of this view, part of which was adduced in 1903,[14] may now be examined a little more closely.

In general the mineral composition of the prevalent kinds of schist, their regular banding where not locally disturbed, and the finely fissile character of most of the rock are indicative of sedimentary origin. That at least a part of the formation was originally sedimentary is clearly proved by the presence near Mineral Creek, at the western base of the Pinal Range, of some layers in which small quartz pebbles are still recognizable. Moreover, as noted above, in the vicinity of Ray and west of that town much of the schist presents the unmistakable aspect of a squeezed and metamorphosed sandstone, accompanied by still finer grained varieties that were evidently at one time shale. In some places the original bedding is plainly apparent. Thin sections of this variety, seen under the microscope, show rotund but irregular grains of quartz 5 millimeters in maximum diameter in a groundmass consisting chiefly of quartz and sericite. The large quartz grains show the effects of granulation with more or less recrystallization under pressure.

Structural features.—As might be expected in rocks so old and so intricately intruded by batholithic granitic masses during more than one geologic period, the Pinal schist shows variations in the strike and dip of its planes of schistosity, and locally these planes are intensely crumpled and contorted. The disturbance is probably least in the broad belt on the lower southwest slope of the Pinal Range. In this area regularly laminated sericite schists, containing some layers in which the original character of quartzose grits is distinctly recognizable, predominate, but toward the Madera diorite they change to more coarsely crystalline muscovite schists. The prevailing strike of the schistose cleavage in this and in other schist areas of considerable extent is northeast. The dip ranges from 45° to vertical and is generally to the northeast. As a rule the schistosity is roughly parallel with whatever larger banding due to differences in the composition of the schists may be discernible. This fact is accepted as an indication that the schistosity is approximately parallel with the original bedding of the rocks. It is noteworthy that the general strike of the schistose cleavage is not parallel with the present mountain ranges of the region but in the largest area of exposure runs nearly at right angles to them.

Excessively crumpled laminae are characteristic of the schist in the vicinity of Miami and on Pinto Creek, near the mouth of Cottonwood Creek. This intense local deformation, though probably favorable for ore deposition, other things being equal, was apparently neither a necessary factor in metallization nor an invariable accompaniment of that process.

Associated with the metallized schist in the vicinity of Ray are bodies of dark, generally soft and decomposed schist that was evidently at one time an igneous rock, probably a diabase. These masses are not large and as a rule are not ore bearing, but they are so related to the ore bodies as to deserve careful study. A detailed account of these bodies appears in another publication.[15]

With respect to fairly high silica, to an excess of over 10 per cent of alumina above the quantity required to combine with the K_2O, MgO, and CaO molecules in a 1:1 ratio, to a preponderance of magnesia over lime, and to a like preponderance of potash over soda, the analyses of the Pinal schist satisfy the chemical criteria for sedimentary origin as summarized by Bastin.[16] The close resemblance of the composition of the schist to those of shales and slates is evident from the composite analysis and the average of analyses given in columns 4 and 5 of the preceding table. On the whole, the analyses of the schist exhibit even more decidedly than those with which they are compared the chemical features characteristic as a rule of shaly sediments in comparison with igneous rocks.

The progressive steps whereby the pre-Cambrian sediments and small associated bodies of igneous material were transformed to schists are not easily retraceable, nor are the causes of the metamorphism entirely clear. The effects of the intrusion of the pre-Cambrian quartz diorite and granite of the Pinal Range are so pronounced near the contacts and decrease so gradually outward as to give considerable force to the suggestion that the first crystalline metamorphism dates from these intrusions. The Pinal schist at Clifton and Bisbee is accompanied by pre-Cambrian granitic intrusives, as are also the probably equivalent Yavapai schist of the Bradshaw Mountains and the schist of the Grand Canyon. Without further discussion of the question here, expression may be given to the opinion that the general metamorphism of the Pinal and equivalent schists in Arizona was probably connected directly with the extensive batholithic invasions of granitoid rocks in pre-Cambrian time. The fact that the Madera diorite and other pre-Cambrian intrusive masses are themselves in places more or less gneissoid shows that metamorphism continued after solidification of their now visible parts. Moreover, the intrusion of the Schultze granite and of the granite porphyries near Ray locally intensified the metamorphism of the Pinal schist. This may be well seen on Granite Mountain, southwest of Ray, where the schist near the granite porphyry is generally more coarsely crystalline than elsewhere and in places carries poikilitic crystals of andalusite. Other varieties are conspicuously spotted by the segregation of chlorite or mica about numerous centers of crystallization.

Although andalusite appears to be confined to the immediate vicinity of the intrusive rocks, there is in general no definite recognizable distinction between the metamorphism effected at different periods or between the local contact modifications and the more general metamorphism.

GRANITIC INTRUSIVE ROCKS.

Principal varieties and their distribution.—In the Globe folio six distinct supposedly pre-Cambrian intrusive rocks were mapped of which one, the Schultze granite, is now believed to be post-Cambrian and two others, the Willow Spring granite and the Lost Gulch monzonite, are possibly also post-Cambrian. Another, the Solitude granite, is exposed only over a small area about 5 miles southwest of Globe and need not be further considered here. This leaves for the pre-Cambrian granitoid rocks of the region two widespread and important types—quartz-mica diorite (Madera diorite) and biotite granite (including the Ruin granite of the Globe folio).

The quartz-mica diorite is most abundant in the Pinal Range, where it is intricately intruded into the Pinal schist. The biotite granite is the principal rock of the Tortilla Range from the vicinity of Ray southward past Kelvin and beyond the southern and western limits of the area here described.

Quartz-mica diorite (Madera diorite).—The name Madera diorite, from Mount Madera, in the Pinal Range, was first applied in the Globe report,[17] in which the diorite was described as generally a gray rock of granitic texture and habit, consisting essentially of plagioclase feldspar (chiefly andesine) with quartz and black mica (biotite). Orthoclase and microcline occur in some varieties that approach granodiorite in composition; in others the occurrence of hornblende indicates gradation toward tonalite. A tendency toward gneissic foliation was noted in some localities.

The rock is not altogether uniform in texture or composition, and it is probable that were the surface scoured clean by glaciation, detailed work would afford data for the discrimination of two or more varieties. But disintegration, in part as a result of pre-Cambrian weathering, is deep and general, so that it is impracticable to treat the rock mass other than as a unit.

In the Globe folio the facies exposed along the stage road northeast of Pioneer Mountain was described as being rather coarser than the typical Madera diorite and as consisting of plagioclase (Ab_1An_1), quartz, biotite, microcline, and a little muscovite, with accessory titanite, apatite, magnetite, and zircon. Biotite is so abundant as to give the rock as a whole a rather dark-gray color as compared with ordinary granite, and there is a suggestion of gneissic foliation in the arrangement of the minerals. The specimen appears to be fairly representative of the Madera diorite east of Pioneer Mountain, along the northern edge of the Ray quadrangle. A chemical analysis of this rock, taken from the Globe report, is given below, together with an analysis of what was regarded as the more nearly typical variety in the Globe quadrangle.

Chemical analyses of quartz-mica diorite from the Globe quadrangle.

[W. F. Hillebrand, analyst.]

	1	2
SiO_2	58.74	61.99
Al_2O_3	16.02	15.81
Fe_2O_3	4.16	3.28
FeO	3.50	2.69
MgO	2.18	2.24
CaO	5.12	4.62
Na_2O	3.26	2.73
K_2O	2.39	2.51
H_2O-	.83	.91
H_2O+	1.60	1.99
TiO_2	1.29	.94
ZrO_2	.05	.03
CO_2	None.	None.
P_2O_5	.56	.11
Cl	Undet.	Undet.
F	Undet.	Undet.
S	[a].06	Trace.
Cr_2O_3		Trace.
NiO	Trace.	Undet.
MnO	.22	Trace.
BaO	.10	.06
SrO	Trace.	Undet.
Li_2O	Trace.	Undet.
FeS_2	.11	
	100.13	99.91

[a] Calculated as FeS_2.

1. Globe-Kelvin stage road, 2 miles south of Pinal Peak or 1½ miles east-northeast of Pioneer Mountain.
2. West slope of Pinal Range, 2 miles southwest of Mount Madera.

At no place southeast of the stage road has any marked change been detected in the general character of the prevailing rock, yet examination of successive exposures in that direction shows a notable increase in pink potassium feldspar in the form of phenocrysts. A specimen collected a mile northeast of Old Baldy is a slightly foliated porphyritic gneiss containing anhedral phenocrysts of potassium feldspar 4 centimeters or less in length in a groundmass closely similar to the general mass of the rock represented by analysis 1, above. The feldspar phenocrysts as seen in thin section show in part the optical character of orthoclase and in part that of microcline, there being in this rock no sharp distinction possible between the two forms. The characteristic microcline twinning is as a rule not conspicuously developed, and, as is well known to petrographers, orthoclase may be regarded as microcline in which the twinning lamellae are submicroscopic.

The relative abundance of phenocrysts and groundmass differs from place to place, and where the porphyritic crystals are numerous the composition of the mass as a whole must be

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[14] U. S. Geol. Survey Prof. Paper 12, p. 27, 1903.

[15] U. S. Geol. Survey Prof. Paper 115, p. 125, 1919.

[16] Bastin, E. S., Jour. Geology, vol. 17, p. 472, 1909.

[17] U. S. Geol. Survey Prof. Paper 12, p. 58, 1903.

considerably different from that given in column 1 of the table on page 4. Such facies should probably be classed as granodiorite or quartz monzonite. In the absence of abundant fresh material, however, it did not appear that decision on the exact place in classification of these variable porphyritic varieties was of such moment as to warrant chemical analysis.

Granite (*biotite granite*).—In all ordinary exposures the granite is weathered and in various stages of disintegration, so that collection of fresh material is rarely possible. This is especially true in the vicinity of the lower Paleozoic sediments, where the granite is generally reddened by pre-Cambrian oxidation.

It consists as a rule of large shapeless phenocrysts of flesh-colored potassium feldspar from 2 to 5 centimeters in length in a groundmass of coarsely crystalline anhedral plagioclase and quartz with a moderate proportion of biotite.

The microscope shows that the phenocrysts are, in the main slightly microperthitic orthoclase, although in parts of each crystal there are obscure suggestions of microcline twinning. These crystals are traversed by microscopic quartz-filled cracks, and the rock as a whole shows evidence of deformation in the zone of fracture. The plagioclase is a sodic variety, probably oligoclase, but is too decomposed for satisfactory identification. Much of the biotite is altered to chlorite.

Owing to its prevalent decomposition no detailed petrographic or chemical study has been made of this rock, which, although it is accompanied by some finer-grained facies, is fairly representative of the coarse, more or less reddish porphyritic granites that are characteristic of the pre-Cambrian generally in Arizona. Its relations to the Madera diorite are not discoverable in this region.

The Ruin granite of the northern part of the Globe quadrangle, including the mass of Porphyry Mountain, which in the Globe report was erroneously classed with the Schultze granite, is virtually identical with the granite of the Tortilla Mountains.

PALEOZOIC ROCKS.

STRATIGRAPHIC DIVISIONS AND SEQUENCE.

The names, thicknesses, and succession of the Paleozoic rocks that in the Ray quadrangle rest with conspicuous unconformity upon the pre-Cambrian crystalline complex are graphically summarized in the columnar section (Fig. 3).

Although in this region the stratified rocks have been elaborately faulted, the fault pattern being on an extraordinarily minute scale, and have been extensively invaded by diabase, excellent sections, of the kind illustrated in Plate VI, may be studied in the Mescal Range and in many of the larger fault blocks of the Dripping Spring Range. The total thickness of the beds below the base of the Carboniferous limestone and above the pre-Cambrian crystalline rocks is about 1,600 feet. The Carboniferous limestone is at least 1,000 feet thick and is limited above by a Mesozoic erosion surface. No evidence of angular unconformity has been detected within the pre-Mesozoic sedimentary series, although the exposures are so good that any appreciable angular discordance could scarcely escape recognition.

In the report on the Globe quadrangle and in the Globe folio the name Apache group was applied to the beds supposed to lie between the base of the Devonian limestone and the ancient erosion surface on the Pinal schist. The Apache group, although mapped as a unit, was described in 1903 as being locally divisible into four formations, which, from the base up, were the Scanlan conglomerate, the Pioneer shale, the Barnes conglomerate, and the Dripping Spring quartzite. In the minutely faulted rocks of the Globe quadrangle no complete section of the group could be found, and the supposed constitution of the whole was arrived at by piecing together fragmentary data from different fault blocks under the assumption that there was in the region but one limestone formation (the Devonian and Carboniferous "Globe limestone") and but one quartzite formation (the Dripping Spring quartzite).

When, however, detailed work in the Ray quadrangle was begun in 1910 and better natural sections were studied, it soon appeared that below the Devonian, as shown in Figure 3, there are two thick formations of quartzite separated by about 250 feet of dolomitic limestone. The initial assumption made in attempting to construct the Globe stratigraphic column was therefore incorrect. The Dripping Spring quartzite as mapped in the Globe report and folio included some of what is now named the Troy quartzite, and the "Globe limestone" of the same publications included not only the Carboniferous and Devonian limestones, to which the name was intended to apply, but also some fragmentary masses, many of them inclusions in diabase, of what is now named the Mescal limestone.

In the present report the name "Globe limestone" is abandoned, as it is now possible to map separately the Devonian and Carboniferous limestones; but Dripping Spring quartzite is retained, with redefinition, as the designation of the lower of the two quartzite formations.

CAMBRIAN SYSTEM.

APACHE GROUP.

SCANLAN CONGLOMERATE.

Name.—The Scanlan conglomerate was first described in the Globe report,[18] where it was said to be from 1 to 6 feet thick and to be composed of imperfectly rounded pebbles of vein quartz with scattered flakes of schist held in a pink arkosic matrix. The name was derived from Scanlan Pass, in the northwestern part of the Globe quadrangle.

Distribution.—In the northeastern part of the Ray quadrangle the Scanlan conglomerate is exposed on Pioneer Mountain, on Old Baldy, and at many other places along the contact of the sedimentary series with the Madera diorite. In the northwestern part of the area the conglomerate appears at a few localities where by the combined action of faulting and erosion some of the underlying Pinal schist has been exposed. Small exposures of the Scanlan conglomerate may be seen also 1¼ miles northeast of Tam o' Shanter Peak, where it rests on a crumbling red granite, and an area too small to map is exposed in the bottom of a ravine half a mile north of Troy.

Character and thickness.—The Scanlan conglomerate is the most variable of the Paleozoic formations both in constitution and in thickness. It was evidently formed with little transportation from the materials that the waves of an advancing sea found lying on a well-worn ancient surface of low relief. Areas of schists were littered with fragments of white vein quartz, and the upper parts of granitic masses were deeply disintegrated. Consequently the basal conglomerate, where it rests on the Pinal schist, is composed chiefly of imperfectly rounded pebbles of quartz in a matrix of small particles of schist, grains of quartz, and flakes of mica; where it rests on granite or quartz-mica diorite the pebbles are also mostly quartz, but the matrix is arkosic, and the layers of pebbles may be associated with beds of arkose that in many places merge imperceptibly with the underlying massive rock or grade upward into the Pioneer shale. These two varieties of the conglomerate, however, are connected by transition facies. The thickness of the formation differs widely from place to place. In some localities the base of the Pioneer shale may be marked only by a few sparsely distributed pebbles or the Scanlan conglomerate may not be recognizable at all. In other places, as between Pioneer Mountain and Old Baldy, the conglomerate attains a thickness of fully 15 feet and carries abundant well-rounded pebbles, including a few of quartzite that are derived from some ancient formation which is not now exposed in this region. Above this well-defined bed, which locally resembles the younger Barnes conglomerate, and under the typical Pioneer shale is a coarse arkosic sandstone from 15 to 30 feet thick. Similar arkosic material accompanies the Scanlan conglomerate in other localities and marks a transition in the conditions of deposition from conglomerate to shale. In the Barnes Peak section, in the northwest part of the Globe quadrangle, the lower Pioneer shale for 25 feet above the Scanlan conglomerate is sandy and arkosic.[19]

In the vicinity of Roosevelt, 35 miles northwest of Ray, the conglomerate rests on granite, is 30 feet thick, and contains well-rounded pebbles as much as 9 inches in diameter. The same conglomerate has been recognized in the Santa Catalina Range, about 45 miles south-southeast of Ray, where its thickness at one locality was estimated at about 12 feet. The original distribution of this basal conglomerate over an area at least 85 miles from northwest to southeast and at least 40 miles wide is well established. In some places weathered, disintegrated, and recemented granitic detritus, or arkose, lies between the conglomerate and the pre-Cambrian granite.

PIONEER SHALE.

Definition.—In the Globe report[20] the name Pioneer shale, derived from the now abandoned mining settlement of Pioneer in the Ray quadrangle, was given to a series of shaly beds that overlie the Scanlan conglomerate and underlie the Barnes conglomerate. The typical section is that exposed on the northeast slope of Pioneer Mountain.

Distribution.—In the part of the Mescal Range included within the northeast corner of the Ray quadrangle the exposures of Pioneer shale form an irregular belt, stretching from El Capitan Mountain northwestward to the vicinity of Pioneer Mountain. The strip of shale is not continuous but has been broken and shifted by intrusions of diabase, so that in places a twofold or threefold repetition of the beds may appear in a single section across the strike of the formations. In the Dripping Spring Range the most extensive exposures of the shale are near the northwest end of the range, west of Walnut Spring and north of Ray. Southeast of Scott Mountain the shale appears here and there in a few of the numerous small fault blocks into which the range is structurally divided, but it nowhere occupies extensive areas of the surface and is not visible at all southeast of Tam o' Shanter Peak.

Character.—As a rule the Pioneer shale consists of dark reddish-brown, more or less arenaceous shales composed largely of fine arkosic detritus with little or no calcareous material. In some beds fragments of pink feldspar are easily recognizable by the unaided eye, and as a rule the shales toward their base grade into arkosic grits. These arkosic basal beds are well developed in the Apache Mountains, just northeast of the Globe quadrangle, where they attain a thickness of approximately 175 feet. For 75 feet above the granite these beds are thick, but higher up in the formation thinner beds appear and these grade upward into the shale.

Abundant round or elliptical spots of light-buff or greenish color, caused by local reduction and removal of the ferruginous pigment, are highly characteristic of the formation and serve in the absence of clear structural relations to distinguish the Pioneer shale from certain similar beds in the stratigraphically higher Dripping Spring quartzite. Surfaces of fresh fracture generally sparkle with minute flakes of white mica.

Although the Pioneer shale is a soft formation in comparison with the conglomerates and quartzites and weathers into smooth slopes it is nevertheless a well-indurated, firm, and in places not very fissile rock. The general color of the formation as seen on the hill slopes is dark red, maroon, chocolate-brown, or dull purplish gray.

Thickness.—In the Globe report the average thickness of the Pioneer shale was given as 200 feet, which is about the thickness in the typical section at Pioneer, in the northeastern part of the Ray quadrangle. In the ravine west of Hackberry Spring, in the southwestern part of the Ray quadrangle, the shale is 100 feet thick. In the canyon of Salt River, below the Roosevelt dam, the formation, which here in its lower part consists of alternating beds of sandstone and shale, has an estimated thickness of 250 feet. The average thickness for the region is estimated to be about 150 feet.

Origin.—The Pioneer shale so far as known is not fossiliferous and presents no characteristics that mark it indubitably as marine or fluviatile in origin. It is believed to be marine and to have been deposited in shallow water. No mud cracks have been observed in it.

BARNES CONGLOMERATE.

Definition.—The Barnes conglomerate, a characteristic, persistent, and readily recognized formation, lies stratigraphically above the Pioneer shale and below the Dripping Spring quartzite. The formation was first described in the Globe report[21] and took its name from Barnes Peak, in the northwestern part of the Globe quadrangle, where it is from 10 to 15 feet thick. There is no apparent unconformity either above or below the conglomerate, although the abrupt change from a fine shale to a deposit of coarse pebbles is indicative of such extensive modification of the conditions of erosion and sedimentation under which the shales accumulated as would seem to demand notable contemporaneous unconformity somewhere within the region of deposition. The surface of contact between the shale and the conglomerate is wavy and irregular, but the adjacent shale layers conform to the unevenness of the contact, as if they had settled under load.

Distribution.—The Barnes conglomerate is one of the most persistent and easily identified formations in the Ray quadrangle, and these properties, with its comparative thinness, give it exceptional value as a stratigraphic datum plane.

In the northeastern part of the quadrangle it crops out low down along the northeastern flank of El Capitan Mountain, and where it crosses El Capitan Canyon it is thrice repeated in consequence of displacements that accompanied the intrusion of diabase. From this canyon the main belt sweeps up over Old Baldy and continues across Silver Creek toward Pioneer Mountain, where faulting and intrusion again cause repetition of the outcrop in sections across the general strike.

In the complexly faulted Dripping Spring Range the Barnes conglomerate is exposed in many of the fault blocks northeast of Ray, in a few places around Troy, and northeast of Tam o' Shanter Peak. In the Tortilla Range it is upturned into a nearly vertical attitude in the vicinity of Hackberry Spring and the Ripsey mine.

Lithologic character and thickness.—In its typical development, as near Pioneer Mountain or on Silver Creek, the Barnes conglomerate consists of smooth pebbles of white quartz and of hard vitreous quartzite in an arkosic matrix. The pebbles are generally not over 6 inches in diameter, but in a few places there are some that reach 8 inches. Although well rounded, the pebbles are not rotund but are flattened ellipsoids or round-edged disks. They are composed only of the most durable materials and doubtless passed through long and varied processes of attrition before they came to rest in the Barnes conglomerate.

In some localities the pebbles, which generally lie with their flat sides roughly parallel with the bedding planes, are in contact and the proportion of arkosic matrix is correspondingly small; in other places the matrix predominates. As a rule in the Ray quadrangle the pebbles are seen to become larger and

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[18] U. S. Geol. Survey Prof. Paper 12, pp. 30-31, 1903.

[19] Op. cit., p. 31.

[20] Op. cit., p. 31.

[21] Op. cit., p. 31.

more abundant as the conglomerate is followed southward, although the gradation is probably not wholly regular. Thus at Barnes Peak the average diameter of the pebbles is 3 or 4 inches[22] and the thickness of the formation 10 to 15 feet. In the vicinity of El Capitan Mountain pebbles 6 inches in diameter are abundant; the average size is probably a little larger than at Barnes Peak, and the thickness of the formation is from 15 to 20 feet, but no rocks capable of supplying the pebbles are known in that direction, although of course exposures of pre-Cambrian quartzitic rocks may have existed in Cambrian time south of the Ray area.

At the north end of the Dripping Spring Range the conglomerate is rather variable. A small exposure about 1½ miles north of Walnut Spring shows thin bands of pebbles associated with pinkish arkose and gray shale. The pebbles, which are chiefly white quartz and not very well rounded, rarely exceed 2 inches in diameter and none were seen over 3 inches. About 2 miles northwest of Walnut Spring the whole formation is from 10 to 12 feet thick, but the arkosic matrix is much more abundant than the pebbles, which although not uniformly distributed are as a rule most numerous near the base. The lower part of the bed thus presents in some places the aspect of the typical Barnes conglomerate, whereas the upper part is distinguishable from the overlying quartzite only by containing few small and scattered pebbles.

Northeast of Tam o' Shanter Peak, on the other hand, the conglomerate is about 40 feet thick and consists chiefly of very smooth rounded pebbles which are generally in contact with one another, there being just enough matrix to fill the interstices. Some pebbles are as much as 10 inches in diameter, but most are under 6 inches. In the Tortilla Range, south of Kelvin, the conglomerate is about 55 feet thick and carries abundant characteristic pebbles as much as 8 inches in diameter.

The arkosic matrix of the conglomerate is generally similar to the material of the overlying Dripping Spring quartzite, although perhaps a little coarser. It varies in hardness, but as a rule all constituents of the conglomerate are cemented by silica into a hard and durable rock in which fractures traverse pebbles and matrix alike. A very characteristic feature of the Barnes conglomerate throughout the region described is the presence in the matrix of small fragments of vermilion-red chert or jasper an inch or so in maximum diameter. The only rocks known that might have furnished these red fragments are certain hematite jaspers associated with schist in the northern part of the Mazatzal Range, about 70 miles north-northwest of Ray.

A view of the upper part of the Barnes conglomerate as exposed on El Capitan Creek, in the northeastern part of the Ray quadrangle, is shown in Plate II.

This conglomerate is very constant in character and has a wide distribution. It has been identified in the Sierra Ancha, to the north, and in the Santa Catalina Range, to the south, two localities about 80 miles apart.

The relation of the Barnes conglomerate to the Pioneer shale may best be studied where the two formations are cut by Silver Creek, west of Old Baldy. Here the contact is gently undulating, and the laminations of the shale just under the contact conform, to some extent at least, to these undulations. The waviness of the contact and of the immediately underlying shale is apparently not due to erosion and unconformity but to a slight unequal yielding of the shale under the weight of the layer of conglomerate before the sediments were changed by induration into hard rock.

DRIPPING SPRING QUARTZITE.

Definition. — The name Dripping Spring quartzite was applied in the Globe report to a quartzite supposed to occupy the whole stratigraphic interval between the Barnes conglomerate and the base of the Devonian limestone, although in the Barnes Peak section, represented in Plate VII of that report, recognition of the fact that the formation there designated the Globe limestone is really the Mescal dolomite gives the Dripping Spring quartzite the limits within which it is now proposed to confine it. In other words, the Dripping Spring quartzite lies conformably above the Barnes conglomerate and under the Mescal dolomite.

Distribution.—The principal areas of the Dripping Spring quartzite are in the Mescal Range in the northeastern part of the quadrangle and in the northwestern part of the Dripping Spring Range. In the Mescal Range the formation is closely associated with a great irregular intrusive sheet of diabase, the eruptive rock, which completely incloses many large masses of the quartzite. In those mountains excellent exposures of the Dripping Spring quartzite may be seen in the deep gorge of Pioneer Creek between the site of the old settlement of Pioneer and the junction of this creek with Silver Creek. These beds also are laid bare over broad areas on the even southwestern slopes, corresponding closely to the dip angle, of the 5,760-foot hill south of Pioneer Mountain, of Old Baldy, and of the 5,716-foot hill between Old Baldy and El Capitan Mountain. On these slopes it is possible to walk for long distances on the clean upper surfaces of the beds (see Pl. III) and to examine in great detail their lithologic features. In the Dripping Spring Range the quartzite is exposed from the vicinity of Tam o' Shanter Peak to the point where the Paleozoic rocks disappear under younger formations along Mineral Creek in the southwest corner of the Globe quadrangle. In this range the formation is divided by faulting into innumerable small blocks, and only in that portion of the uplift northeast of Ray and north of Scott Mountain is the Dripping Spring quartzite prominent in surface exposures. In the Tortilla Range it occurs with the other steeply upturned Paleozoic beds in the vicinity of Hackberry Spring and the Ripsey mine.

Lithologic character.—At only one place in the Ray quadrangle, about 1½ miles west-southwest of Pioneer Mountain, is there exposed an apparently continuous section of the Dripping Spring quartzite from the Barnes conglomerate at its base to the Mescal dolomite at its top. Unfortunately this exposure is not a satisfactory one for the study of the character and thickness of individual beds, and the constitution of the whole formation will have to be described in rather general terms. Approximately the lower third of the formation consists of hard fine-grained arkosic quartzites, which, as seen in natural sections, show no very definite division into distinct beds but do exhibit a pronounced striping, due to the alternation of dull-red and dark-gray or nearly black bands parallel with the planes of stratification. These bands as a rule are less than 1 foot wide and give a generally thin-bedded aspect to this portion of the formation. About midway between the top and bottom of the formation the striped beds are succeeded by fairly massive beds, as much as 6 feet thick, of even-grained buff or pinkish quartzite associated with flaggy variegated red, brown, and gray beds and with some layers of gray and reddish shales suggestive of the Pioneer shale. In the upper part of the formation the beds become thin, flaggy, and rusty and show a tendency to grade into the Mescal limestone.

The Dripping Spring quartzite was deposited in shallow water, and the sand was at times exposed to the air, as may be seen from the ripple marks, sun cracks, and fossil worm casts visible on the surface of the beds. It is, however, composed throughout of fine material and contains no pebbles so far as known. This feature and the banding of its lower beds serve to distinguish this quartzite from the pebbly cross-bedded Troy quartzite, described below. The formation in most localities in the Ray quadrangle is closely associated with intrusive masses of diabase, usually in the form of sheets. Some of the characteristics of the quartzite are probably due to the effect of the diabase intrusions.

Thickness.—Where almost vertically upturned in the Tortilla Range the Dripping Spring quartzite is apparently about 500 feet thick, but the presence of intrusive diabase detracts a little from the reliability of this measurement, as movements during the intrusion may have increased the apparent thickness. Southwest of Pioneer Mountain, where apparently the whole of the quartzite is exposed without noticeable faulting, the thickness, obtained by calculation from the width of the outcrop as mapped, the average dip of the beds, and the general angle of topographic slope, is between 450 and 500 feet. At Barnes Peak, in the Globe quadrangle, the thickness was estimated at 400 feet.[23] The average thickness for the Ray quadrangle is taken at 450 feet, which is probably under rather than above the actual thickness.

MESCAL LIMESTONE.

Definition.—The Mescal limestone was first recognized as a distinct formation in the course of mapping the Ray quadrangle. It is named from the Mescal Mountains, where it is well exposed. Stratigraphically it is limited below by the Dripping Spring quartzite and above by the Troy quartzite. Some fragments of this formation, most of them intimately associated with intrusive diabase, occur in the Globe quadrangle, but when the report on that area was prepared these masses of strata were supposed to be somewhat metamorphosed portions of the thin Devonian beds in the lower part of the "Globe limestone."

Distribution.—In the Ray quadrangle also the Mescal limestone and the diabase are closely associated. Lying between the two heavy quartzitic formations, the thin-bedded dolomitic limestone proved an easy path for the invading diabase magma and retains little of its former continuity. In the development of the topography the diabase tends to wear down into swales and hollows, and an extended view over one of these depressions shows the generally olive-tinted surface characteristic of diabase areas varied by blotches of white. These light patches represent included blocks of the Mescal limestone, some of which are nearly a quarter of a square mile in area. Other portions of the formation rest in their original position on the Dripping Spring quartzite, with the diabase in igneous contact above them, as may be seen 1½ miles southwest of Old Baldy. Still other portions crop out along the bases of cliffs formed by the Troy quartzite and have the intruded diabase below them. Rarely the limestone lies unbroken between the two quartzites, as on the north side of Troy Mountain.

The Mescal limestone has been recognized in the Sierra Ancha and in the Santa Catalina Range. It is in part lithologically identical with and is possibly the stratigraphic equivalent of the Abrigo limestone of Bisbee and Tombstone, which contains Upper Cambrian fossils. This correlation, however, is not regarded as sufficiently well established to justify definite application of the name Abrigo in the Ray area.

Lithologic character.—The Mescal limestone is composed of thin beds that have a varied range of color but are persistently cherty. The siliceous segregations as a rule form irregular layers parallel with the bedding planes, and on weathered surfaces these layers stand out in relief and give to the limestone the rough, gnarled banding that is its most characteristic feature. The usual appearance of the Mescal on outcropping edges is shown in Plate IV. The general hue of the formation is gray or white, but some beds are yellow, buff, brown, or rusty. In some localities the rough, gnarled strata are accompanied by others in which there are thin, regular buff and gray layers.

Between the limestone and the overlying quartzite is a layer of decomposed vesicular basalt whose maximum observed thickness is from 75 to 100 feet. Although the basalt is in places much thinner than this, the flow was apparently coextensive with the Mescal limestone throughout the Ray and Globe quadrangles, over an area of at least 500 square miles, and has been recognized as far north as Roosevelt. Where the basalt is in contact with the later intrusive diabase it is difficult to distinguish between the two rocks in the absence of good exposures, and in the earlier work in the Globe quadrangle the altered vesicular basalt was supposed to be merely a contact modification of the diabase.

As the basalt is generally too thin to map separately it is included with the Mescal on the geologic map, although, strictly speaking, it is not embraced within the definition of that formation.

The basalt in weathered exposures is generally dark rusty brown to nearly black, with abundant small vesicles, which as a rule are flattened parallel with the top and bottom of the flow. Freshly broken material is dark reddish brown and shows that the vesicles are for the most part filled with epidote and calcite. At one locality on Pioneer Creek, half a mile east of Pasadera Mountain, the basalt has been partly altered to epidote, garnet, and specularite, perphaps through the metamorphic action of a diorite porphyry dike.

Under the microscope the basalt is seen to retain much of its primary texture, but the original minerals have been almost entirely altered to aggregates of calcite, epidote, quartz, serpentine, and iron oxide. It was probably a rather coarsely crystalline olivinitic basalt.

A section of the Mescal limestone with the overlying basalt flow, as exposed on the east side of El Capitan Canyon, is as follows:

Section of the Mescal limestone in El Capitan Canyon.

[Thicknesses approximate.]

	Feet.
Base of Troy quartzite.	
Vesicular basalt	75
4. Striped buff and gray dolomitic limestone, weathering in sharp channels and ridges	15
3. Very rough cherty dolomitic limestone with no distinct division into beds; weathers with gnarly dark rusty brown surface	30
2. Gnarled, knotty cherty limestone, mostly dolomitic, in beds as much as 2 feet thick; some beds light gray and some dark brown; shaly partings	125
1. Thin impure shaly limestone with perhaps some dolomite; splits into thin leaves; mostly light gray	50
Top of Dripping Spring quartzite.	
	295

A partial chemical analysis of a sample from division 2 of the foregoing section is as follows:

Partial chemical analysis of Mescal limestone.

[R. C. Wells, analyst.]

SiO_2	29.93
Al_2O_3	.42
CaO	21.90
MgO	14.90

This rock weathers brown but is nearly white on fresh fracture. The molecular ratio of lime and magnesia is nearly that of dolomite, but as the beds are not all of the same character the foregoing analysis does not represent accurately the composition of the whole formation.

Thickness.—In the narrow gorge just west of Hackberry Spring, in the southwestern part of the Ray quadrangle, the Mescal limestone stands almost vertical and has a thickness of 225 feet. In the section just given the total thickness is recorded as 220 feet, exclusive of the vesicular basalt. This, however, is an estimate based on barometric readings corrected for a dip of about 25°. The average thickness of the formation as mapped in the Ray quadrangle and including the basalt flow may be taken as about 250 feet.

TROY QUARTZITE.

Definition.—The Troy quartzite lies conformably above the Mescal limestone and below the Martin limestone. Before the detailed mapping of the Ray quadrangle this quartzite had not been recognized as a formation distinct from the lower or Dripping Spring quartzite, for in the Globe quadrangle there are no

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[22] Op. cit., p. 31.

[23] U. S. Geol. Survey Prof. Paper 12, p. 31, 1903.

sections that show the two quartzites separated by the intervening Mescal limestone, and such brief papers on the geology of the Ray quadrangle as have appeared since the Globe report was published have dealt only with the immediate surroundings of the copper deposits at Ray, where the stratigraphic relations of the sedimentary rocks are less clearly displayed than elsewhere in the quadrangle. The name of the formation is derived from Troy Mountain, in the Dripping Spring Range.

Distribution.—The Troy quartzite is one of the most prominent and widely exposed formations in the Ray quadrangle. From it have been carved the bold cliffs of El Capitan Mountain, and on the southern slope of that eminence the quartzite has been laid bare over an area of about 3 square miles by the stripping away of the overlying Paleozoic limestones. Northwest of El Capitan it outcrops almost continuously for 7 miles to the area where it is overlapped by the Gila conglomerate. In the Dripping Spring Range the quartzite, dipping at angles near 20°, appears near the London-Arizona mine north of Tornado Peak and is the most extensively exposed rock in the range between Tam o' Shanter Peak and Scott Mountain, forming most of the prominent summits in this stretch of about 11 miles. In the Tortilla Range, in the southwest corner of the quadrangle, in consequence of its nearly vertical attitude it occupies a very small area.

Lithologic character.—The beds of the Troy quartzite differ greatly in thickness, ranging from thin flaggy or shaly layers to cross-bedded pebbly beds from 25 to 50 feet thick. On the whole the thicker beds are characteristic of the lower and middle parts of the formation. The upper part is invariably composed of thin, generally yellowish or rusty worm-marked shaly quartzite, indicative of a change in sedimentation that preceded the deposition of the Devonian limestone. The most characteristic material of these upper beds consists of layers of fine-grained unevenly colored brown, pink, and green quartzite, an inch or two thick, separated by films of olive-gray shale whose cleavage surfaces are ridged and knotted with numerous worm casts. The quartzite layers appear almost dolomitic in color and texture, but the microscope shows them to consist chiefly of closely fitting quartz grains with specks of flocculent limonite and little nests of a green chlorite mica. The most noteworthy features of the thicker beds are their conspicuous cross-bedding and their generally pebbly character, which is a useful means of distinguishing isolated exposures of the Troy quartzite from the pebble-free Dripping Spring quartzite. Both of these characteristics are illustrated in Plate V. The Dripping Spring quartzite is nearly all arkosic, but the Troy quartzite shows little or no feldspar.

A section of the Troy quartzite as exposed in nearly horizontal attitude 1½ miles southeast of Tam o' Shanter Peak, in the Dripping Spring Range, not quite complete, is as follows:

Section of Troy quartzite in Dripping Spring Range.

[Thicknesses approximate.]

	Feet.
Yellowish, rusty thin-bedded quartzites with olive-gray shale partings roughened by worm casts	50+
Fine-grained quartzite with very regular laminations from 2 to 6 inches thick	1½
Rather thin beds of white fine-pebble quartzite	50
A single bed of massive, cross-bedded fine-pebble, white quartzite, with layers of small quartz pebbles every few feet; forms a cliff	50
Sheet of porphyry	25
Partly concealed, apparently rather thin-bedded gray pebbly quartzite	10
Two beds of cross-bedded coarse quartzite or grit, with scattered pebbles of white quartz 6 inches or less in diameter; forms a scarp	15
Conspicuously cross-bedded gray quartzite with many layers of small quartz pebbles; no distinct separation into beds, but obscure laminations average about 1 foot thick; forms a stepped slope; microscope shows typical quartzite texture with enlarged interlocking quartz grains	75
Conglomerate with fairly well-rounded pebbles, mostly of white quartz, as much as 4 inches in diameter, in an abundant cross-bedded matrix of coarse quartzite	6
Soil-covered slope apparently underlain by a yellowish shale or fine-grained quartzite	25
Cross-bedded pebbly quartzite in beds 4 to 10 feet thick; pebbles of quartz, rarely over 2 inches in diameter, in places scattered and in places concentrated in irregular lenticular layers; weathers gray or rusty; forms a stepped slope	25
Bed of irregularly banded gray quartzitic breccia grading up into cross-bedded coarse grit or conglomerate with quartz pebbles; breccia in lower part of bed contains angular fragments of white quartz, the largest 6 inches in diameter; forms a cliff	30
Vesicular basalt at top of Mescal dolomite.	
	362½

Although much of the Troy quartzite is light gray or white on fresh fracture the weathered exposures are generally buff, brown, rusty, or maroon. In the canyon northwest of Tam o' Shanter Peak, where the quartzite is finely exposed, the general tint is reddish brown, but the different parts of the formation vary in color from white or pale buff to dull dark red.

Thickness. — Determination of the exact thickness of the Troy quartzite is difficult, owing to the fact that few of the many fault blocks show a full section of the formation or give opportunity for detailed measurements. The section recorded above gives a total thickness of about 362½ feet but probably does not include quite all the upper beds. In the gorge west of Hackberry Spring a measurement across the edges of the nearly vertical beds gave 300 feet, but here also there are beds missing from the top of the formation. A little less than 2 miles northwest of Tam o' Shanter Peak the formation, here nearly horizontal, is exposed in full section between the Mescal dolomite and the Devonian limestone. The mapping indicates a thickness at this place of a little more than 350 feet. On Troy and Scott mountains the quartzite as mapped appears to be unduly thick, the distribution on Scott Mountain calling for a thickness of about 1,000 feet. This is clearly in excess of any possible real increase in the formation and probably is to be accounted for by faulting or flexing that is not distinctly shown at the surface. From all available information the average thickness of the formation is estimated to be about 400 feet. In the Ray and Globe quadrangles the name quartzite is generally applicable to this formation, but farther north, near Roosevelt and in Sierra Ancha, the rock is essentially a sandstone.

DEVONIAN SYSTEM.

MARTIN LIMESTONE.

Definition.—The Martin limestone occupies conformably the stratigraphic interval between the underlying quartzite and the overlying Tornado limestone, and with the possible exception of some of its unfossiliferous lower beds is of Devonian age. The name was originally applied to the Devonian limestone of the Bisbee district,[24] with which the formation here described is correlated. The beds now separated as the Martin limestone were in the Globe report and folio mapped with the overlying Carboniferous under the name "Globe limestone."

Distribution.—In a general way the distribution of the Martin limestone corresponds to that of the Troy quartzite, although it neither outcrops so prominently nor occupies so large areas of the surface as that resistant rock.

Lithologic character.—As a whole the Martin limestone is a comparatively thin-bedded formation, which weathers into slopes, broken here and there by a low scarp that marks the outcrop of some bed a little harder or thicker than the rest. A typical natural section of the formation is shown in Plate VI. Distant views of such slopes show that the formation is divisible on the basis of color into two nearly equal parts. The prevailing hue of the lower division is light yellowish gray; the upper division, which is less uniform in tint, displays alternations of deeper yellow and darker gray. Detailed examination proves the lower division to consist mainly of very compact, hard gray limestone in beds rarely more than 2 feet thick and, at the base, a bed of impure yellow limestone containing abundant grains of quartz. This lowest bed, which in places is cross-bedded and contains so much detrital material that it might be classed as a calcareous grit, weathers to a rough sandy surface, but the overlying gray beds are characterized by solution surfaces that although uneven in general are smooth in detail. A characteristic feature of these compact lower limestones is the presence of little spherical, ovoid, or irregular concretions of dark chert, which as a rule are about the size of peas. No identifiable fossils have been found in this lower division of the Martin limestone, although it contains traces of organic life.

About midway in the section is a bed about 15 feet thick of rusty yellow impure sandy limestone with flaggy lamination. Above this lie dark-gray and yellowish limestones in beds of different thicknesses, with shaly partings. These strata are generally fossiliferous, some of the shaly partings particularly being crowded with *Atrypa reticularis* and other small Devonian brachiopods. Some very dark beds in this upper division of the formation are marked with an obscure mottling, suggestive of the former presence of some of the corals which are abundant in certain beds of the Martin limestone at Bisbee but which in the Ray-Globe region have been less perfectly preserved. The top bed of the Devonian is a yellow calcareous shale that breaks up on exposure into minute thin flakes and consequently has no prominent outcrops. The yellow color is characteristic of all natural exposures, although before weathering the shale is gray. Being overlain by the massive cliff-making Carboniferous limestone, the bed of shale is in many places concealed by talus, and its thickness was not exactly determined. It may be from 15 to 20 feet thick, but its base is not very clearly defined, for layers of similar shale occur between some of the limestone beds in the upper part of the formation.

The Devonian limestone is generally magnesian and does not effervesce freely in cold dilute acid. A partial chemical analysis of a typical specimen from the lower division of the formation is as follows:

Partial chemical analysis of Martin limestone.

[R. C. Wells, analyst.]

SiO_2	3.11
Al_2O_3	.33
Fe_2O_3 FeO	1.22
CaO	31.65
MgO	18.65

Thickness.—Measurements and estimates of the thickness of the Martin limestone in different parts of the region range from 300 to 350 feet. The average thickness is considered to be 325 feet.

Fossils.—In contrast with the older formations, which have yielded no determinable organic remains, the Martin limestone contains fossils at many horizons in the upper division, from the top of the rusty bed at its base to the lower layers of the yellow shale. In all 15 lots of fossils were collected and were referred to E. M. Kindle, then of the United States Geological Survey, who has kindly prepared the following note:

> The identified forms with their local distribution as indicated by the collections examined are given in the following table:
>
> *Distribution of species of Devonian fossils in the Ray quadrangle.*
>
> | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
> |---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
> | Zaphrentis sp. undet. | | | | × | | | | × | | | | | | | |
> | Productella hallana | × | | × | | × | × | | | | | | | × | | |
> | Stropheodonta arcuata | | × | | | | | × | | | | × | | × | × | |
> | Stropheodonta demissa | | | | | | | | | | | | | | × | |
> | Stropheodonta varistriata | | | | | | | | × | | | | | | | |
> | Stropheodonta sp. | | | | | | | | × | | | | | | | |
> | Leptostrophia cf. L. interstrialis | | | | | | | | | | × | | | | | |
> | Strophonella cf. S. ampla | | | | | | | × | × | | | × | | | | × |
> | Schuchertella chemungensis | | | | | | | | × | | | | | | | |
> | Schizophoria striatula | | | × | | × | × | | | | | | | | | |
> | Atrypa reticularis | × | × | × | × | × | × | | | | | | × | × | × | × |
> | Atrypa hystrix occidentalis | | | | × | | | × | | × | × | × | | × | | × |
> | Atrypa spinosa | | | | | | | | × | | | | | | | |
> | Camarotoechia sp. | | | | | | | | × | | | | | | | |
> | Pugnax pugnus | | | | | | | | | | | | | × | | |
> | Spirifer orestes | × | | | | × | × | | | | | | | | | |
> | Spirifer hungerfordi | × | | | | | | | | | | | | | | |
> | Cyrtia cyrtinae formis | × | | | | | | | × | | | × | | | | × |
> | Schizodus sp. | | | | | | | | × | | | | | | | |
> | Paracyclascf. P. elliptica | | | | | | | | × | | | × | | × | | × |
> | Euomphalus cyclostomus? | | | | | | | | × | | | × | | | | |
> | Euomphalus sp. | | | | | | | | × | | | | | | | |
> | Bellerophon sp. undet. | | | | | | | | | | | × | | | | |
>
> 1. Extreme northeast corner of quadrangle. In thin bed of yellow limestone.
> 2. Saddle 2 miles west-southwest of triangulation station on El Capitan Mountain. From lower beds of upper division of the Martin limestone, just above the thick bed of rusty-yellow sandy limestone.
> 3. Same locality as No. 2 but higher in section.
> 4. Same locality as No. 3 but higher in section.
> 5. Same locality as No. 4 but higher in section.
> 6. South slope of Pasadera Mountain. From beds just under yellow shale at top of Devonian.
> 7. Same locality as No. 6 but from basalt part of the upper or fossiliferous division of the formation.
> 8. Two miles in a direction a little east of north from Tornado Peak.
> 9. Ridge 1.2 miles north of Tornado Peak. From lower part of upper division of Devonian.
> 10. Same locality as No. 8 but stratigraphically from 10 to 15 feet higher in section.
> 11. Ridge 3½ miles west-southwest of triangulation station on El Capitan Mountain. In lower part of upper division of the Martin limestone.
> 12. One mile south-southwest of Dripping Spring ranch. From same stratigraphic horizon as No. 2.
> 13. One-half mile southeast of Haley's cabin.
> 14. Saddle 1.2 miles southeast of the triangulation station on Troy Mountain. Near base of upper division of the formation.
> 15. One-half mile north-northwest of Burro Spring. Same stratigraphic horizon as No. 2.
>
> About half the species in the above list occur in the Lime Creek shale of Iowa, and the coincidence leaves no doubt that this is a southwestern representative of the Iowa fauna. This close relationship it shares with the fauna of the Martin limestone of Arizona, with which it should be correlated. Although the resemblance between the Devonian fauna from the Ray quadrangle and that in the Martin limestone of the Bisbee quadrangle and in the lower part of the "Globe limestone" of the Globe quadrangle is sufficiently strong to justify their correlation, there are some interesting contrasts indicated by the fossils that have been collected. *Spirifer whitneyi*, which is one of the most abundant species in the fauna from the Bisbee quadrangle, as it is in the Iowa fauna, is absent from the collection from the Ray quadrangle. Corals are also almost entirely wanting in this collection, whereas they are conspicuous in the Bisbee collections. One of the species which occurs in the fauna of the Ray quadrangle but which is absent from the known Martin faunas of Globe and Bisbee is *Paracyclas* cf. *P. elliptica*.
>
> The assignment of the Devonian fauna of the Ray quadrangle to its proper place in the time scale involves the consideration of the very closely related faunas of the Martin limestone in Arizona and the Lime Creek shale of Iowa. Prof. H. S. Williams[25] has pointed out the identity of the latter faunas. He concludes that the Martin limestone fauna is of Middle Devonian age. This conclusion is arrived at through adopting Tschernyschew's view that the *Spirifer anasofia* fauna of Russia, which is very closely allied to the Arizona Devonian fauna, is the equivalent of the *Stringocephalus* fauna of western Europe, which is generally considered to be of Middle Devonian age. The points of resemblance between the Arizona, Russian, and western European faunas are interesting, but it appears to the writer that more dependable evidence for determining the relative age of the fauna is available without going so far afield. The Lime Creek fauna of Iowa, with which the Arizona fauna is correlated, contains a large percentage of species common to the Upper Devonian fauna of New York and has been generally considered to be of Upper Devonian age. In Arizona Ransome[26] has found no evidence of a

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[24] Ransome, F. L., Geology and ore deposits of the Bisbee quadrangle, Ariz.: U. S. Geol. Survey Prof. Paper 21, p. 33, 1904.

[25] See U. S. Geol. Survey Prof. Paper 21, p. 38, 1904.

[26] U. S. Geol. Survey Prof. Paper 21, pp. 34-35, pl. 12, 1904.

stratigraphic break between the Devonian limestone and the Carboniferous limestone. The evidence of the Arizona sections indicates that the fauna under consideration is the immediate predecessor in that region of a fauna of Mississippian age. On the ground of its close relationship to an Upper Devonian fauna of Iowa and its stratigraphic relations to the Carboniferous fauna of the Arizona section I would place the fauna of the Martin limestone and its equivalent, the Devonian fauna of the Ray quadrangle, in the Upper Devonian. It is of course possible that the time range of this fauna in Arizona may include Middle as well as Upper Devonian, but that it includes the Upper Devonian in any event seems well established by the available evidence.

A fauna identical with the Devonian fauna of the Ray quadrangle, occurring in the lower part of the "Globe limestone," has been correlated by Prof. H. S. Williams[27] with the Ithaca fauna of New York. There is no question that the Ithaca or *Pugnax pugnus* fauna is the equivalent of a portion of the fauna found in the Martin, "Globe," and equivalent limestones of the Ray quadrangle, but I believe the fauna of the Ray quadrangle is the representative not only of the Ithaca fauna but of the Chemung as well. Since Professor Williams's note was written considerable additions have been made to our knowledge of the Upper Devonian section in Montana, Idaho, Colorado, and New Mexico. All the later work seems to indicate that there is no fauna in the Rocky Mountain region which resembles very closely the Chemung fauna. For the time equivalents of the Chemung in this extensive region we have to look to the faunas, some of them having but slight resemblance to it, which characterize the terminal beds of the Devonian system. In Colorado and New Mexico we find this time equivalent in the *Camarotoechia endlichi* fauna, and in Arizona the *Pugnax pugnus* fauna of the Ray quadrangle and of the "Globe" and Martin limestones appears to represent both the Ithaca and the Chemung faunas of New York.

As the Devonian portion of the "Globe limestone," as mapped in the Globe quadrangle, is continuous and identical with what is now named the Martin limestone, fossils collected from it should be included in the Martin fauna. The report of Prof. H. S. Williams[28] on the older collections is therefore reprinted below, with slight changes made by Mr. Kindle and at the Geological Survey to bring it into accord with present biologic and geologic nomenclature.

Two collections of fossils made by Dr. F. L. Ransome in the Globe quadrangle, Arizona, were submitted to the writer November 14, 1901, and March 17, 1902, for report upon the age of the horizon represented and the list of the faunas. The collections comprise 10 small lots, which are designated A, B, C, etc., and labeled as follows:

A. Limestone bluff, west side of Pinal Creek, 3¾ miles northwest of Globe. Thin bed of gray limestone about 100 feet above base of exposed limestone section.

B. Same locality as A. Band of gray limestone about 15 feet above A.

C. Buff limestone about 20 feet thick, immediately overlying bed B.

D. Gray limestone, with crinoid stems, overlying C. About 40 feet thick to top of section.

E. One-quarter mile southwest of Sleeping Beauty Peak, from near base of limestones which rest on quartzite.

F. Eastern slope of 5,300-foot limestone hill, southeast corner of quadrangle.

G. Same locality as F, and probably from same bed.

H. Limestone hill, west side of Gold Gulch.

I. Steep slope forming east side of Pinto Creek gorge on western edge of quadrangle.

J. Same locality as I. About 40 feet higher in section.

The accompanying list of species has been identified, and their presence in the several faunules [that is, local faunas—F. L. R.] is indicated by the checks in the vertical columns opposite the names of the species. The names by which the forms have been recognized by American authors have been used, though in several cases the forms here met with may be regarded as but varieties of species described by European paleontologists.

Devonian fossils collected in the Globe quadrangle.

	A	B	C	D	E	F	G	H	I	J
Cf. Sponge	×									
Cf. Rhodocrinus, crinoid stems and plates		×	×	×						
Atrypa reticularis Linnaeus	×	×			×	×	×		×	×
Productella hallana Walcott	×	×	×				×	?		×
Stropheodonta calvini Miller	×						×			×
Cyrtia cyrtiniformis (Hall and Whitfield)	×					×	×			×
Spirifer hungerfordi Hall			×							
Spirifer orestes Hall and Whitfield	×					×	×			
Spirifer whitneyi Hall	×									
Reticularia fimbriata (Conrad)							×			
Cyrtina hamiltonensis Hall	×									
Martinia subumbona (Hall); cf. Spirifer infima Whidborne						×	×			
Pugnax pugnus (Martin)							×			
Schuchertella chemungensis (Conrad) var.	×									
Dielasma cf. D. calvini (Hall and Whitfield)								×		

With the exception of the faunule H, the several faunules are probably from the same geological formation, as indicated by the species as well as by the similarity of the rock in which they are contained.

The fauna represented is the same as that from Rockford and Independence, Iowa, which as a fauna may be appropriately called the *Pugnax* fauna, on account of the wide distribution of *Pugnax pugnus* wherever the associated species of the fauna appears.

The fauna appears in the New York column after the Tully limestone in the fossiliferous zone preceding the typical Chemung formation, in what has been called the Ithaca formation in central New York.

The first 12 identified species of the list are brachiopods. In the material examined they are the only class of organisms recognized, except the crinoid stems and the sponge; the crinoids may have supplied the calcareous material for the limestones in which the species are preserved.

The species, or varieties of the same species, are dominant in a fauna of wide distribution in the Northern Hemisphere. Eight of the 12 species are represented in the Devonian of Nevada and Utah; 9 have been reported from the Manitoba and Mackenzie River province; all of the 12 from the Lime Creek shale of Iowa; 7 are present in the Lummaton limestone of southern England; 9 of them are reported from Russia; 5 of them are among the limited number of known Chinese Devonian species; and 6 of them have been seen in the Ithaca shale member of the Portage formation of central New York between the typical Hamilton and the typical Chemung formations.

They constitute the typical species of the Lime Creek shale of Iowa, but in New York these species are mostly rare in the Ithaca member.

So far as at present known, the fauna did not coexist with the typical *Spirifer disjunctus* fauna of the New York province, but in the eastern part of the State several of the dominant species of the *Tropidoleptus* fauna of the Hamilton appear in the same fossiliferous zone with these species.

As measured by the New York standard geologic column, the *Pugnax* fauna is Neo-Devonian in age and is to be correlated with the epoch of the Ithaca member.

In its general distribution in Europe it is Neo-Devonian rather than Meso-Devonian, and although there its species have a Carboniferous aspect they are occasionally represented in faunas classified as of Meso-Devonian age.

It is therefore appropriate on paleontologic grounds to classify the formations holding the fauna in Arizona as early Neo-Devonian.

Correlation.—Kindle makes clear the general equivalency of the Devonian limestone of the Ray quadrangle with the Martin limestone at Bisbee,[29] which is 340 feet thick. The Martin limestone occurs at Tombstone, 20 miles north of Bisbee, although here it is apparently thinner than it is farther south.

Devonian rocks, presumably the Martin limestone, have been found by C. F. Tolman, jr.,[30] in the Santa Catalina Range.

Walcott's notes[31] on the Deer Creek coal field, together with the strike toward that locality of the regular and persistent Martin limestone in the Mescal Range, make it reasonably certain that the Devonian is there represented, although Campbell[32] expresses himself rather doubtfully as to its presence. Walcott apparently was the first to record the presence of Devonian strata in this region, the note being published, however, in a place likely to escape the attention of geologists and bibliographers.

In the Clifton-Morenci district, about 80 miles due east of the Ray quadrangle, the Devonian is represented by the Morenci shale, 175 feet thick, which includes 75 feet of argillaceous limestone at its base.[33] The fauna is meager and comes from the limestone.

The presence of the Martin limestone in the Roosevelt section also has been fully established by the collection in 1914 of sufficient fossils to confirm a lithologic and indecisive paleontologic identification made a year earlier. A list of the fossils from Roosevelt, as determined by Edwin Kirk, is as follows:

Spirifer whitneyi var. animasensis (Girty).
Camarotoechia contracta Hall?
Camarotoechia sp.
Schuchertella sp.
Modiomorpha sp.
Atrypa spinosa Hall.
Schizophoria striatula var. australis Kindle.
Cladopora sp.

Mr. Kirk remarks that this fauna can be correlated with that of the Martin limestone of Bisbee and that of the lower or Devonian part of the Ouray limestone of Colorado. He states that there can be no doubt as to the Devonian age of the material.

At Jerome, 125 miles northwest of Ray and about 100 miles south of the best-known part of the Grand Canyon of the Colorado, the Cambrian Tapeats sandstone, 75 to 80 feet thick, rests upon the schists on the hillside just west of the United Verde mine. Conformably above this sandstone are light-yellowish, very compact limestones in beds from 2 to 3 feet thick which contain only obscure traces of fossils. These beds resemble the compact limestones of the lower part of the Martin limestone at Ray. This part of the formation, about 150 feet thick, is overlain by darker-gray limestones, some of which are sandy. Fossils are fairly abundant in these strata, but are as a rule poorly preserved and extremely difficult to collect. About 350 feet above the base of the limestone a light-gray bed about 5 feet thick, sandy in its lower part but grading upward into a purer and more compact limestone, carries abundant small poorly preserved shells near its base and corals in its upper part. Fossils collected from this bed and those just above it were submitted to E. M. Kindle, who has identified the following species:

Aulopora sp. undet.
Zaphrentis sp. undet.
Camarotoechia sp. undet.
Spirifer orestes.
Cyrtia cyrtiniformis.
Bellerophon maera.

Kindle writes: "These species represent an Upper Devonian fauna of the same general facies as that previously collected by you at various points in Arizona." In other words, it is the fauna of the Martin limestone. The total thickness of the beds provisionally assigned to the Devonian at Jerome is about 500 feet. Of course there is a possibility that the lower compact limestones, from which no fossils were obtained, may be older than Devonian.

In the Grand Canyon the Devonian Temple Butte limestone, 100 feet in maximum thickness, is in many places absent. Recent work of L. F. Noble[34] supplies many details of its occurrence and of the unconformities between it and the overlying Redwall limestone and the underlying Muav limestone.

CARBONIFEROUS SYSTEM.

TORNADO LIMESTONE.

Definition.—The Tornado limestone, named from Tornado Peak, in the southeastern part of the Ray quadrangle, where it is extensively exposed, overlies with apparent conformity the Martin limestone and is equivalent to the Carboniferous portion of the "Globe limestone" as originally mapped in the Globe quadrangle. Its local upper limit is a surface of erosion upon which in general rests the Quaternary Gila conglomerate, although in the southeastern part of the Ray quadrangle there is an intervening andesitic formation, probably of Mesozoic age.

Distribution.—In consequence of the thickness and resistant character of its beds the Tornado limestone is nearly or quite as prominent a member of the sedimentary series as the Troy quartzite. In the Mescal Range it emerges from beneath the Gila conglomerate in smooth slopes that correspond nearly to the dip of the beds and sweep up in a series of bold cuestas or "hogbacks," whose precipitous scarps face northeast. Beginning inconspicuously at the northwest end of the range, these cuestas increase in size toward the southeast and become imposing features of the topography in the vicinity of the Gila gorge, east of the Ray quadrangle. From any commanding point near Tam o' Shanter Peak the limestone cuestas just south of the river attract attention by the model-like clearness with which their structural features are displayed, and from a distance of many miles the outcrops of successive overlapping limestone beds may be seen lapping up over the flat backs of the cuestas in flowing concentric curves.

In the Dripping Spring Range the most extensive exposures of the Tornado limestone are between Tam o' Shanter Peak and Gila River. The limestone here has not the regular monoclinal attitude characteristic of the Mescal Range, but its tendency to give rise to lofty cliffs under the action of erosion is none the less marked, as may be seen in the ridge that extends from Tornado Peak to the river.

Another extensive area of the Tornado limestone lies between Troy Mountain and Ray. From the vicinity of Haley's cabin northward the range is composed mainly of sediments older than the Carboniferous, with associated younger igneous rocks. About 1¾ miles northwest of Walnut Spring, however, is a single small area of Tornado limestone. This fragment is intruded by diabase, is much broken, and is surrounded by small fault blocks containing rocks several hundred feet lower in the bedded series, so that it has been shifted far out of its normal stratigraphic position. Whether this movement was due to the intrusion of the diabase, the block being an inclusion, or whether it is the effect of faulting, is not clear.

In the Tortilla Range the faulted upturned strips of Tornado limestone form sharp, narrow, rugged ridges that project conspicuously above the Gila conglomerate.

Lithologic character.—The Tornado limestone is generally light lead-gray in color and is divisible with respect to thickness and character of bedding into at least three members.

The basal division, directly overlying the Devonian, is about 75 feet thick and forms the lower part of the scarp that is so prevalent a feature of the Carboniferous outcrops in central and southern Arizona. Under the action of erosion this division behaves as a single massive bed, but in reality it is made up of alternating dark and light gray layers, a foot or two thick, which in cliff faces give it a banded appearance, as may be seen in Plate VI. This banded division, with a few transitional beds at its top, is succeeded by a very massive member, fully 100 feet thick, within which, as exposed in cliff faces, there is as a rule little more than a suggestion of divisional bedding planes. This massive member, as may be seen

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[27] U. S. Geol. Survey Prof. Paper 12, pp. 40–42, pl. 9, 1903.

[28] U. S. Geol. Survey Prof. Paper 21, p. 38, 1904.

[29] Ransome, F. L., The geology and ore deposits of the Bisbee quadrangle, Ariz.: U. S. Geol. Survey Prof. Paper 21, pp. 33–42, 1904.

[30] Unpublished manuscript of Tucson folio.

[31] Forty-eighth Cong., 2d sess., S. Ex. Doc. 20, Appendix I, pp. 5–7, 1885.

[32] Campbell, M. R., The Deer Creek coal field, Ariz.: U. S. Geol. Survey Bull. 225, p. 243, 1904.

[33] Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Ariz.: U. S. Geol. Survey Prof. Paper 43, pp. 66–69, 1905.

[34] Noble, L. F., A section of the Paleozoic formations of the Grand Canyon at the Bass trail: U. S. Geol. Survey Prof. Paper 131, pp. 23–73, 1922.

from Plate VI, is of lighter and more uniform tint than the basal member. The two together constitute the principal cliff-forming part of the Carboniferous limestone. The third division consists of beds generally thinner than those in the other two divisions but not separable from them by any marked lithologic distinction.

The Tornado limestone consists essentially of calcium carbonate and effervesces freely in dilute acid. A partial analysis of a typical sample is as follows:

Partial chemical analysis of Tornado limestone.

[W. T. Schaller, analyst.]

SiO_2	1.36
Al_2O_3	.22
CaO	54.91
MgO	.21

Thin layers of calcareous shale separate some of the beds, but these are a very subordinate part of the formation.

Fossils and correlation.—Nearly all the Carboniferous limestone contains fossil remains, but there are few localities where full and satisfactory collections can be made. The beds of the two lower divisions carry abundant fragments of crinoid stems and less numerous rugose corals with long-winged spirifers and *Rhipidomella.* These appear in silicified form on weathered surfaces of the rock, but they can not readily be separated from their matrix. In the upper division appear different species of *Productus* and *Spirifer, Derbya crassa, Composita subtilita,* and *Fusulina.*

The eight collections that were made were submitted to G. H. Girty for determination. The following table shows the identification and distribution of the fossils collected:

Distribution of Carboniferous fossils.

	1	2	3	4	5	6	7	8
Leptaena rhomboidalis	×	---	---	---	---	---	---	---
Dielasma burlingtonensis	×	---	---	---	---	---	---	---
Dielasma? sp.	---	---	×	---	---	---	---	---
Spirifer centronatus	×	×	×	×	---	---	---	---
Spirifer peculiaris?	---	---	×	---	---	---	---	---
Spirifer cameratus	---	---	---	---	---	---	---	×
Spirifer boonensis?	---	---	---	---	---	×	×	---
Spiriferina solidirostris	---	---	×	---	---	---	---	---
Syringothyris sp.	×	---	---	---	---	---	---	---
Zaphrentis sp.	×	---	---	×	---	---	---	---
Menophyllum sp.	---	×	×	---	---	---	---	---
Composita subtilita	---	---	---	---	---	×	×	×
Composita humilis?	---	×	---	---	---	---	---	---
Composita aff. C. humilis	---	---	---	×	---	---	---	---
Cliothyridina sp.	---	×	×	---	---	---	---	---
Syringopora aculeata?	---	---	×	---	---	---	---	---
Syringopora surcularia?	---	---	---	---	×	---	---	---
Amplexus? sp.	---	---	×	---	---	---	---	---
Rhipidomella aff. R. oweni	---	---	×	---	---	---	---	---
Rhipidomella dubia?	---	---	---	×	---	---	---	---
Camarotoechia metallica	---	---	×	---	---	---	---	---
Fusulina sp.	---	---	---	---	---	×	---	---
Myalina subquadrata	---	---	---	---	---	×	---	---
Derbya sp.	---	---	---	---	---	---	×	---
Derbya crassa	---	---	---	---	---	---	---	×
Productus semireticulatus	---	---	---	---	---	---	×	---
Productus arcuatus?	---	---	---	×	---	---	---	---
Productus cora	---	---	---	---	---	---	---	×
Productus punctatus	---	---	---	---	---	---	---	×
Chonetes sp.	---	---	---	×	---	---	---	---
Schuchertella inflata?	---	---	---	×	---	---	---	---

1. Northeast corner of Ray quadrangle.
2. South slope of Pasadera Mountain.
3. Ridge 2 miles a little west of south from the triangulation cairn on El Capitan Mountain.
4. One mile northwest of summit of Troy Mountain.
5. One and three-quarters miles south of summit of Tornado Peak.
6. One mile northeast of London-Arizona mine.
7. One and one-third miles northeast of London-Arizona mine.
8. Two and three-quarters miles southeast of summit of Tornado Peak, near contact with overlying andesite.

According to Mr. Girty the older of these two faunas is early Mississippian and the other is early Pennsylvanian. He notes that the conditions exhibited in the Ray quadrangle are apparently similar to those at Bisbee, where a limestone of probable early Pennsylvanian age (the Naco) rests directly on a limestone of early Mississippian age (the Escabrosa). The Mississippian in the Ray quadrangle therefore corresponds to the Escabrosa limestone at Bisbee, and the Pennsylvanian limestone near Ray to the lower part of the Naco limestone.

In the Bisbee quadrangle the distinction between the Mississippian and Pennsylvanian limestones proved practicable, although the plane of demarcation is not definite. In the Ray quadrangle a similar distinction might possibly be made, but no satisfactory basis for it appeared in the course of the field work, and it is doubtful whether its accomplishment would be worth the additional labor involved. The cliff-making lower members of the Tornado limestone are certainly Mississippian, and probably a considerable part of the upper member also belongs to that epoch.

Thickness.—The original thickness of the Tornado limestone is unknown, for the formation was extensively eroded before the eruption of the andesitic lavas and before the deposition of the Gila conglomerate. In the vicinity of Tornado Peak and along the eastern flank of the Tortilla Range the limestone at present must be fully 1,000 feet thick, and it may at one time have greatly exceeded this thickness.

CONDITIONS OF DEPOSITION.

The Tornado limestone and the Martin limestone, as shown by their fossils, are unquestionably marine. Ten or fifteen years ago most geologists would probably have had no hesitation in classing the sediments of the Apache group also as marine deposits, although no marine fossils have been found in them. They were so considered in the Globe report, written in 1902, and in the Globe folio, prepared about the same time. Recent studies, however, particularly those of Barrell,[35] have shown the necessity of taking into account continental and especially fluviatile deposition.

That the beds of the Apache group were laid down in water there can be no question. They have none of the characteristics of eolian deposits. The evidence as to marine or fluviatile deposition, however, is less conclusive.

The Scanlan conglomerate, with its pebbles of local origin, appears to be most reasonably accounted for as a basal marine conglomerate, although this interpretation has little definite evidence in its favor. The succeeding Pioneer shale gives no clear indication whether it is of marine, lacustrine, or fluviatile origin. It contains no fossil remains or mud cracks, so far as known. The most puzzling feature of the succeeding Barnes conglomerate is its relation to the Pioneer shale. A coarse conglomerate with well-rounded pebbles, indicative of vigorous abrasion and powerful currents, rests on material that when the pebbles accumulated was presumably a sandy mud. The pebbles evidently could not have been shaped near their present resting place but must have come from a distance. The surface of contact between conglomerate and shale, in the very few places where it is well exposed, is undulatory, but the shale layers, instead of being cut by the uneven surface, conform to it, as if the conglomerate had been deposited gently on a soft, yielding foundation.

A similar relation appears to hold between the conglomerate of the Eastern Rand, South Africa, and the underlying formation. Mellor[36] says:

> One of the most remarkable features of the principal conglomerate bed of the Eastern Rand is that it was laid down over many hundreds of square miles directly upon a wide sheet of muddy or very fine sandy material, which over the whole of that area formed the uppermost portion of a sequence of similar strata some hundreds of feet in thickness. That this abrupt change in the character of the sedimentation was probably brought about simultaneously over the whole area is to some extent shown by the considerations already alluded to. Among further indications may be mentioned the fact that nowhere do we find evidence of that type of erosion of the underlying muddy deposits which might be looked for with the gradual extension of pebbly deposits over them. On the other hand, we do find evidence of such erosion as might be expected to occur with the rapid sweeping of the pebbly deposits over a previously existing expanse of hardened silt. Thus in the Kleinfontein mine I recently found numerous examples of the inclusion of fragments of the footwall in the overlying conglomerate, particularly its lower portion. One of these fragments was a foot in length and about 2 inches in thickness and of irregular tabular form, with angular edges. It appeared to be one of many pieces of partly consolidated sediment which had been torn from the underlying muddy material and immediately included in the pebbly mass which had swept over it.

Other conglomerates in the Witwatersrand series, according to Mellor, show similar relations to underlying shales. The evidence of erosion of the shale found by him in South Africa is lacking, so far as known, in Arizona. Mellor's conclusion, that the Witwatersrand series is a delta deposit, accords with an earlier suggestion by De Launay.[37]

On the whole such meager evidence as is obtainable appears to indicate that the Barnes conglomerate represents stream action rather than shore (littoral) or marine action.

The unfossiliferous Dripping Spring quartzite contains some mud cracks in its thin upper beds, showing that these layers must have been exposed to the air during the period of deposition. The formation is tentatively regarded as of delta origin.

The deposition of the impure dolomitic Mescal limestone marks a change of conditions of sedimentation—apparently a subsidence of the land and an incursion of shallow marine waters. On the other hand, the overlying rusty vesicular basalt appears to have been exposed to the air before it was covered by the sands that are now the Troy quartzite.

The Troy quartzite with its abundant pebbly layers and conspicuous cross-bedding is suggestive of fluviatile or deltaic deposition. The upper part of this formation shows gradation into the undoubtedly marine deposition of the Devonian Martin limestone, although the grit beds and gritty limestones in the Martin show that that formation was laid down in shallower water than the overlying Tornado limestone.

On the whole, the evidence bearing on the mode of deposition of the pre-Devonian beds is to some extent conflicting and is inconclusive. They are fluviatile or shoal-water marine deposits, but it does not appear possible at present to determine definitely to which class they belong, or, if both classes are represented, where the deposits of one class give place to those of the other.

GENERAL SUMMARY OF CORRELATIONS.

As has been shown in the preceding pages, there is little difficulty in correlating the Devonian and Carboniferous formations of the Ray-Miami region with those of other parts of Arizona. As regards the unfossiliferous formations embraced within the Apache group and provisionally assigned to the Cambrian, the problem is more perplexing.

Inasmuch as in the Grand Canyon there is a profound unconformity between the Algonkian sediments (Unkar and Chuar groups) and the Cambrian beds of the Tonto group, and as in the Globe region all the beds from Carboniferous down to the Scanlan conglomerate are apparently conformable, the Apache group was in the Globe report and folio treated provisionally as Cambrian. At the same time, it was recognized that the Apache group had lithologically little in common with the Cambrian Tonto group of the Grand Canyon.

In 1905 Lee[38] briefly described and figured the section of beds exposed in the gorge of Salt River below the Roosevelt dam. He quotes a statement from a letter to him from Dr. Charles D. Walcott to the effect that at this locality the Carboniferous limestones rest directly and unconformably upon the quartzites and argillites of the Algonkian. He mentions the fact that the same supposedly Algonkian formations occur in the Sierra Ancha. Two years earlier Reagan[39] also appears to have included in the Algonkian most of the beds that make up the Sierra Ancha, although he stated that the sandstone of the Tonto group overlies these beds unconformably on the crest of the range.

Later reconnaissance work by Ransome has shown conclusively that the Roosevelt section contains the same formations that have been recognized in the Ray-Miami region. The beds dip upstream and in ascending order are the Scanlan conglomerate, resting on granite, the Pioneer shale, the Barnes conglomerate, the Dripping Spring quartzite, the Mescal limestone (at the dam), and the Troy quartzite, here perhaps more properly referred to as a sandstone. These formations constitute the Apache group. As usual, there is a thick sheet of diabase, which in this locality has invaded the Pioneer shale.

This reconnaissance has shown also that the Devonian (Martin limestone) is not missing at Roosevelt but is well represented by about 300 feet of thin-bedded limestones, which as stated on page 8 contain a characteristic Devonian fauna. As in the Ray quadrangle, the entire Paleozoic sequence from the Scanlan conglomerate to the Carboniferous limestone appears to be conformable. Certainly there is no unconformity present that brings the Carboniferous limestone against the Apache group.

The same reconnaissance showed that, as Reagan and Lee have both stated, the Sierra Ancha, in its southern part, where they saw it, is composed chiefly of these same Apache rocks, with a sheet of diabase, probably at least 1,000 feet thick, intruded in the Mescal limestone. No trace was found, however, of an unconformably overlying "Tonto" (Tapeats) sandstone. As far north as Gun Creek, an eastern tributary of Tonto Creek, the sedimentary rocks of the Sierra Ancha can readily be interpreted in terms of the Globe-Ray section and are recognizable as belonging to the Apache group.

From the mouth of Gun Creek north to Payson and East Verde River the distance is only about 20 miles, but in this interval a striking change takes place in the character of the older Paleozoic rocks. Where the road from Payson to Pine crosses the East Verde, the following section was somewhat roughly measured on the south bank of the river:

Section on East Verde River.

	Feet.
Top of bluff.	
Rather thin-bedded, in part flaggy light-gray compact limestone with some intercalated thin sandstone beds near top	130
Pinkish and grayish sandy limestone grading upward into overlying limestone	50
Hard compact gray limestone in beds 2 to 3 feet thick	50
Red shale with 2 to 3 feet of gray laminated quartzite near top	20
Thin-bedded gray limestone with some pink limestone near top and flaggy, somewhat sandy limestone in lower 25 or 30 feet	100
Thin-bedded reddish sandstone with one gray bed near top, overlain by a layer of shale which grades into limestone above	30
Pebbly cross-bedded red-brown sandstone, with some irregular horizontal lamination in cliff exposures but no distinct division into beds	80
Moderately coarse crumbling red granite, probably Archean.	
	460

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[35] Barrell, Joseph, Relative geological importance of continental, littoral, and marine sedimentation: Jour. Geology, vol. 14, pp. 316–356, 430–457, 524–568, 1906; Criteria for the recognition of ancient delta deposits: Geol. Soc. America Bull., vol. 23, pp. 377–446, 1912.

[36] Mellor, E. T., Conditions of deposition of the Witwatersrand system: Mining Mag., vol. 13, pp. 255–262, 1915 (from advance proofs of an article on "The upper Witwatersrand system" read before the Geological Society of South Africa).

[37] De Launay, L., Les richesses minérales de l'Afrique, p. 72, footnote, Paris, 1903.

[38] Lee, W. T., Underground waters of Salt River valley, Ariz.: U. S. Geol. Survey Water-Supply Paper 136, pp. 96–97, 1905.

[39] Reagan, A. B., Geology of the Fort Apache region, Ariz.: Am. Geologist, vol. 32, p. 277, 1903.

The foregoing section is entirely different from the Paleozoic section of the Ray-Miami region, and although the section as a whole probably can not yet be fully correlated with the Grand Canyon section, the basal sandstone is without much doubt the Tapeats sandstone of the Tonto group. The southernmost point to which this sandstone has been traced is a ridge just south of Payson, where it rests on a gray dioritic rock belonging to the pre-Cambrian complex. To the north, along the Mogollon escarpment, the beds just described pass under other limestones, probably including the Redwall, and a thick series of red beds that are probably Supai, overlain by the Coconino sandstone.

At Jerome, 65 miles northwest of Payson, the same basal sandstone, 75 to 80 feet thick, rests on pre-Cambrian schist. It is overlain by limestones which about 350 feet above the top of the sandstone carry Devonian fossils.

In another publication[40] the correlation of the Paleozoic strata in Arizona has been considered more at length. The facts here presented, however, are probably sufficient to show that below the Devonian beds, which are fossiliferous and are readily identified from Bisbee to the Grand Canyon, there are in central Arizona two markedly dissimilar groups of strata. On the north is the Tonto group, consisting in the Grand Canyon, from the base up, of the Tapeats sandstone, the Bright Angel shale, and the Muav limestone. The Tapeats sandstone can be followed with a few interruptions from the mouth of the Grand Canyon along the base of the cliffs bounding the Arizona Plateau on the southwest to the vicinity of Payson, in Tonto Basin. The Bright Angel shale and Muav limestone apparently do not maintain their characteristic features south of the Grand Canyon and have not been definitely recognized at Jerome or in Tonto Basin.

South of Tonto Basin, from the northern portion of the Sierra Ancha, at least as far south as the Santa Catalina Range, there are, in ascending order beneath the Devonian, the Scanlan conglomerate, the Pioneer shale, the Barnes conglomerate, the Dripping Spring quartzite, the Mescal limestone, and the Troy quartzite.

POST-PALEOZOIC ROCKS.

GENERAL CHARACTER AND SEQUENCE.

The post-Paleozoic rocks of the Ray quadrangle comprise both igneous and sedimentary kinds. The igneous rocks occur as intrusive sheets and irregular masses, as lava flows, and as accumulations of volcanic fragments. The sedimentary rocks comprise stony land detritus that has been only slightly moved from its place of origin, and coarse stream deposits that grade away from the mountains into finer material and even into lake sediments; they are essentially fluviolacustrine deposits of continental as opposed to marine deposition.

It is a common practice in geologic reports to describe all the sedimentary rocks separately from the igneous rocks. That practice has not been followed in this folio. It is thought that, in this field at least, greater clearness can be attained and descriptive matter can be made more interesting to the reader by following a historical sequence, the rocks, of whatever kind, being described in the order of their appearance on the geologic scene. This plan has already been followed as regards the basalt overlying the Mescal limestone and will receive more conspicuous exemplification in what now follows.

The first recorded addition to the rocks of the Ray quadrangle after the deposition of the Tornado limestone in Carboniferous time was intrusive olivine diabase. Then followed the accumulation, in the southern part of the area, of andesite breccia and lava flows and the irruption of closely related dikes. These igneous rocks are probably all of Mesozoic age. Tertiary time was marked by the intrusion of (1) quartz diorite, in small irregular masses and a few dikes of considerable size; (2) granite, quartz monzonite porphyry, and granodiorite in masses, some of which, as the Schultze granite, are now exposed over areas several miles in diameter; and (3) quartz diorite porphyry, in dikes, sills, and small intrusive masses. After some erosion, the coarse detrital Whitetail formation was accumulated, and then followed extensive outpourings of dacite. After much deformation and during consequent vigorous erosion the Gila conglomerate was laid down during early Quaternary time. There was at least one minor eruption of basalt during the accumulation of the conglomerate, which was followed by erosion and the deposition of younger sediments of no great areal importance. All these rocks will now be described in chronologic order.

DIABASE.

Occurrence and distribution.—The diabase of the Ray quadrangle is identical in age, geologic relations, and general character with the rock in the Globe quadrangle described some years ago under that name, and many of the descriptive petrographic details here presented have been taken with slight modification from the Globe folio.

The diabase is intrusive, and although it is highly probable, in view of the great disturbance which accompanied the intrusion, that at the time of eruption some of the magma reached the surface, there are now in the region no effusive or pyroclastic rocks referable to this period of igneous activity. The magma forced its way between the sedimentary strata as sills, but these are not persistent sheets of uniform thickness; the magma broke across the bedding at so many places and followed so many different planes of stratification that the resulting structure, in spite of the fact that the blocks of strata retain a common strike and dip, is highly irregular, and great masses of the sediments are now surrounded by and enmeshed in the intrusive rock. The intruded sheets range from a few inches to many hundreds of feet in thickness, and the sizes of the included blocks of strata are equally diverse. The main zone of intrusion in the Ray quadrangle was along the Mescal limestone, but the diabase is not confined to that horizon.

The relations of the diabase to the sedimentary rocks are remarkably well displayed in the northeastern part of the Ray quadrangle, in the Mescal Range, where blocks of quartzite and more or less altered limestone, all dipping about 20° SW., are dispersed through the diabase, which in this part of the area has invaded all the rocks older than the Devonian. One sill, roughly parallel with the bedding of the sediments, traverses the Madera diorite north of Pioneer Mountain and Old Baldy.

Into the beds now forming the Dripping Spring Range the diabase was intruded in the same manner as in the Mescal Mountains, but faulting has here introduced much greater structural complexity. In the Dripping Spring Range also the principal zone of intrusion was the Mescal limestone, but in a few places, as at Steamboat Mountain, small bodies or dikes of the diabase cut the Martin and Tornado limestones.

In the Tortilla Mountains the diabase cuts all rocks up to and including the Tornado limestone. Some of the intrusions in the granite are curiously irregular, as may be seen in the vicinity of Kelvin. Although in some parts of the area diabase to the thickness of several hundred feet has been injected at the horizon of the Mescal limestone, the same limestone where upturned in the gorge west of Hackberry Spring has been only slightly invaded by the igneous rock in the form of thin sills and small dikes.

In many places the diabase of the intruded sheets is divided by close joints parallel with the stratification of the sediments above and below. The effect is that the diabase, when viewed at a distance, resembles a bedded rock, as may be seen in the gorge of Pioneer Creek.

Diabase of the same kind as that in the Globe-Ray region and undoubtedly belonging to the same period of intrusion is abundant to the north, in the vicinity of Roosevelt and in the Sierra Ancha. Near Roosevelt the diabase forms a thick sill in the Pioneer shale. In the Sierra Ancha a sheet fully 1,000 feet thick has invaded the Mescal limestone. Diabase also correlated with that of the Globe-Ray region occurs in the Santa Catalina Range, northeast of Tucson.

Petrography.—When fresh, the diabase typical of all the larger areas in the region is a tough, heavy dark-gray holocrystalline rock of medium grain as a whole but grading here and there into fine-grained (aphanitic) varieties or into coarser, exceedingly tough facies with large tabular plagioclase crystals and abundant magnetite. Some of the finer-grained varieties are younger than the mass of the diabase, which they cut as dikes. The minerals readily visible to the unaided eye are plagioclase, augite, and magnetite.

The augite is particularly noticeable on many natural surfaces of the rock, as it forms brilliantly flashing spots, some of which are 2 centimeters in breadth. Close examination of these reflecting cleavage surfaces shows that the augite is crowded with inclusions of the other minerals composing the diabase, giving what the petrographer calls poikilitic texture. The weathered rock is greenish, and the diabase masses can ordinarily be distinguished from a distance by the very characteristic dark olive hue of their bare slopes. Hard residual boulders or pebbles of various sizes, with curiously nodular surfaces, are extremely characteristic of the disintegration of the typical diabase. The rock crumbles to a greenish sandy soil (saprolite). Embedded within this material are residual kernels of sound rock, ranging in diameter from that of a pea up to a foot or more. The larger masses have the characteristic lumpy or warty surfaces, and with the further progress of disintegration these lumps separate as small nodules. Close examination of these little bodies shows that their form and resistance to disintegration are dependent on the presence of rounded poikilitic crystals of augite. The various steps in this process of disintegration are clearly displayed along the Globe-Kelvin stage road where it crosses the main diabase belt south of Pioneer station, and an excellent opportunity for study of the rock in fresher condition is afforded by the narrow gorge of Pioneer Creek, south of the road, and by the road from Troy down to the mouth of the Pratt tunnel, southwest of Troy. In addition to the excrescences with which exposed surfaces of the diabase are usually studded there are in some localities well-marked projecting ribs or ridges an inch or two in height. These are due to the development of secondary hornblende along minute fissures in the rock and the resistance of this mineral to weathering.

Thin sections of the typical diabase examined under the microscope show a fresh ophitic aggregate of calcic labradorite or bytownite, faintly brownish augite, olivine, and a little biotite, magnetite, apatite, and titanite. In many places the diabase is so fresh that the olivine, which occurs in the usual rounded forms more or less inclosed in the augite, shows scarcely a trace of serpentinization. The augite is broadly poikilitic, the apparently isolated angular areas between the subhedral crystals of plagioclase showing optical continuity over large areas of the microscopic slides. The angle $c \wedge c$ is approximately 45°.

A chemical analysis of the diabase is given elsewhere.[41]

In the Globe report[42] attention was called to the occurrence here and there within the diabase of the larger areas of rather coarsely crystalline reddish rock having the general composition of a hornblende syenite. At a few places in the Ray quadrangle the diabase shows similar differentiation facies. Thus in the crest of a ridge 1.6 miles northwest of the summit of Scott Mountain the diabase grades into an exceedingly tough fine-grained rock of which the obvious minerals are dull-green hornblende and pink feldspar. The microscope shows that the essential constituents are hornblende, quartz, and orthoclase, micropegmatitically intergrown, and decomposed plagioclase. A part of the hornblende appears to have been derived from pyroxene by uralitization, but none of the original mineral remains. This rock, which is apparently nothing more than a local facies of the normal diabase, may be called a "basic" or more accurately a mafic quartz monzonite.

Although there is generally no difficulty in procuring specimens of fresh diabase from most of the larger areas, greenish uralitic varieties are common, even where ravines have cut deeply into the diabase and the rock exposed is firm and hard. Such facies illustrate all stages of alteration from those in which the augite is only partly altered to those in which the augite is completely changed to aggregates of green hornblende.

The diabase occurring as dikes in the pre-Cambrian complex or in the Martin and Tornado limestones is as a rule more finely crystalline than that of the larger sills and in places is nearly aphanitic.

Contact metamorphism.—In general the contact metamorphism effected by the diabase is inconspicuous. In the vicinity of the large intrusions the quartzites, especially the Dripping Spring quartzite, are exceptionally hard and well indurated, and near the contact the Pioneer shale is in places baked and hardened. The Mescal limestone, which is in contact with the diabase at so many places, shows, as might be expected, more noticeable metamorphism than the shale and quartzite. Three-fourths of a mile southwest of Walnut Spring, in the northern part of the Ray quadrangle, the Mescal limestone near the diabase contains abundant tremolite. In the bed of Pioneer Creek, 1½ miles south of bench mark 4504 on the stage road near Pioneer, in the northeastern part of the Ray quadrangle, the limestone near the diabase contains nodular segregations of silicate minerals. These include a member of the olivine group having an index of refraction higher than that of pure forsterite, tremolite, and diopside, associated with calcite and abundant serpentine, the latter derived for the most part from the olivine.

In connection with the discussion of the contact metamorphism effected by the diabase attention may be called to a small body of peculiar granitic rock that is exposed on the stage road nine-tenths of a mile south of bench mark 4504, near Pioneer, in the northeastern part of the Ray quadrangle. The mass is about 200 yards long and is surrounded by diabase. The rock composing it is strikingly variable in color and texture. Some parts are fine granular, show conspicuous although rather vaguely defined pink and greenish-gray mottling, and suggest in appearance and texture a metamorphosed quartzite. Other parts are greenish gray and evidently contain considerable chlorite. Such material is suggestive of an altered quartz diorite. Still other varieties are more granitic in appearance. One of these, a fine-grained pink rock, evidently contains abundant pink orthoclase with specks of green-brown chlorite. This rock is miarolitic, and the cavities contain partly free crystals of quartz and orthoclase. Another variety, resembling this but finer grained, is traversed by cracks whose walls are lined with small crystals of orthoclase and quartz.

The microscope confirms the impression gained in the field that the varieties are all parts of one rock mass. The feldspar is in part microcline and in part orthoclase. It poikilitically incloses the other constituents or, less commonly, is in micropegmatitic intergrowth with quartz. The characteristic occurrence of the quartz is as rounded but minutely irregular grains, about 0.6 millimeter in greatest diameter, embedded in the feldspar. As seen in thin section the boundaries of these grains are irregularly scalloped, much as would be those of a section through a blackberry. The dark constituent in most of the specimens is chlorite, but in one thin section was noted a little pale biotite, and from this mineral the chlorite was evidently derived. All thin sections show rather abundant titanite and a little zircon.

The origin of this mass of rock is not clear. The material has little in common with the other granitic rocks of the region and has an unusual texture for a normal igneous rock. If the mass is regarded as a product of local differentiation of the diabase magma, it is difficult to understand why differentiation should have taken place at this particular spot in the molten material, unsubjected apparently to any conditions favoring a departure from homogeneity. The mass may represent an included block, or xenolith, of arkosic quartzite that has been metamorphosed by reaction with the diabasic magma, although there is admittedly no conclusive evidence for this suggestion.

Age.—Intrusive relations show very clearly that the diabase is younger than the Troy quartzite. The Mescal and Tornado limestones have been cut only here and there by small bodies of diabase, but these may represent parts of the same magma

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[40] Ransome, F. L., Some Paleozoic sections in Arizona and their correlation: U. S. Geol. Survey Prof. Paper 98, pp. 133-166, 1916.

[41] U. S. Geol. Survey Prof. Paper 115, p. 54, 1919.

[42] U. S. Geol. Survey Prof. Paper 12, p. 85, 1903.

that solidified in the larger masses. If so the diabase is younger than the Pennsylvanian epoch of the Carboniferous. The relation of the diabase to the andesite in the vicinity of Tornado Peak is not definitely determinable within the area studied, but the diabase is thought to be probably the older rock. Campbell's reconnaissance of the Deer Creek coal field[43] showed that the andesite is probably Cretaceous, which would make the diabase assignable to the early Mesozoic or late Paleozoic.

CRETACEOUS SEDIMENTARY ROCKS.

The Tornado limestone constitutes the latest record of marine sedimentation preserved in the Globe-Ray region. The Deer Creek coal field,[44] which lies about 12 miles east of the Ray quadrangle, contains several hundred feet of coal-bearing sandstone and shale from which were collected plant remains whose forms, according to F. H. Knowlton, are suggestive of Upper Cretaceous age, and at a lower horizon in the same beds were obtained imperfect specimens of *Ostrea* and *Exogyra*, which, according to T. W. Stanton, are also indicative of Cretaceous time. Campbell described the major portion of the sediments as overlain by a thick mass of andesitic volcanic rocks within which are intercalated some sedimentary layers. According to him, the main body of coal-bearing sediments under the andesite thins rapidly to the west. These beds are not represented in the Ray quadrangle, although the andesitic formation, presumably also of Cretaceous age, extends into the southeastern part of the quadrangle, east of Tornado Peak, and will be next described.

ANDESITE TUFF AND BRECCIA.

Occurrence and distribution.—In their reports on the Deer Creek coal field both Walcott[45] and Campbell[46] refer briefly to the occurrence of large masses of andesite overlying the Cretaceous sediments and connected with them by the intercalation of sedimentary layers containing a little coal.

Southeast of Tornado Peak and stretching as a broad belt in that direction across Gila River lies an area of somber-colored hills composed of andesitic tuff. This material is undoubtedly the andesite referred to in the Deer Creek reports, although in the Ray quadrangle it rests not on the Cretaceous but directly on the Pennsylvanian limestone. In part the material may consist of lava flows, and certainly it is traversed by many porphyry dikes of andesitic to dioritic or monzonitic character, but in the main it is an indurated, more or less decomposed tuff or tuff-breccia. It caps the high ridge between Tornado Peak and Christmas and thins out to disappearance toward the north but thickens greatly toward the southeast, where the general dip carries its base down to and under the river. The most northerly occurrence of the andesite tuff within the Ray quadrangle is at the edge of Dripping Spring Valley, 2 miles northeast of the London-Arizona mine, where it has been dropped by faulting against the Tornado limestone. Southeast of the quadrangle, on the other hand, the formation, as may be seen from any high point near Christmas, is the prevailing rock for many square miles.

In some places the ordinary andesitic breccia, as a rule green because of the large amount of epidote near its base, rests directly on the limestone. South of O'Carroll Canyon, however, the limestone is unconformably overlain by a layer of angular cherty fragments, derived from the limestone, embedded in a gray clayey matrix. Above this is a layer, a few feet thick, of clay and fine soft tuff succeeded in turn by the prevailing indurated tuff-breccia. The coarse conglomerate mentioned by Campbell as lying at the base of the andesite was not seen within the Ray quadrangle but was observed at a few places along the Gila between Winkelman and the mouth of Dripping Spring Valley. It consists of large partly rounded fragments of granite, quartzite, and andesite in an andesitic matrix. No close study was made of it, but it probably represents material thrown out by explosive eruptions early in the andesitic epoch. The fact that the andesite rests on Carboniferous limestone in the Ray quadrangle, whereas, according to Campbell, its eruption followed the deposition of the Cretaceous sediments of the Deer Creek field without any marked interval of erosion, indicates that those sediments were deposited in a local basin and that the area of the Ray quadrangle was then land.

The tuff-breccia is cut by many dikes ranging from dark-gray andesitic porphyries with sharp lustrous phenocrysts of hornblende to more coarsely crystalline and lighter-colored quartz diorite or quartz monzonite porphyries.

Thickness.—The relations of the andesitic rocks to the underlying limestone and to the surface east of Tornado Peak indicate a thickness of at least 1,000 feet.

Petrography.—The general color of the andesite is dark greenish or reddish gray. The texture is minutely porphyritic, small phenocrysts of plagioclase being embedded in a fine-grained or aphanitic groundmass. The clastic character is not everywhere apparent, but on many weathered surfaces the faint outlines of the constituent fragments are visible on close inspection. A large proportion of the rock is so jointed and cracked that specimens of the ordinary shape and size are difficult to obtain, and the material as a whole has undergone considerable decomposition. In some localities, especially north of the latitude of Tornado Peak, the basal portion of the tuff-breccia contains much secondary epidote and in places is altered to a hard, dense yellow-green aggregate which under the microscope shows the outlines of feldspars and ferromagnesian minerals, although these minerals have been completely replaced by epidote with a little quartz and iron oxide.

The freshest obtainable specimens of the andesite tuff-breccia show more or less decomposition, as seen in thin section. The fragments were originally an ordinary feldspathic hyalopilitic pyroxene andesite. The pyroxene, so far as could be determined in partly decomposed material, is all augite, and the few thin sections examined contain no hornblende.

The dikes that traverse the pyroclastic andesite fall into three main classes — hornblende andesite, holocrystalline dioritic or monzonitic porphyries, and rhyolite porphyries. Those of the first class appear to be restricted to the andesitic area and to belong to the same epoch of eruptive activity as the tuffs. Many of them are handsome rocks, showing sparkling black phenocrysts of hornblende, generally about half a centimeter in length, and less conspicuous crystals of plagioclase in a partly glassy gray groundmass of ordinary andesitic character. Augite occurs sparingly as phenocrysts and in the groundmass. Although the rocks of this type are certainly in part dikes, some of the material may possibly represent flows. At all events they are an integral part of the volcanic complex. The porphyries of the second class are not limited to the andesitic area but belong to a group of rocks widely distributed over the quadrangle and will be described in another place. Finally, the rhyolite porphyry occurs as a group of dikes that lie generally east of Tam o' Shanter Peak and cut both the andesite and the older rocks.

Age.—Beyond the fact that the andesitic rocks rest on an erosion surface of the Pennsylvanian limestone, the Ray quadrangle supplies no clue to their age. The work of Campbell in the Deer Creek coal field, however, shows that they are late Cretaceous or Tertiary. They are provisionally assigned to the close of the Cretaceous and are thought to be younger than the diabase. Their altered condition, moreover, suggests that they are older than the dacite.

QUARTZ DIORITE.

Occurrence and distribution.—The quartz diorite forms small irregular intrusive masses and a few dikes of considerable size. The largest mass in the Ray quadrangle lies about a mile northwest of Kelvin and is intrusive in granite and diabase but is itself cut by dikes of quartz diorite porphyry similar to the rock of some of the dikes near Troy. Another mass southwest of Ray is intrusive into Pinal schist. This mass in turn is cut by a dike of quartz diorite porphyry and probably also by the Granite Mountain porphyry. Two smaller bodies on the north side of Rustler Gulch have invaded the Dripping Spring quartzite.

Three miles northeast of Kelvin, near the head of Elder Gulch, the quartz diorite is intrusive into the Tornado limestone, within which it has effected some local metamorphism. Other small bodies of the same igneous rock lie north and east of Troy Mountain. An irregular mass about one-fourth of a square mile in area cuts granite, diabase, and the Paleozoic formations up to the Mescal limestone just west of Hackberry Spring, in the southwestern part of the Ray quadrangle. Three dikes and a small intrusive body of the same rock cut granite and diabase northeast of Ripsey Spring. Finally, a small body of the quartz diorite in diabase is exposed on Pioneer Creek in the Mescal Range.

As bearing on the age of the quartz diorite intrusions, the fact should be noted that dikes of this rock are fairly abundant in the andesite breccia southeast of Tornado Peak. Most of these dikes are east of the Ray quadrangle.

Petrography.—The obvious characteristics of the typical quartz diorite are light to dark gray color, even fine-grained texture, and general freshness as compared with most of the dioritic porphyries. The constituent minerals are generally not more than 3 millimeters across, and phenocrysts as a rule are very sparsely disseminated or lacking. On fresh fracture the rock sparkles with small crystals of hornblende, augite, or biotite; all three minerals are present in some varieties.

Although the foregoing description applies to the prevalent variety, the rock is not wholly uniform in general appearance. In certain local facies the crystals of hornblende may be 2 centimeters or more in length, with the feldspars of proportional size. The mineral composition of the rock is also somewhat variable.[47]

In a few places the quartz diorite grades into local coarsely crystalline facies, some of which are highly hornblendic.

Contact metamorphism.—Quartz diorite which crops out in a small triangular area about a mile northwest of Troy contains an included block of Mescal limestone. This has been strongly metamorphosed, and the igneous rock near the limestone is more coarsely crystalline and more conspicuously hornblendic than elsewhere. The principal minerals developed by metamorphism in the limestone are vesuvianite, clinochlore, diopside, epidote, hornblende, and garnet. The vesuvianite is in stout, nearly sulphur-yellow crystals which, according to W. T. Schaller, who verified the determination of the mineral, present no unusual faces. The garnet is a yellow-brown variety in crystals as much as a centimeter in diameter.

Similar metamorphism has been undergone by a block of limestone included in quartz diorite 2 miles northwest of Troy. Here the garnet shows no crystal faces and is full of inclusions of diopside. The rock in places is a fine-grained aggregate of colorless anhedral diopside.

Another locality where limestone, in this place the Tornado limestone, has been metamorphosed by the quartz diorite is in Elder Gulch, 3 miles northeast of Kelvin. At the contact wollastonite has been developed in coarsely crystalline masses and occurs also associated with diopside, vesuvianite, and garnet.

QUARTZ MONZONITE PORPHYRY.

Occurrence and distribution.—The quartz monzonite porphyry of the Ray quadrangle is confined to the vicinity of Ray and occurs for the most part west of that town. Two varieties are recognized. One, designated the Granite Mountain porphyry, is intrusive into the Pinal schist southwest of Ray as a number of irregular masses, of which the largest forms part of Granite Mountain. (See the geologic map of the Ray district.) There are also two small bodies of this rock east of Ray. Most of the altered porphyry in the copper-bearing area west of Ray appears to belong to this variety, although, owing to alteration, close identification is not everywhere possible.

The other variety, distinguished as the Teapot Mountain porphyry, occurs chiefly northwest of Ray and north of the recognized copper-bearing area. One small mass only, that about a mile northeast of Ray, is represented on the geologic map of the Ray quadrangle. But, as shown by the geologic map of the Ray district, which covers an area extending west of the Ray quadrangle, there are many dikes and one irregular mass of considerable size exposed on the flanks of Teapot Mountain, a prominent landmark northwest of Ray.

Granite Mountain porphyry.—The quartz monzonite porphyry west of Ray is a light-gray, nearly white rock, which on slightly weathered surfaces has generally a faint yellow tint and closely resembles some of the Schultze granite. This lightness of hue is due to the preponderance of feldspar and quartz, the only dark constituent being black mica in small and sparsely disseminated scales.

The texture of the larger masses, such as that intrusive into the schist of Granite Mountain, resembles on casual inspection that of a porphyritic granite of medium grain, with phenocrysts of orthoclase and quartz not, as a rule, sharply differentiated from the groundmass.[48]

Teapot Mountain porphyry.—Closely associated with the Granite Mountain porphyry of Ray is a slightly different variety of quartz monzonite porphyry, which occurs for the most part north and west of the copper-bearing area, on the southeastern slopes of Teapot Mountain, as dikes and irregular masses in the Pinal schist.

The rock is, as a rule, a little darker in color than the Granite Mountain porphyry and is more obviously porphyritic. The general color of the fresh rock is gray, but surface exposures are generally light yellowish brown from decomposition. Contrasting sharply with the gray groundmass are phenocrysts of pink orthoclase as much as 3 centimeters in length. These are associated with smaller phenocrysts of quartz and of milky-white feldspar.

Under the microscope the matrix in which occur the large orthoclase crystals itself shows phenocrysts of plagioclase, orthoclase, quartz, and biotite in a very fine grained granular groundmass that is probably chiefly quartz and orthoclase. A single twinned crystal of allanite about 0.65 millimeter long was noted in one thin section. Although this porphyry is younger than the Granite Mountain porphyry, it is more subject to decomposition than that rock, and ordinary exposures do not afford satisfactory material for petrographic and chemical study. The feldspars are largely changed to calcite and sericite and the biotite to chlorite and epidote.

Contact metamorphism. — The contact action of the quartz monzonite porphyry near Ray is most apparent on the diabase, which, near the porphyry, glistens with abundant secondary biotite. This alteration is of the same sort as that produced by quartz diorite porphyry in diabase near the London-Arizona mine, and is described on page 12. Altered diabase of the kind referred to may be well seen on the dump of the Blue Bell shaft, southeast of the town of Ray.

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[43] Campbell, M. R., The Deer Creek coal field, Ariz.: U. S. Geol. Survey Bull. 225, pp. 240–258, 1904.

[44] Campbell, M. R., op. cit.

[45] Walcott, C. D., Description of the [Deer Creek] coal field: 48th Cong. 2d sess., S. Ex. Doc. 20, Appendix I, pp. 5–7, 1885.

[46] Op. cit.

[47] The appearance of this rock under the microscope and its chemical analysis are shown in U. S. Geol. Survey Prof. Paper 115, p. 58, 1919.

[48] See U. S. Geol. Survey Prof. Paper 115, p. 62, for petrographic details and a chemical analysis.

GRANODIORITE.

Occurrence and distribution.—The little settlement of Troy, in the Dripping Spring Range, is situated in a small upland basin floored with granodiorite and inclosed by hills of diabase and Paleozoic sediments, into which the granodiorite is intrusive. The principal area of this granite-like rock is roughly pear-shaped in outline, with the point to the east. Its length is 1¾ miles and its greatest width nearly 1¼ miles. A small outlying area half a mile northwest of Troy, although inclosed at the surface by Pioneer shale, is probably part of the main Troy mass.

Petrography.—The granodiorite of Troy is a light-gray evenly granular rock whose principal constituents, easily recognized as plagioclase, quartz, and black mica, average about 3 millimeters in diameter. Although over much of the surface of the basin the rock is disintegrated and crumbling, it is not difficult to procure material that is fresh or that shows under the microscope only slight development of epidote and chlorite in the biotite or of calcite and sericite in the feldspars.

In thin section under the microscope the rock appears as a granular aggregate of andesine (near Ab_3An_2), quartz, orthoclase, biotite, hornblende, titanite, magnetite, and zircon. With the exception of the quartz and orthoclase, which are anhedral, the principal constituents are subhedral, and some of the hornblende shows automorphic sections in the prism zone. The minerals have the usual character of those found in rocks of this class and call for no detailed description. The orthoclase and hornblende are both rather variable, being fairly abundant in some facies and inconspicuous or absent in others. They are nowhere, however, other than subordinate constituents.

A chemical analysis of a typical sample of the granodiorite, from a point half a mile northeast of Troy, is as follows:

Chemical analysis of granodiorite.

[R. C. Wells, analyst.]

SiO_2	64.84
Al_2O_3	16.49
Fe_2O_3	1.87
FeO	2.28
MgO	1.58
CaO	4.54
Na_2O	4.18
K_2O	2.46
H_2O-	.19
H_2O+	.98
TiO_2	.50
ZrO_2	.01
CO_2	Trace.
P_2O_5	.19
S	None.
MnO	.06
BaO	.02
SrO	None.
Li_2O	None.
	100.19

The name in the norm system for a rock of the above composition is yellowstonose.

The rock of the little area half a mile northwest of Troy resembles that of the main mass, although it is slightly finer grained and, as the microscope shows, approaches granodiorite porphyry in texture.

Contact metamorphism.—The most noticeable metamorphism near the granodiorite of Troy is on the northwest side of the intrusive mass, where the igneous rock is in contact with fine-grained gray schist. This schist is not unlike some of the finer-grained varieties of the Pinal schist, but its geologic relations at this place show that it is locally metamorphosed Pioneer shale. The schistosity conforms to the bedding of the former shale, dipping about 15° SW.

One specimen of the schist, when examined in thin section, proved to consist of quartz, biotite, and muscovite with andalusite in long ragged prisms and rather abundant corundum in grains, granular aggregates, and larger individuals without external crystal form.

Other specimens from the same small area of schist showed neither andalusite nor corundum, although all contain a little dark tourmaline as a microscopic constituent.

The schist is overlain by the Barnes conglomerate, which is so metamorphosed as to be scarcely recognizable. It looks at first glance like a nearly homogeneous white quartzite, and close examination is required to distinguish the shadowy outlines of the original pebbles.

The diabase near the granodiorite in places shows noticeable alteration. It is more glittering than the normal diabase and evidently contains abundant biotite. The microscope shows that this rock, while retaining the general texture of the diabase, has undergone extensive recrystallization. The original feldspars have a reddish turbidity and are full of minute inclusions. The augite and olivine have totally disappeared and are replaced by aggregates of green hornblende and biotite. There is considerable clear secondary feldspar, generally in optical continuity with the original feldspar and containing flakes of biotite and needles of amphibole. The rock is perfectly fresh, and it is clear that the change was produced by a more active agency than those which effect the ordinary uralitization of pyroxenic rocks.

Certain of the ore deposits near Troy are to be interpreted as the results of contact metamorphism by the granodiorite magma. Such are the deposits of the Rattlesnake or Manhattan mine, 1 mile east of Troy, on the south side of the granodiorite area. Here magnetite, chalcopyrite, and pyrite occur as irregular replacement layers in the Mescal limestone, which has been altered to an aggregate of diopside, white mica, and other silicates. The chalcopyrite has been in part changed to chalcocite, and the white mica apparently to a green micaceous mineral of the chlorite group, probably clinochlore. The white mica, although suggestive of muscovite, is probably not that mineral and may be a colorless phlogopite. No detailed study has yet been made of the metamorphic minerals at this locality.

QUARTZ DIORITE PORPHYRY.

Occurrence and distribution. — The rocks here included under the heading quartz diorite porphyry are widely distributed over the Ray quadrangle as dikes, sills, and small intrusive masses. In dikes they are abundant in the vicinity of Troy and are likely to attract the attention of a traveler over the stage road from the fact that they crop out in the granodiorite area as narrow ridges of darker color than the surrounding granitic rock. The general trend of the dikes near Troy is nearly due east, but in the vicinity of the Alice and Buckeye mines, southwest of the settlement, some of the dikes branch into nearly northward-trending fault fissures. The width of most of the dikes is between 10 and 100 feet.

Intrusions of this porphyry are abundant also between Tam o' Shanter Peak and Gila River. In this part of the Mescal Range the porphyry cuts the andesite tuff and has invaded the Tornado limestone both as dikes and sills. The ore deposits of the London-Arizona mine and at Christmas appear to be genetically dependent upon the quartz diorite porphyry.

Petrography.—More or less decomposition is so prevalent a feature of the quartz diorite as to be one of its chief characteristics, and the crumbling condition of most surface exposures makes it difficult to collect satisfactory petrographic material. Furthermore, in view of the facts that the porphyry in different parts of the same dike may be wholly unlike in color and texture and that the mineralogic and chemical distinction between quartz diorite porphyry and other members of the dioritic and monzonitic families is at best not sharp, it is obvious that among the many intrusive bodies mapped as quartz diorite there are possibly a few that belong to other rock types. Probability, not infallibility, is all that can be claimed for the classification of some of these bodies.

The typical quartz diorite porphyry, as exemplified by some of the larger dikes near Troy and by the intrusive bodies of various form near the London-Arizona mine and near Christmas, is a rather light gray speckled rock within which may readily be seen phenocrysts of white feldspar, of black mica, and of quartz. The relative size and abundance of these constituents is generally in the order named. The phenocrysts rarely exceed a centimeter in length and as a rule are smaller. They lie in a gray groundmass apparently composed in part of the same minerals. Some varieties show hornblende, but it is generally not abundant or conspicuous. Small crystals of rosin-yellow titanite have been noted in one or two specimens. With the progress of decomposition the bright granitic gray color changes to various shades of greenish or yellowish gray in consequence of the development of epidote and chlorite.

Under the microscope in thin section the typical fresh porphyry shows subhedral phenocrysts of andesine (near Ab_2An_1) and biotite, with rounded or embayed phenocrysts of quartz and generally a few phenocrysts of hornblende which may be intergrown with the biotite. These lie in a fine granular groundmass consisting chiefly of quartz and plagioclase granules under 0.3 millimeter in diameter, with more or less biotite and hornblende and the usual accessory minerals magnetite, apatite, titanite, and zircon. Allanite appears to be a characteristic though sparsely disseminated constituent of the porphyry, but it is not present in every thin section. The largest crystal seen was a millimeter in length.

Comparatively few thin sections show all the above-mentioned minerals in fresh condition. The feldspars are as a rule partly altered to sericite and calcite, the biotite is partly or wholly changed to chlorite and epidote, and the hornblende is represented by aggregates of calcite, epidote, and chlorite.

Deviations from the type are many and varied. Some facies are finer grained, some show no quartz phenocrysts to the naked eye, others show prominent phenocrysts in an aphanitic groundmass, and still others are almost aphanitic throughout.

A common facies among the dikes in the Troy basin is characterized by abundant phenocrysts of dull, slightly pinkish feldspar and of rounded quartz, the largest 1 centimeter in diameter, with inconspicuous phenocrysts of hornblende and biotite, in a dark greenish-gray aphanitic groundmass. The microscope shows that the pink feldspar is not, as its appearance at first suggests, orthoclase but is plagioclase, probably andesine, largely altered to kaolinite, calcite, and sericite. Hornblende, rather more abundant in the groundmass than in the typical quartz diorite porphyry, has been for the most part changed to epidote and chlorite. Biotite, in this facies less abundant than in the typical variety, has been altered to the usual secondary products.

Dikes, resembling those just described in being more hornblendic than the typical quartz diorite porphyry, occur in diabase, about a mile west of Kelvin.

Some of the wider dikes near Troy grade on their margins into fine-grained facies having very little resemblance to the main rock of the dike. This gradation is shown exceptionally well by the dikes south and west of bench mark 3644. The marginal facies is generally a compact greenish-gray or brown rock with minute phenocrysts of hornblende in an aphanitic groundmass. Some varieties show also small phenocrysts of plagioclase and biotite. The rock has invariably an original rough cleavage parallel with the sides of the dike and has acquired by weathering a pronounced platy structure. Under the microscope these marginal rocks are seen to be much decomposed and to contain abundant calcite, chlorite, and other secondary products, but there appear to have been originally small phenocrysts of plagioclase and hornblende in a groundmass consisting chiefly of tiny felted laths of plagioclase. Were the rocks fresher the dikes of Troy would provide the material for an interesting study of local magmatic differentiation. As it is, however, little more can be done than to call attention to the marked difference in general character between the medial portions and sides of the dikes and to point out that the marginal facies are more hornblendic and less quartzose than the typical quartz diorite.

Among the quartz diorite porphyry dikes near Cane Spring are a few thin, short dikes of compact greenish-gray andesite. As their importance scarcely warrants an individual color and as they were perhaps intruded at the same time as the other dikes, they are mapped as quartz diorite porphyry.

Contact metamorphism.—Notable contact metamorphism has been produced by the intrusion of quartz diorite porphyry in the vicinity of the London-Arizona mine, in the southern part of the Ray quadrangle, and at Christmas, just east of the quadrangle. Near the London-Arizona mine the diabase close to the porphyry has the glittering appearance that denotes the development of secondary biotite and in places has become a dark biotite schist. The alteration is the same in kind but more intense than that near Troy described above. Here and there in the Carboniferous limestones, not everywhere in actual contact with the porphyry but in all probability a consequence of its intrusion, are masses of garnet rock. About a mile southwest of the London-Arizona mine the dump of the London Range shaft, in Tornado limestone, shows considerable thulite, the pink manganese epidote, associated with some common epidote. This occurrence is perhaps also due to the intrusion of the quartz diorite porphyry, although none of that rock is visible at the surface at this place.

At Christmas the copper deposits are of contact-metamorphic origin, occurring in the Tornado limestone in close association with quartz diorite porphyry. The principal sulphides are pyrite, chalcopyrite, and sphalerite associated with garnet, magnetite, serpentine, diopside in granular and in part radial microscopic aggregates, and calcite. It is likely that other silicates are also present, as the mineralogy of the deposits has not been fully studied. A little bornite and chalcocite were noted, the latter clearly of supergene origin.

COMPARISON OF THE GRANITIC ROCKS.

The accompanying table of chemical analyses shows the close relationship existing between the post-Paleozoic granitic rocks and porphyries. The Lost Gulch monzonite is lower in alumina than the others and differs from them also in containing more potash than soda. This tends to support the suggestion made elsewhere[49] that the monzonite may be older than the other post-Paleozoic granitic rocks of the region.

Chemical analyses of post-Paleozoic granitic rocks and related porphyries of the Globe-Ray region.

	1	2	3	4	5	6	7	8	9
SiO_2	70.95	70.52	69.35	68.95	68.63	68.26	65.30	64.84	60.42
Al_2O_3	16.30	15.54	15.71	15.84	13.68	15.91	15.92	16.49	17.27
Fe_2O_3	1.01	.77	1.18	1.14	2.53	3.04	1.37	1.87	2.60
FeO	.36	1.31	.43	.56	1.81		2.19	2.28	3.47
MgO	.23	.66	.36	.24	1.10	.87	1.59	1.58	2.30
CaO	1.85	2.49	1.79	1.96	2.51	2.11	3.89	4.54	6.36
Na_2O	5.16	3.96	4.78	4.56	2.94	3.65	4.01	4.18	3.14
K_2O	3.34	3.72	3.63	3.69	4.04	2.80	3.08	2.46	2.34
H_2O-	.26	.36	1.17	.86	.70		.34	.19	.40
H_2O+	.37	.88	.97	1.49	.87		.78	.98	.86
TiO_2	.23	.27	.19	.22	.69	.29	.50	.50	.83
ZrO_2	Trace	None	Trace	.01	.01		None	.01	None
CO_2		None					.27	Trace	None
P_2O_5	Trace	.09	.08	.08	.24		.29	.19	.20
SO_3	Trace								None
FeS_2					.11				
S	Trace	Trace	Trace	None			.20	None	.05
Cr_2O_3							None		
MnO	Trace	.02	Trace	Trace	.15		.05	.06	.13
BaO	.04	.03	.07	.07	.05		.12	.02	.03
SrO		None			Trace		None	None	.06
Li_2O					Trace		None	None	
	100.10	100.62	99.71	99.67	100.06	(96.93)	99.90	100.19	100.46

1. Schultze granite, 1 mile west of Schultze ranch, Globe quadrangle. E. T. Allen, analyst.
2. Granite Mountain porphyry (quartz monzonite porphyry), Granite Mountain, Ray district. R. C. Wells, analyst.
3. Granite porphyry (facies of Schultze granite), 2 miles south of Schultze ranch. E. T. Allen, analyst.
4. Granite porphyry, 4½ miles south of Schultze ranch. E. T. Allen, analyst.

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[49] U. S. Geol. Survey Prof. Paper 115, pp. 51–52, 1919.

5. Lost Gulch monzonite (quartz monzonite), Lost Gulch, Globe quadrangle. W. F. Hillebrand, analyst.

6. Quartz diorite porphyry dike in granodiorite, Troy, Ray quadrangle. R. C. Wells, analyst.

7. Diorite porphyry dike in granodiorite, half a mile north of Troy. W. T. Schaller, analyst.

8. Granodiorite, Troy, Ray quadrangle. R. C. Wells, analyst.

9. Quartz diorite, 2 miles northwest of Kelvin, Ray quadrangle. George Steiger, analyst.

RHYOLITE PORPHYRY.

A few dikes of light-colored quartzose porphyry occur in the Dripping Spring Mountains east of Tam o' Shanter Peak. Loss of the few specimens representative of these dikes has prevented petrographic study of them, but they appeared in the field to be ordinary rhyolite porphyries. These dikes cut the quartz diorite porphyry.

WHITETAIL CONGLOMERATE (LATE TERTIARY?).

In the reports on the Globe quadrangle the Whitetail formation was described as a deposit of rather coarse and in many places somewhat angular stony detritus that lay in the hollows of a former land surface and together with that surface was covered by dacitic lava. The material is generally of local origin and varies with the underlying rock. It appears to have accumulated particularly on areas of diabase and in such situations is made up of angular or very imperfectly rounded fragments of that rock with a minor proportion of limestone fragments. The fragments are as much as a foot in diameter and are generally more or less decomposed.

The formation is the record of the operation, prior to the dacite eruptions, of forces and processes similar to those that afterward, on a larger scale, accumulated the Gila conglomerate, which in some places is almost identical with the Whitetail. Apparently then as now areas of diabase tended to become lowlands and were strewn more abundantly than at present with stony detritus, locally reworked and partly stratified by transient streams. Detrital fans at the mouths of shallow gulches, merging with the stony litter of an arid surface, were covered by the tuff and lava of the dacitic eruptions and so preserved. In the absence of fossils a rough approximation to the age of the Whitetail conglomerate, deduced from the general physical history of the region, is all that is possible. As it lay on the surface over which the probably early Tertiary dacitic lavas were erupted, it also is referred to the same period.

Excellent places to observe the Whitetail conglomerate are the steep slopes of Teapot Mountain near Ray (Pl. VIII) and near the Continental mine, in the northwestern part of the Globe quadrangle.

DACITE.

Definition.—The dacites are porphyritic effusive rocks in which crystals of plagioclase, quartz, and hornblende or biotite, as the common essential minerals, are embedded in a more or less glassy groundmass. The biotite dacites are closely related to the rhyolites, which they commonly resemble. The relation of the dacites to the rhyolites and andesites among the volcanic rocks is similar to that of the quartz diorites to the granites and diorites among the plutonic rocks.

Occurrence and distribution.—Dacite covers large areas and is widely distributed in the Globe quadrangle, but in the Ray quadrangle it occurs only at the north end of the Dripping Spring Range. The mass through which Mineral Creek has cut its gorge north of Ray is merely the southern extremity of a thick and extensive flow whose surface may be seen from any of the summits north of Scott Mountain stretching in rugged desolation for many miles to the northwest. Into this thick mass of lava Mineral Creek and its tributary Devils Creek have incised deep, narrow canyons of notably picturesque character. The main portion of this flow is faulted down against the older rocks of the Dripping Spring Range, but outlying remnants rest here and there on the higher parts of this range north of Scott Mountain, and a considerable area of dacite, partly covered by the Gila conglomerate, extends southward to the vicinity of Ray.

Originally this flow probably covered most of the Globe quadrangle and much of the Ray quadrangle, but its continuity has been greatly reduced by faulting. The maximum thickness is unknown, but existing remnants show that it must have exceeded 1,000 feet. In spite of vigorous postdacitic deformation of the region, it is clear that the flow was poured out over an irregular surface in whose ravines and valleys the Whitetail conglomerate had previously accumulated.

The basal portion of the dacite is well exposed 2 miles northwest of Walnut Spring, where a small body of this rock caps a prominent flat-topped summit in the Dripping Spring Range and rests partly on diabase and partly on the Mescal limestone, with here and there a little of the Whitetail formation intervening. Here the lower 3 or 4 feet of the dacitic formation consists of a light pinkish-gray, rather soft rock, with small sparkling flakes of black mica and fragments of diabase and limestone. It closely resembles the typical dacite, presently to be described, but is a shade lighter in color and, as shown by the microscope, is a glassy dacite tuff. Above this is a layer, 12 to 15 feet thick, composed of a brittle, nearly black vitrophyre, with resinous luster, which is a persistent and characteristic feature at the base of the lava flow. This vitrophyre grades upward into the typical pink dacite, which maintains its lithologic character with scarcely any variation wherever it occurs in the Globe and Ray quadrangles.

Petrography.—In natural exposures the dacite has a very characteristic light pinkish-gray color. It has a tendency to weather into large, boulder-like masses, forming characteristically rocky surfaces, which are difficult of traverse. Many of these loose masses are over 6 feet in diameter, and, owing to differential weathering of glassy lithoidal portions of the rock, they show curiously pitted exteriors. The origin of the boulders is traceable to a rather irregular division of the rock into rude cuboidal blocks by systems of joints, which may not be visible until brought out by initial disintegration. Such joints can well be seen in the cliffs along Mineral Creek, in the northwest corner of the Ray quadrangle, and at the Sixty-six ranch, in the southwest corner of the Globe quadrangle, where various intermediate stages may be observed between angular joint blocks and rounded boulders. As a rule, the weathering of the dacite is a very superficial process, being confined to the disintegration of exposed surfaces. Decomposition has in few places penetrated the rock for more than a fraction of an inch.

The color of the freshly fractured dacite is light gray, usually of a decided pinkish tinge, with small streaks or blotches of nearly white material. The rock is harsh to the touch and at first glance appears to be more porous than it actually is. It is firm and tough rather than hard and brittle, and being easily quarried and fairly durable, it makes a good building stone.[50]

It has been noted above that there is at the bottom of the dacite flow a more glassy variety with megascopic flow banding. This rock ranges in color from light gray to dark gray or black. In many specimens the banding is obviously due to the alternation of streaks of glistening black glass with those of more lithoidal material. Small included rock fragments, particularly of diabase, are perhaps more numerous in this facies than in the more common pink dacite described above. The phenocrysts recognizable by the unaided eye are of the same kind as those of the pink rock.

Under the microscope this glassy dacite is seen to differ from the pink facies chiefly in the groundmass, which, being less crowded with incipient crystal growths, is more transparent and is as a rule a pale-brown, slightly globulitic or trichitic glass. Microscopic flow structure is developed in great perfection and beauty, and the rock is typically vitrophyric. The phenocrysts are the same as in the more lithoidal dacite, but green hornblende occurs a little more abundantly in the thin sections examined and is in a few sections nearly as abundant as the biotite. The other accessory minerals are zircon, apatite, titanite, and iron oxide, as in the common lithoidal dacite.

Here and there a yet more glassy facies is associated with the dark vitrophyre just described. This is a gray brittle volcanic glass of greasy luster in which can be seen small phenocrysts of fresh feldspar, quartz, and biotite. Under the microscope the rock appears as a colorless perlitic glass containing scattered phenocrysts of plagioclase, orthoclase, quartz, and biotite and minute microlites of feldspar.

Some of the tuff that occurs locally at the base of the massive dacite is exceedingly troublesome to separate in the field from the overlying massive dacite. It is particularly difficult to separate the white or slightly pinkish tuff that immediately underlies the gray vitrophyric dacite. This is a firm rock that shows small crystals or fragments of feldspar, quartz, and biotite in an abundant, uniformly fine-grained base. It might easily be taken for a massive lithoidal rhyolite. Under the microscope fractured or corroded crystals of plagioclase, biotite, hornblende, and quartz are seen to lie thinly scattered in a dusty-gray glassy groundmass that somewhat indistinctly reveals the reentrant curves and sharp points of minute glass sherds—the characteristic structure of glassy volcanic ash. In parts of the Globe quadrangle this tuff has undergone some decomposition. With nicols crossed it is seen that very little true glass remains, the groundmass having been changed into a very minute aggregate of indefinite and shadowy crystal forms. Calcite, which is unknown in the massive dacite, is here abundant, not only throughout the devitrified glassy base but as an alteration product of the plagioclase. In this alteration there is none of the general clouding and breaking down of the feldspar, as is often seen in weathered rocks, but the calcite is separated by a sharp boundary from the perfectly clear and fresh plagioclase at the expense of which it is forming.

Age.—There are no available data for fixing the exact time of the dacitic eruption. It is known to have occurred after the irruption of the granitic, monzonitic, and dioritic rocks of the region. On the other hand, it clearly preceded the deposition of the Gila conglomerate and the development of the present topography. The dacite is therefore considered as probably of Tertiary age.

GILA CONGLOMERATE (PLEISTOCENE).

Character and distribution.—The Gila conglomerate as it occurs in the Globe quadrangle has been fully described in publications on that area.[51]

It is essentially a fluviolacustrine deposit consisting of coarse, imperfectly rounded or angular rock detritus near the mountains but grading into gypsiferous silts in the central portions of the larger valleys.

The general character of the Gila formation as it occurs within the Globe quadrangle is that of a firm but not hard conglomerate, the material of which ranges in coarseness from boulders or angular masses 8 or 10 feet in diameter to fine sand. As a rule it is roughly stratified, but individual beds show little persistence, layers of conglomerate passing into sand or vice versa. Some of the pebbles are well rounded and probably were derived for the most part from one of the Paleozoic conglomerates, but most of them are subangular or angular, and the formation might in places be termed a sedimentary breccia. Although the Gila conglomerate has in places been subjected to considerable deformation and erosion, it is obviously in the main a deposit laid down in the existing valleys and extends in characteristic long dissected slopes up the flanks of the ranges from which its materials were derived.

In the Ray quadrangle the Gila conglomerate is well developed and plays a more conspicuous part in the landscape than in the Globe quadrangle. Dissected slopes of the conglomerate in Dripping Spring Valley are shown in Plate I, and a nearer view of the material in Plate VII. In the middle part of this valley coarse material is in places overlain by brown silts and sandy clays, in part pebble bearing and containing at least one bed of impure diatomaceous earth. These silty beds grade both downward and laterally into the usual coarse angular detritus. They evidently record the former existence of a lake in which the finer materials brought down by torrential streams from the neighboring mountain sides settled quietly to the bottom. Evidence of contemporaneous stream channeling is clearly shown in some exposures of the conglomerate. It is not always easy to distinguish such contemporaneous stream cutting from later channeling and filling accomplished by streams during the general dissection of the conglomerate.

South of Ray, along Mineral Creek, the Gila conglomerate is harder than in most other parts of the Ray quadrangle and has weathered into steep bluffs and picturesque rounded towers, of which Big Dome is a good example. Overlying the dacite north of Ray is a coarse, irregularly bedded rubble of dacite, quartzite, and limestone fragments, above which lies about 200 feet of well-stratified tuffaceous beds composed mainly of glassy dacite detritus. This material was presumably washed from the upper part of the dacite flow beneath it. All the conglomerate in this part of the Ray quadrangle contains abundant dacite fragments, and in places, as near Government Spring or Mineral Creek, in the southwest corner of the Globe quadrangle, layers of glassy tuffaceous detritus are interbedded with the coarse conglomerate. The tuffaceous beds, considered by themselves, might be taken as indicative of a continuance of dacitic eruptions during the accumulation of the Gila conglomerate, but it is more accordant with the history of deformation in the region to conclude that those eruptions had ceased and that the particles of glassy dacite were eroded from the solidified lava and swept by streams into depressions where they accumulated, probably in part in short-lived lakes.

Some of the coarsest material noted in the Gila conglomerate is on the east fork of Mineral Creek, near the northern border of the Ray quadrangle. Here one partly rounded mass of granitic rock from the Pinal Range measured about 7 by 10 by 25 feet and was estimated to weigh 300 tons. As a rule, the higher the neighboring mountains and the more massive and resistant their rocks the larger the fragments in the Gila conglomerate.

In the southwestern part of the Ray quadrangle, southwest of Gila River, the Gila formation shows a greater thickness of distinctly bedded strata than in any other locality studied. The general dip is to the east-northeast at about 30°, but along the east side of the older rocks of the Tortilla Range the dip is in places fully 75°.

The beds are of varied composition. Probably the most abundant material is a brownish-gray conglomerate in rather thin beds in which the coarse constituents are angular fragments of andesite, andesitic porphyries, and limestone. Many of these fragments are 2 feet or more in diameter, and some of the masses were observed to lie partly in one bed and partly in another, as if they had been thrown independently into the accumulating material. The matrix of these blocks and imperfectly rounded boulders is a poorly washed brown-gray sand in which grains of minute size are mingled with larger particles and fragments of all sizes up to the blocks mentioned. The material of the sand is partly granitic and partly andesitic. The granitic material probably came from the west or south and the andesitic material from the east or southeast.

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[50] See U. S. Geol. Survey Prof. Paper 62, pp. 69–70, for petrographic details and a chemical analysis.

[51] Ransome, F. L., Geology of the Globe copper district, Ariz.: U. S. Geol. Survey Prof. Paper 12, pp. 47–57, 1903; U. S. Geol. Survey Geol. Atlas, Globe folio (No. 111), pp. 5–6, 1904.

The variety of the conglomerate described is not very different, so far as material is concerned, from that east of Gila River in the vicinity of Hayden. The conglomerate there also contains much andesitic material but is not so well bedded as that between Branaman station and Hackberry Spring.

Associated with the prevailing variety of sedimentary material between Branaman and Hackberry Spring were observed one bed, about 1 foot thick, of fine-grained creamy-white sandstone and, a little higher in the series, another thin bed of light-gray tuff. The sandstone consists chiefly of sharply angular particles of quartz with a few minute flakes of brown biotite. The tuff under the microscope shows fragments of pyroxene, feldspars of various kinds, biotite, and bits of andesite or basalt, in a groundmass of partly devitrified glass sherds.

Near Hackberry Spring the Gila formation consists of well-bedded coarse sandstone, composed almost entirely of partly rounded granitic crumbs derived from the coarse pre-Cambrian granite of the Tortilla Range. Along the upper, north-south portion of Hackberry Wash the Gila is prevailingly reddish and sandy and occurs in beds for the most part about a foot thick. These beds consist largely of andesitic detritus and contain some fragments of andesite as much as 2 feet across. Stratigraphically under them and lapping up against the Paleozoic rocks to the west is fully 100 feet of soft, crumbling brownish-gray sandstone and sandy shale. There is much faulting in this vicinity, and the silty material is probably faulted against the older rocks and is not the real base of the Gila formation. Where the basal part of the formation is exposed, as farther north along the east side of the Tortilla Range, it consists of coarse fragments of obviously local derivation. The brown sand and shale are made up principally of mineral particles derived from the granite of the range.

In the extreme southwest corner of the Ray quadrangle is a synclinal basin of Gila conglomerate surrounded for the most part by hills of pre-Cambrian granite. This basin is drained by the intermittent Ripsey Wash, near the mouth of which, about 3 miles west of Kelvin, the Gila formation may be seen resting on the granite. Here the formation consists of light pinkish-gray tuffaceous-looking beds carrying fragments of granite in a matrix composed largely of volcanic material, apparently dacitic. The beds vary much in thickness, ranging from shaly seams to strata measuring over 6 feet. Other facies appear farther south. Much of the material is a coarse breccia, the beds of which are thick and rather vaguely laminated. Blocks of granite 3 feet in greatest length are embedded in coarse granitic sand or in a matrix of granitic and dacitic débris. In places beds of soft sandstone or fine silt separate the coarser layers.

The beds southwest of Gila River are in part so different from the Gila conglomerate elsewhere in the quadrangle and are as a whole so much better stratified as to suggest, on first examination, that they may be an older formation, probably having an unconformable relation to the Gila. No evidence of unconformity, however, could be detected, and the well-bedded material appears to grade upward and laterally into Gila conglomerate of the common variety. Evidently the basin in which deposition took place in the southwestern part of the Ray quadrangle was exceptionally deep, and rapidly accumulating coarse fluviatile material graded at times into finer sediments laid down in comparatively still water.

The deformation of these beds is considered below under "Structure."

The accumulation of the Gila conglomerate is clearly indicative of intensely active erosion consequent upon the period of vigorous deformation that outlined the present mountains and valleys of the region. As a result of the block faulting and earth movements that followed the eruption of the dacite, the mountain ranges were much higher than at present and the larger or structural valleys much deeper. Consequently the stream grades were steep and the erosive and transporting powers of the running water were far greater than they are now in the same region. Possibly the greater height of the mountains was accompanied by greater precipitation than at present, but the general character of the deposit points to a decided preponderance of mechanical disintegration over rock decay and to an arid rather than a humid climate.

The same indication is afforded by the occurrence of gypsum associated with the silty facies of the Gila formation on Salt River north of the area here especially considered. To one familiar with the intensive work occasionally accomplished in a few hours by the fierce rush of local storm water along one of the present streamways there appears to be little necessity to require any great increase in precipitation to account for the deposition of the Gila conglomerate under the conditions of waste supply and grade then prevailing. Some increase there may have been, but not enough to make the conditions of plant growth, rock disintegration, erosion, transportation, and deposition very different in kind from those of to-day.

Thickness.—The thickness of the Gila conglomerate differs greatly from place to place, and probably no measurement gives the true maximum. Between Hackberry Spring and Gila River near Branaman station a simple computation, based on the average dip of 30° to 35° and the width of outcrop, gives a thickness of 7,500 to 8,500 feet, or, say, 8,000 feet. This estimate is based on the supposition that the beds near the base of the section continue northeastward under the beds exposed near the river and that there has been no duplication by faulting or folding.

It is quite possible that some of the lower beds are of slight areal extent, but any considerable duplication could hardly have escaped notice. The foregoing estimate does not take account of the 3½-mile belt of Gila conglomerate between Branaman station and the Dripping Spring Range to the northeast. Near the river there is certainly several hundred feet of this conglomerate that is stratigraphically higher than the beds southwest of the river. The total thickness of these upper deposits and the extent to which they are underlain by the more regularly bedded material exposed southwest of them could be determined only by boring.

In 1910 some borings were made near Hayden with a view to obtaining a water supply for the reduction works then building. Drill hole No. 1 started at an elevation of 1,950 feet above sea level on the flood plain of the Gila, went through 80 feet of sand and gravel and then through 770 feet of Gila conglomerate, in which it was abandoned. Drill hole No. 2, which was started at an elevation of 2,097 feet in the gulch near the power house, penetrated 920 feet into the conglomerate and was abandoned in that formation. No. 4 shaft of the Miami mine is 710 feet deep, all in Gila conglomerate.

In 1915 a churn-drill hole 20 inches in diameter was begun by the Miami Copper Co. about 1,600 feet east-southeast of No. 4 shaft. It was intended to drill through the conglomerate in order to explore the underlying schist, which was estimated to lie at a depth of about 2,300 feet. The hole attained a depth of 2,050 feet, reported to be all in conglomerate, and then had to be abandoned, in October, 1916. The conglomerate apparently is of the same general character from top to bottom of the hole. Probably the drill would have penetrated dacite before reaching the schist.

About a mile southeast of the A shaft of the Old Dominion mine a drill hole in 1915 went through 1,000 feet of Gila conglomerate, which was ascertained at this place to be underlain by quartz diorite (Madera diorite), possibly overthrust material. (See p. 15.)

Age.—No identifiable fossils were found in the Gila conglomerate of the Globe-Ray area in the course of the investigations upon which this folio is based. A few small crumbling particles of bone, however, noted near the head of Dripping Spring Valley, show that the deposit is not wholly devoid of animal remains. The formation has generally been regarded as probably of early Quaternary age. The present investigation has brought out no evidence requiring a revision of this supposition, unless the great thickness and deformation of the beds southwest of Gila River are considered as incompatible with assignment to the youngest of the geologic periods. In 1906 Dr. T. Shields Collins, of Globe, forwarded to the Survey a fossil bone said to have come from the Gila conglomerate near that town. J. W. Gidley, of the National Museum, to whom it was referred for determination, reported that it is the distal half of the right humerus of an extinct species of horse, probably *Equus complicatus*, and is indicative of Pleistocene age.

BASALT.

During the deposition of the Gila conglomerate there were minor outpourings of basalt, although none of these flows occur within the area of the Ray quadrangle. The largest body of this rock in the Ray-Globe region, a flow from 50 to 150 feet thick, in an area of conglomerate about 5 miles west of Miami, near the western border of the Globe quadrangle, has been fully described in the Globe folio.

RECENT DEPOSITS.

Detrital accumulations younger than the Gila conglomerate and probably referable to the later part of Quaternary time include certain sheets of unconsolidated or only partly consolidated rock waste that have been considerably dissected by the present intermittent streams and now form sloping terraces or low flat-topped ridges. These are particularly well developed in the neighborhood of Ray and are well shown on the geologic map of Ray and vicinity. The material forming the tops of these terraces has been derived from the adjacent hill slopes and merges with the ordinary stony detritus of those slopes. It represents a series of low-angle confluent alluvial fans formed during a halt in the dissection of the Gila conglomerate. Terraces along Mineral Creek south of Ray, on one of which the village of Kelvin is situated, and similar benches and mesas in the Gila conglomerate areas of the Gila and Dripping Spring valleys mark the same and perhaps other steps in the development of the present topography. As these terraces originally had wide ranges of slope and altitude, their close correlation by reference to sea level is impossible.

Lower and younger than the terraces are the flood-plain deposits of the Gila and its principal tributaries. Along the river there are considerable areas of excellent agricultural land, but the tenure of this is uncertain, menace from flood being always imminent. Inundations such as have deposited the silt are no respecters of human occupancy and may destroy in a few hours the labor of years. Near Hayden large areas of ranch land have been utilized by the Ray Consolidated Copper Co. as a dumping ground for mill tailings.

In connection with recent deposits mention may be made of local conglomerates cemented by copper silicate and carbonates that occur along some of the streamways where they pass through areas of copper-bearing rocks. These occur at various elevations up to 50 feet or perhaps more above the present arroyo bottoms. They are stream gravels cemented by the action of cupriferous water that seeps slowly from the adjacent rock, and the process has probably continued up to the present time. These copper-bearing conglomerates may be seen in Copper Canyon, and with the vivid stains on the cliffs probably suggested the name of that ravine.

STRUCTURE.

GENERAL FEATURES.

Some mountains, such as the Appalachians, stand in relief because the neighboring valleys, with which they are in contrast, have been carved by erosion below a surface once broadly coincident with the present ridge crests. Others, such as those in southwestern Idaho and southeastern Oregon, which Russell[52] has described, owe their prominence to direct uplift relative to the valley floors, and their forms have been modified only very slightly by running water. Still others, like Mount Shasta in California, are mountains of volcanic accumulation piled above an older surface. In actuality few if any mountains belong exclusively to one of the three ideal types. Most exhibit some erosional modification, and as regards many of them it is difficult or impossible to decide whether deformation or erosion has had the larger share in their development.

As shown in the general description of its topography, the Ray quadrangle is characterized by ranges trending nearly northwest, separated by detritus-laden valleys. This larger differentiation of the surface into ridges and troughs or mountains and valleys is a direct result of earth movements. The ranges are essentially tectonic features. Erosion, however, has profoundly modified their primitive form, and all those details that attract the eye and are retained by the mind as pictures of the highland landscape are the work chiefly of streams, for the most part intermittent in their activity. So far as concerns the main valleys erosion has been merely incidental to the extensive accumulation of rock waste washed from the neighboring mountain slopes or has been limited to the dissection of the material thus laid down. The depressions as a whole represent actual deformation of the lithosphere, not a mere carving of its surface.

In a final analysis deformation of rocks under stress takes place by fracture or flowage, or by some combination of the two processes. In a broader structural sense and without present consideration of that kind of flowage which is associated with the development of schistosity or with general recrystallization, rocks may be deformed by folding or by faulting. In most regions both of these kinds of major deformation are exemplified, and the character of the resultant structure depends upon the relative share of each. In the Ray quadrangle folding has played practically no part in the development of post-Cambrian structure. Faults, on the other hand, are extraordinarily numerous, and the characteristic structural unit is the tilted fault block. Such folding as has been observed in this region is apparent chiefly in the limestones and nowhere indicates strong compression, the resulting dips rarely exceeding 25°. It is exemplified generally by a slight sagging or arching of the strata in some fault block. Where the Gila flows across the Tornado limestone, in the southeast corner of the Ray quadrangle, the beds form a gently arching anticline with northwesterly axis, exposed for a width of 1¼ miles along the river. The dip is nearly horizontal on the southwestern flank, where the limestone passes beneath the Gila conglomerate, and about 30° on the northeastern flank, where cut by the river section. Many gentle minor folds are associated with the main anticline.

Although faulting has been the dominant mode of deformation in the region, the mountains, as will presently be shown, are not merely uptilted blocks of the simple Great Basin range type, nor is the evidence for their tectonic origin of the obvious ocular sort that is immediately convincing. Before it is considered the character of the faults in general will be briefly described and the structure of each range will be sketched in outline.

FAULTS.

Nomenclature of faults.—As there has been wide diversity in the use of terms in descriptions of faulting, clearness can be attained only by an initial explanation of the nomenclature to be followed in this text. All terms relating to

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[52] Russell, I. C., Notes on the geology of southwestern Idaho and southeastern Oregon: U. S. Geol. Survey Bull. 217, pp. 13–17, 1903.

faulting will be here used as recommended or defined by the committee on the nomenclature of faults of the Geological Society of America.[53] The application of some of the more important of these terms is illustrated in Figure 4.

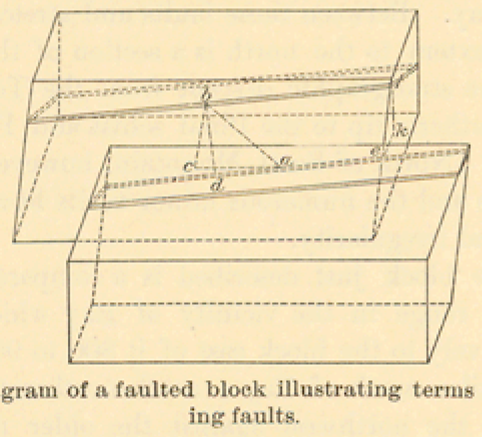

FIGURE 4.—Diagram of a faulted block illustrating terms used in describing faults.

The upper and lower surfaces of the block are horizontal; the end faces are vertical and at right angles to the fault strike. *a*, *b*, *c*, *d*, *e*, and *f* lie in the fault plane; *e*, *f*, and *k* in the end face. *a*, *d*, *b*, *e*, and *f* lie in an inclined bed in the block. Let the point originally adjacent to *a* move to *b*; then *ab*=slip or net slip; *cb*=dip slip; *ac*=strike slip; *bd*=perpendicular slip; *ad*=trace slip; *fk*=throw; *ek*=heave.

Evidence of faulting.—In many regions the presence of faults is inferred as the most reasonable way of explaining certain observed structural relations. In the Ray quadrangle the evidence as a rule is of a more direct character. The very topography of the Dripping Spring Range, for example, as stated on page 2, is indicative of intricate faulting. A distant view of the range suggests neither the simplicity of a single homoclinal block nor the linear elements of form that we have learned to associate with mountains of folded strata. A view from any high point over parts of this range or over much of the Globe quadrangle is equally suggestive of dislocation. The Globe report[54] contains the following paragraph:

> If one will stand upon the top of Webster Mountain and look northward or eastward over the confusedly hilly country spread out before him, he will be struck with the apparently chaotic distribution of the various rocks, as indicated by their respective and characteristic tints in the landscape. Here and there patches of limestone gleam white through the thin screen of scanty vegetation, while areas of quartzite are indicated by a reddish color and masses of diabase by a dull olive tint. The beds show no trace of folding, and the eye seeks in vain for any persistent or regular structure that may account for this rocky patchwork. * * * In traversing this faulted region one steps with bewildering frequency from quartzite to limestone, granite, or diabase, the line of separation being often clearly defined by a fault breccia, forming a bold outcrop that may be followed over the country for miles. Probably few equal areas of the earth's surface have been so thoroughly dislocated by an irregular network of normal faults and at the same time exhibit so clearly the details of the fracturing.

When the foregoing was written the Dripping Spring Range in the Ray quadrangle had not been geologically mapped and studied. It displays perhaps still better than any equally large area in the Globe quadrangle the fine-textured fault mosaic characteristic of the region.

Indurated, boldly outcropping fault breccias mark the courses of many faults, particularly those that traverse quartzite or have quartzite in one wall. This brittle but weather-resisting rock is the great breccia maker. Even those faults that, at the surface, pass through other rocks than quartzite, may have quartzitic breccias, the fragments having been derived from some place along the break where the fissure passes through or beside that rock. A number of illustrations of fault breccias were published in the Globe report.

Distribution.—The faults are not evenly distributed over the region here described. They are particularly numerous in the northern part of the Globe quadrangle and in the Dripping Spring Range but are comparatively rare or at least inconspicuous in the main mass of the Pinal Range and in the Mescal Range. These differences will be more fully brought out in describing the structure of each range.

Directions of faulting.—The geologist after mapping the faults in a region studies their directions and tries to determine whether they can be classified into groups, each group characterized by a certain trend or strike. By this means he hopes to get some clue to the relative ages of the faults and to the character of the stresses that produced them. Without regard to any possible major fault that may be concealed by the Gila conglomerate, there apparently is no significant preponderance of faults having one direction of trend over those running in other directions. Here and there in the Ray quadrangle some of the principal faults are nearly parallel, but the direction of parallelism at one locality differs from that in another. For example, in the vicinity of Tornado and Tam o' Shanter peaks, in the Dripping Spring Range, the more persistent faults strike about N. 12° W., but at the north end of the same range the locally prominent faults strike nearly N. 35° E.

Apparently no general and significant grouping of the faults on the basis of common trends is possible. It follows that if the faults are of distinctly different ages, discrimination must be based on other criteria than that of difference in strike.

Dip.—Of the many faults that have been mapped in the course of the detailed geologic work on the Globe and Ray quadrangles, comparatively few are so exposed as to permit a measurement of the dip of the fault fissure. As a rule the dips are high, mostly over 45° and probably averaging about 70°.

Kind of movement.—The result of the movement has generally been what is termed a normal fault. To what extent the slipping has been up or down the dip (dip slip) or horizontal (strike slip) is rarely determinable.

In a few places the displacement is of the reverse or overthrust type. One such fault near the Old Dominion mine, near Globe, has been described in another publication.[55] Here a mass of shattered Madera diorite (pre-Cambrian) has been thrust from the southwest over dacite (Tertiary) up a plane of 37°. Only the thin edge of the upthrust block is now in part exposed, the greater part of the mass being buried under the Gila conglomerate, which was deposited after the faulting. The general relations are shown diagrammatically in section in Figure 5.

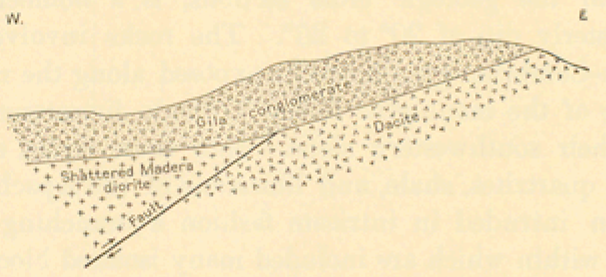

FIGURE 5.—Diagrammatic section illustrating the thrust of Madera diorite (pre Cambrian) over dacite (Tertiary) near the Old Dominion mine.

Another reverse fault is recognizable on the west bank of Mineral Creek, about a mile below the town of Ray. The Pinal schist on the west has been thrust up over the smooth footwall of Dripping Spring quartzite on the east. The dip of this footwall is about 45° W. The throw must be at least 150 feet, for the Pioneer shale has been cut out.

In Elder Gulch, 3 miles northeast of Kelvin, the Tornado limestone rests on pre-Cambrian granite, and the contact dips west at 15° or less. The limestone is disturbed and fissured. Although the younger rock here rests upon the older, it does not appear probable that normal slipping could take place on so low a slope, and the dislocation is supposedly due to thrusting. On the northwest the fault ends against an intrusive mass of quartz diorite, and about a third of a mile away on the southeast it ends against another fault that is apparently of normal type, with downthrow to the east.

Running north from the east side of Tam o' Shanter Peak in the Dripping Spring Range is the outcrop of a fault that appears to record a thrust of the rocks west of it toward the north and east. The dip of the fault ranges along the strike from 20° to 45°. North of the peak the effect of the fault has been to cause the Troy quartzite to override the Dripping Spring quartzite, the diabase, and perhaps also the Mescal limestone, which does not appear at the surface. The front of the overthrust mass as seen from Dripping Spring Valley forms a rough scarplike outcrop. A notable feature of this scarp is the unusual quantity of quartzite débris, much of it in huge blocks, that litters the slope in front of it. Evidently this material is residual and has been left by the erosional retreat of the edge of a flat-lying overthrust mass. The material is too abundant to have been derived from the upthrown side of a steep fault scarp. Close inspection of the cliff shows that the Troy quartzite is greatly shattered and jointed, and at a few places along the base of the cliff are exposed overhanging irregular billowy surfaces of movement. The mass appears to be roughly spoon-shaped and to have been thrust forward to the northeast in the direction of its tip.

The overthrust faults have been described in some detail, not because they are important structural features but rather because they are exceptional and are of interest in their connection with deformation so preponderantly of another type.

The part played by thrust faulting in any region is likely to be obscure, for unless the thrust plane crops out distinctly the existence of the fault may entirely escape notice. Even if the presence of a fault is known, its structural importance can not always be estimated.

Minor thrust faults are to be expected in a region of normal faulting, for as the blocks wedge together local thrusts are exerted and part of one block may be shoved over another. There is apparently no way of determining whether obscure thrust faults, such as the fault near the Old Dominion mine, which disappears westward under the Gila conglomerate, belong to this group of minor or secondary dislocations.

Extent of displacement.—The throws of the individual faults, exclusive of faults concealed by the Gila conglomerate, consideration of which is for the present postponed, are not as a rule very great. Probably few of them exceed 1,000 feet. Along the west slope of the Dripping Spring Range one of the most persistent faults has been traced from Hackberry Gulch,[56] 2 miles southwest of Troy, nearly to Rustler Gulch, north-northeast of Ray, a distance of more than 5 miles. Half a mile south of Rustler Gulch this fault brings Troy quartzite on the east against Pinal schist on the west, indicating a throw of 875 feet. In Susie D. Gulch, southeast of Ray, the same fault brings into juxtaposition the lower part of the Tornado limestone and the Mescal limestone, indicating a throw of 725 feet or more.

The same strata are brought together half a mile west of Troy Mountain by a nearly north-south fault that crosses the Dripping Spring Range. A mile north of Troy a nearly east-west fault brings the Tornado limestone against the Dripping Spring quartzite, a throw of at least 975 feet, and in the same locality another fault brings the Devonian limestone against the Cambrian Pioneer shale, a throw of 1,100 feet or more. One mile southwest of the London-Arizona mine a north-northwesterly fault has dropped the Tornado limestone against the basal portion of the Troy quartzite, a throw of 725 feet or more. A mile and a quarter north of the same mine the Tornado limestone in contact with the Mescal limestone shows a throw of at least 725 feet. The examples given probably show more than the average displacement of those faults in the region that are not concealed beneath the Gila conglomerate.

Relative ages.—The faults clearly are not all of one age. Many of them, so far as can be determined, do not displace the Gila conglomerate. This appears to be generally true of the faults in the Dripping Spring Range. On the other hand, certain fault fissures north of Ray do cut the conglomerate, and some faults in the Tortilla Range southwest of Gila River also appear to displace it. Many faults dislocate the dacite, and from the extent of this displacement it appears probable that a large part of the faulting in the region is postdacitic. In a few places, however, fault fissures along which, in the older rocks, there has been considerable movement apparently pass under dacite without any disturbance of that rock. Such places, however, are not numerous.

Faulting and igneous intrusion.—To what extent faulting actually preceded the intrusion of diabase in Mesozoic time and prepared the way for the great shifting of blocks of strata in the liquid magma is unknown. The character of some of the contacts of the diabase with the other rocks suggests, however, that the invasion by the magma was facilitated to some extent by previous faulting. Be that as it may, it is certain that at the time of the intrusion the beds, particularly those beneath the Troy quartzite, were broken in rather extraordinary fashion into irregular blocks, and that these, after more or less movement in the magma, became fixed as huge inclusions in the solidified diabase, as may be well seen in the Mescal Range, in the northeast corner of the Ray quadrangle.

At a number of places dikes of diorite porphyry have been injected along fault fissures. This is most clearly shown southwest of Troy, where the dikes in part follow fault fissures and in part fissures of no apparent displacement.

Expression in topography.—None of the faults, so far as known, finds superficial expression as a simple unmodified fault scarp. Minor scarps exist here and there, but these are due to the erosion of the softer rock on one side of the fissure. The rock which has undergone the greater erosion may or may not be on the downthrown side.

That the steeper faces of some of the ranges may be erosionally modified and in part complex fault scarps is probable. The extent to which this may be true will be discussed below.

Over minor drainage lines the faults appear to have exercised no direct control, and the ravines do not as a rule coincide with lines of fissuring. Yet the faulting, by bringing into juxtaposition rocks of diverse behavior under erosion, has in an indirect and irregular way conditioned much of the topographic detail. The minute and unsystematic character of the fault dissection is reflected by a correspondingly irregular and intricate topography. The diabase and the granitic rocks are on the whole more readily eroded than the sedimentary rocks, and had the faulting been of such a character as to bring to the surface long belts of these rocks, the drainage would undoubtedly have shown some tendency to conform to their distribution. The existing fault pattern, however, is too patchy, too lacking in linear elements, and too much like a gigantic terrazzo pavement to influence appreciably or persistently the direction of stream erosion. Beyond the fact that a majority of the fault outcrops cross prominent ridges in swales or saddles, topography alone gives little clue to the course of a fault.

Cause of the faulting.—Whatever the causes that led to the extraordinary faulting of the Globe-Ray region, they were probably not local and are not likely to be clearly understood until our knowledge of the geology of Arizona is much more comprehensive and accurate than at present. The outstanding fact is the contrast between the broad, monotonous structural features of the Arizona Plateau and the jumble of jostled fault blocks in the country here described along its southwest border. The faulting is unquestionably connected with the forces and movements that differentiated the Colorado Plateaus province from the Basin and Range province,[57] and the question of its

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[53] Geol. Soc. America Bull., vol. 24, pp. 163–186, 1913.

[54] U. S. Geol. Survey Prof. Paper 12, pp. 97–98, 1903.

[55] Ransome, F. L., Geology at Globe, Ariz.: Min. and Sci. Press, vol. 100, p. 257, 1910.

[56] Not the same as Hackberry Wash or Hackberry Spring, south of Kelvin.

[57] Preliminary map of the physiographic divisions of the United States: Assoc. Am. Geographers Annals, vol. 6, pl. 1, 1917.

origin is a broad regional problem. Faulting of the kind described appears to be the result of collapse—of a widespread inability of the deeper rocks of the earth's crust to support their load. As a whole, however, the mountain region of Arizona does not appear to have subsided generally with respect to the plateau. Had it done so its ranges might be expected to contain a large proportion of rocks younger than those exposed in the plateau scarp, and conditions would resemble somewhat those near El Paso, Tex., where, from the precipitous Franklin Mountains, composed of Paleozoic and pre-Cambrian rocks, the eye may range for hundreds of miles into Mexico, where the only rocks visible are Mesozoic or younger. On the contrary, the rocks making up the ranges of the Arizona region, exclusive of Mesozoic and Tertiary igneous rocks, are to a large extent older than those exposed in the bounding cliffs of the plateau. North of Payson and about 75 miles north-northwest of Miami, for example, the plateau surface is formed on the Coconino sandstone and has an elevation, near the brink, of about 8,000 feet. The Pinal Range attains nearly as great an elevation, but its crest is composed of pre-Cambrian rocks. In the Pinal Range the pre-Cambrian rocks therefore appear to have been elevated with respect to the same rocks in the plateau. Of course, 75 miles is a long distance, even in Arizona, and it might not be safe to base a conclusion on this one comparison. The inference is in accord, however, with what has been observed elsewhere and at places much nearer the plateau edge, as in the Mazatzal Range and in the Sierra Ancha. In fact, the general impression gained from fairly extensive reconnaissance trips in this part of Arizona is that the pre-Cambrian rocks in the range region stand on the whole rather higher than in the plateau and in places are much higher. If this impression is correct, then it follows that the structural collapse of the range region must have been preceded by an uplift in which the fundamental crystalline rocks were raised above the general level of the corresponding rocks under the plateau.

Notwithstanding the irregular character of the diabase intrusion, the prevalence of the sill form and the general parallelism of intrusive diabase sheets in pre-Cambrian granite with those in the overlying Paleozoic sedimentary rocks are approaches to regularity that would hardly be expected if the rocks at the time of intrusion were greatly faulted and if the sedimentary beds had their present dip. Along the northeastern base of the Mescal Range, for example, there is a fairly regular sheet of diabase in pre-Cambrian granite. This sheet dips southwest at about 20°, or approximately at the same angle as the dip of the stratified rocks on El Capitan. If these beds were nearly horizontal when the diabase magma was injected, conditions of equal load might have caused the diabase in the granite to follow in places an approximately horizontal plane of intrusion. If, on the other hand, the beds were then inclined 20° it is difficult to see what conditions could have induced the diabase to cut the structureless granite at so nearly the same angle. There appears to be a suggestion here that at the time the diabase was intruded the beds of the Ray quadrangle were nearly horizontal and the region itself was structurally a part of what is now the plateau.

Presumably the extensive faulting that followed the eruption of the dacite in Tertiary time was coincident with part of the structural separation between the plateau and the range regions. Whether it initiated this differentiation or merely accentuated a distinction that had already appeared is not known.

THE MOUNTAIN RANGES.

Area discussed.—In the following discussion of the structure of the mountain ranges no attempt has been made to confine the attention strictly to the Ray quadrangle. The structure of that area can best be understood by considering it in relation to structural features of the Globe quadrangle and of the immediately adjacent region.

Apache Mountains.—About 4 miles northeast of the Globe quadrangle are the Apache Mountains. These have the usual northwesterly trend of the ranges of the region, and their line is continued northwest of Salt River by the Sierra Ancha. Both ranges are structurally homoclines, with dip to the northeast, and are composed chiefly of Cambrian rocks with intrusive sheets of diabase and diorite porphyry. Between the Apache Mountains and Globe are the relatively low Globe Hills, which consist of Paleozoic and pre-Cambrian rocks ranging from coarse Archean granite at the base to the Tornado limestone at the top. The sedimentary rocks have been invaded by a huge irregular sill of diabase, and all the rocks, including some overlying dacite, have been displaced by numerous faults.

Pinal Range.—The Pinal Range, southwest of the Globe Hills and separated from them by the area of Gila conglomerate traversed by Pinal Creek, is divisible into three portions that, superficially at least, present different tectonic features. The high middle portion of the range and some of the lower ground to the northwest consist of the Pinal schist intricately intruded by the Madera diorite (quartz-mica diorite) and other granitic rocks. The quartz diorite in some localities is crowded with inclusions of schist, and the schist in places is cut by countless small offshoots from the main intrusive mass. This pre-Cambrian complex, within the area over which it is now exposed, together with the younger intrusive masses of Schultze granite, Willow Spring granite, and Lost Gulch monzonite, appears to have behaved substantially as a unit in the post-Cambrian movements to which the region has been subjected. North of this division is a part of the range that is elaborately dissected by faults, so that rocks of very different ages, from pre-Cambrian granite to Tertiary dacite, are brought into juxtaposition in different blocks. The result is a fine-textured fault mosaic such as is very characteristic of the region and is especially well illustrated in the Dripping Spring Range, presently to be described.

Overlapping the middle massive section of the Pinal Range on the southwest and extending southeastward toward Gila River is the third division, sometimes distinguished by a separate name—the Mescal Range. This range, as may readily be seen from the geologic cross sections, is a homocline with southwesterly dip of 20° to 25°. The rocks involved range from pre-Cambrian granitic rocks exposed along the northeastern base of the mountains to the Tornado limestone lapping up on their southwestern slope. Into these rocks, especially into the quartzites, shale, and limestone of the Apache group, has been intruded in intricate fashion a branching sheet of diabase, within which are included many isolated blocks of the invaded strata.

El Capitan, the culminating summit of the Mescal Range in the Ray quadrangle, presents to the northeast a bold scarplike face, in which the edges of the southwestward-dipping beds are exposed. Part of the lowland which this peak overlooks to the north is occupied by some of the same rocks of which the main ridge of the Mescal Range is composed, and, like the beds in that ridge, these also dip to the southwest. On the northwest they are faulted down against the schist and Madera diorite of the main Pinal mass. In all probability another fault, concealed by the Gila conglomerate, bounds them on the southwest and accounts for their present position with reference to the strata of El Capitan.

The second and third divisions of the Pinal Range may be considered broadly as a single structural unit, a homoclinal block.

Dripping Spring Range.—Southwest of the Pinal and Mescal ranges and separated from them by Dripping Spring or Disappointment Valley is the Dripping Spring Range. This range is a remarkable example of a fault mosaic. The fault fissures intersect in all directions and form an intricate network. Although in some parts of the range it is possible to recognize the predominance of faults trending in some one general direction, the fault net as a whole does not appear to be susceptible of analysis into groups of fissures classified on the basis of direction or age.

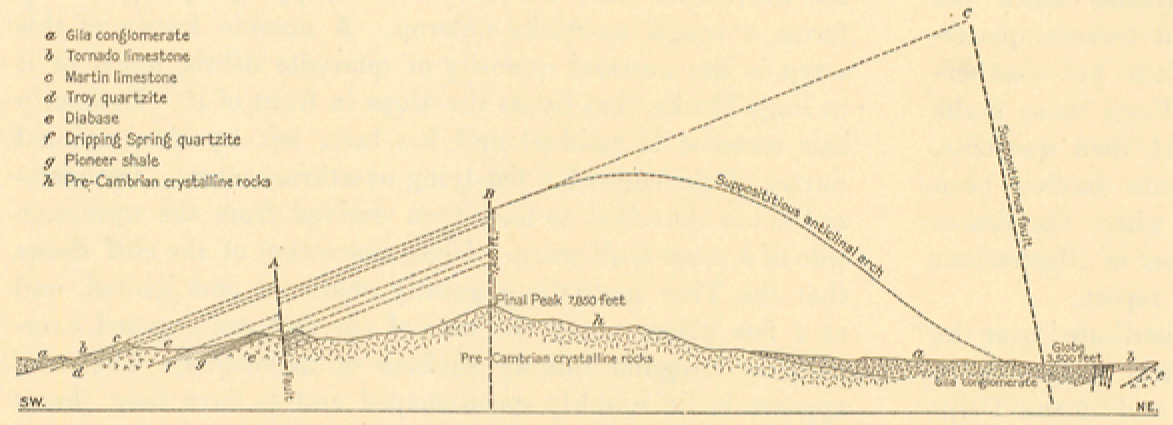

FIGURE 6.—Diagrammatic section illustrating the structure of the Pinal Range. Horizontal and vertical scales, 1 inch=15,000 feet.

In consequence of the generally excellent exposures and the readiness with which, as a rule, the different formations may be recognized by one familiar with their lithology, the major faults are not difficult to detect and can generally be traced for considerable distances, usually to the point where the dislocating fissure passes into rocks of one kind, meets another fault, or disappears beneath the Gila conglomerate.

The part of the range lying east of the nearly north-south zone of faulting that passes just east of Tam o' Shanter Peak shows a general progression from younger rocks in the south to older rocks in the north. In other words, if the irregularities due to minor faulting be disregarded, this part of the range is a homoclinal block with a general dip to the south. A similar progression and structure is shown by the section of the range lying between the Tam o' Shanter Peak fault zone and the zone extending northward past Steamboat Mountain to the Dripping Spring ranch. At the south end of this shattered block is the Cretaceous andesite overlapping the Carboniferous limestone; at the north end is the Cambrian Pioneer shale.

Between the fault zone last mentioned and the strong north-south fault that passes half a mile west of Troy Mountain is the section of the range that contains the intrusive granodiorite mass of Troy. This section shows some tendency toward the same southward-dipping homoclinal structure, but the irregularity of the minor faulting and doubtless also the structural effects of the granodiorite intrusion almost completely mask this suggestion of uniformity.

From Hackberry Gulch, 2 miles southwest of Troy, two conspicuous faults diverge northward. One is the fault already referred to as passing half a mile west of Troy Mountain. The other runs northwestward, passing about three-quarters of a mile east of Ray. Between these faults and stretching beyond their known extent to the north is a section of the range that shows the same stratigraphic descent from the Tornado limestone at its southern tip to the Pinal schist and Pioneer shale on the north. North of Scott Mountain, however, the intrusion of diabase and the numerous minor faults have introduced much structural irregularity.

West of the block just described is a comparatively small section of the range in the vicinity of Ray which has been uplifted relatively to the block east of it 800 to 900 feet.

About 4 miles north of Ray a north-northeast fault drops the dacite on the northwest against the older rocks on the southeast.

If a simple homoclinal range, tilted like the Mescal Range, to the southwest, were cut into sections by north-south faults, each section being displaced so as to be from 500 to 1,000 feet lower than its neighbor to the southeast, and if, further, each section were cut by numerous minor faults into a correspondingly numerous set of small blocks which underwent considerable jostling and movement before they came to rest, the resulting structure would be approximately that of the Dripping Spring Range. Whether the movements took place in the order just given is not known and perhaps can never be ascertained.

Tortilla Range.—That part of the Tortilla Range within the Ray quadrangle presents a rather striking difference in structure from the ranges just described. It is in the main a ridge of pre-Cambrian granite cut by various intrusive rocks. At its north end near Ray, where it coalesces with the Dripping Spring Range, it is composed largely of Pinal schist. In the southern part of the Ray quadrangle the granite is flanked on the east by the same Paleozoic beds that are found in the Dripping Spring and Mescal ranges, but in the Tortilla Range these beds have dips of 80° to 90° and consequently appear on the geologic map as inconspicuous narrow bands. These steeply upturned beds are considerably faulted, and at least a part of the faulting appears to have taken place after the deposition of the Gila conglomerate. The conglomerate itself is sharply upturned along the mountain flank, with dips as high as 60°.

EVIDENCE THAT THE VALLEYS ARE TECTONIC.

In the Pinal Range the strata on the southwest side of the main pre-Cambrian mass dip regularly to the southwest at 20° to 25°. When these strata are projected upward, as indicated in the accompanying diagram (Fig. 6), at the same general dip, with allowance for a fault or intrusion displacement at A, it will be seen that the base of the Pioneer shale, if extended to B, would be about 3,400 feet above the summit of Pinal Peak and the base of the Tornado limestone would be about 7,400 feet above the same summit. In terms of elevation above sea level the base of the Cambrian would stand at 11,250 feet, where the Pinal Range stands now. About 10 miles north-northeast of Pinal Peak and just northeast of the town of Globe, in the Globe Hills, these same Paleozoic rocks appear at altitudes of less than 5,000 feet. Without question these beds were once continuous with those that overlap the southwest flank of the Pinal Range.

Two hypotheses readily suggest themselves in explanation of the present relation of the beds on the opposite sides of the range. It may be supposed that they swept over the crystalline rocks in a great arch, as indicated in Figure 6; or it may be supposed that they continued upward, past the present crest of the range, at approximately the same dip of 20° to 25°, and that on the northeast they were cut off and dropped by a profound fault, a supposition also illustrated diagrammatically in Figure 6. In either case, if the full movement indicated, either of folding or of faulting, took place at one time, before erosion could make much impression on the uplift, a range of enormous height must have resulted. In all probability, however, the range never had any such altitude as the diagram shows but was worn down by erosion during a long period of slow uplift.

There is nothing inherently improbable in the explanation of the present relations by former folding, but this hypothesis has to be considered with reference to other tectonic features of the region. Wherever the structure is exposed to view one of the most notable of such features, as has already been shown, is the practical absence of folding and the extraordinary abundance of faults. On all sides of the main Pinal mass of crystalline rocks faults abound and folds are absent. If the Pinal Range in the southern part of the Globe quadrangle represents an eroded anticline, the southern limb of which is shown at the right end of section A–A′ on the structure-section sheet, then it is a remarkable exception to the general structure of the region. It might be urged that the intricate faulting so characteristic of the Globe and Ray quadrangles is the result of the collapse of just such folds as the one here suggested. If so, the uncovered crystalline rocks of the Pinal Range should show a multitude of intersecting fault fissures, whereas in fact they appear to be unusually free from them.

The second hypothesis, that the present structural relation between the beds on opposite sides of the Pinal Range is the result of faulting, appears to be more in accord with what is known of the general structure, not only of the Globe-Ray region but of a more extensive area of which the two quadrangles mentioned are merely a part. It may well be doubted, however, whether the displacement was effected by a single great fault such as is indicated in the diagram of Figure 6. In all probability an area of complex faulting underlies the Gila conglomerate of the valley adjacent to Globe, and the great total displacement, a throw of over 5 miles, was accomplished by slipping along many fractures distributed over a considerable period of time during which erosion actively attacked the mass on the upthrown side of the fault zone.

Similar reasoning applies also to the relation between the beds in the Mescal Range and the continuations of these same beds in the Dripping Spring Range. The southwest versant of the Mescal Range is virtually a dip slope, the Tornado limestone disappearing under the Gila conglomerate with a dip of about 20°. If Dripping Spring Valley were a synclinal trough the Dripping Spring Range should be an anticlinal ridge. The range does not have that character but, as has been shown on page 16, is a much faulted homocline in which the rocks, if they were not so thoroughly faulted, would have a similar attitude to those in the Mescal homocline.

The part of the Tortilla Range within the Ray quadrangle is composed chiefly of pre-Cambrian granite, and there is little to indicate the structural relation of this mass to the adjacent valleys. The nearly vertical attitude of the Paleozoic beds in the southwest corner of the quadrangle, the known presence of considerable faults in the same locality, and the steep upturning of the Gila conglomerate along the eastern flanks of the ridges, are all suggestive of faulting rather than folding as the kind of deformation that brought the range into existence.

In order to establish the truth of the statement that the mountain ranges and principal valleys are tectonic features it is necessary, of course, to prove not only that the mountains owe their structural features mainly to faulting but that the general effect of dislocation has been the elevation of the mountain tracts relatively to the valley tracts. This to some extent has been shown to be probably true for the Pinal Range. There remains for consideration, however, the question, How far can the valleys be accounted for by erosion on the supposition that they are not due to deformation? In other words, Can the tectonic hypothesis be established by the elimination of its only alternative?

If after the region was affected by the last general deformation the land in the areas now corresponding to the valleys were as high as or higher than the land in the areas now corresponding to the mountains and if the valleys had been cut out by erosion, then obviously the valleys should show an intimate and characteristic relation either to the present drainage plan or to some older drainage plan. It is not enough that they should be occupied by streams or by intermittent watercourses. That would follow, no matter what the origin of the valleys. But, with all due regard for differences in the resistance of various rocks to erosion, the valleys, if they were the work of running water, should be roughly proportional in size to the occupying streams and should show the adjustment of shape, width, and depth to the different sections of the stream that is characteristic of a fluvial valley. To pursue this branch of inquiry thoroughly would require the study of a much larger area than that now under consideration, but observation, so far as it has gone, shows that the streams or arroyos are not in close adjustment to the valleys. The Gila, for example, as shown on page 2, breaks across the ranges from one valley to another. Its present course must have been determined when the valleys not only were in existence but were more deeply filled with detritus than they are now. The valley in which stands the town of Globe appears much too large to be the work of Pinal Creek and its tributaries and has not the shape that might be expected were it of erosional origin. Dripping Spring Valley also appears too large for the intermittent streams by which it is drained.

The valleys are now occupied by the Gila conglomerate and must therefore have been formed before the conglomerate was deposited. This conclusion, on the supposition that the valleys are erosional features, would require a period of intense denudation in pre-Gila time, during which not only were the valleys excavated but the neighboring mountains were correspondingly worn down. Moreover, the detritus resulting from all this erosion must have been swept completely out of the region, for clearly the excavation of the valleys and the accumulation within them of a vast deposit of gravelly and silty detritus could not go on simultaneously. This removal could have been effected only by a drainage system entirely different from that now existing and under climatic conditions totally unlike those that now prevail. The erosional hypothesis is confronted, moveover, with the difficulty of explaining why, after all this erosion, the process of valley filling should have been begun and so energetically prosecuted and how detritus, so abundant and in part so coarse, could have been supplied from mountains worn down almost to their present heights.

On the other hand, if the valleys are essentially structural features their subsequent history is readily interpreted. Whether the faulting that differentiated mountains from valleys was sudden or took place by successive small slips, the result must have been a pronounced steepening of stream grade, an abundant supply of débris from the uplifted fault blocks, and consequently a rapid accumulation of detritus in the valleys. These valleys, being tectonic, would have no regular gradient from head to outlet but would in all probability be closed basins in which the sediment-laden storm waters from the mountains would evaporate, or, possibly, in some places, form a lake having an outlet over some low pass in the valley rim. Under such circumstances the Gila formation may have accumulated under climatic conditions very little different from those of to-day.

GEOLOGIC HISTORY.[58]

Long before Cambrian time the Globe-Ray region was part of a sea bottom upon which were accumulating fine grits and silts, probably derived from granitic rocks. The source of these sediments is unknown, and no trace of the ancient rocky floor upon which they were laid down is now visible. In the course of time sedimentation ceased, and the beds were folded and compressed by forces acting in a generally northwest-southeast direction; were intruded by great masses of quartz-mica diorite (the Madera diorite); and underwent crystalline metamorphism into the Pinal schist. Later intrusions of granitic rocks followed, and at the end of this period of plutonic eruptive activity the region had risen above the sea and become mountainous. A new physiographic cycle was thus initiated, but it was probably well under way before the constructive processes that have just been outlined were concluded. Before the rocks attained their final elevation erosion was vigorously at work, and upon becoming ascendant it began the actual reduction of the mountainous topography, which it carried successively through the various intermediate stages of the geographic cycle to the final one of the nearly featureless worn-down plain of old age—a peneplain.

So much, in brief, of pre-Cambrian history is decipherable from the character, structure, and texture of the older rocks. The cycle was run, and the beginning of Cambrian time was marked by subsidence and a fresh advance of the sea over what had so long been dry land. The sea as it swept over the land found it littered in part with fragments of quartz weathered out from veins in the schists and granitic rocks, and with smaller particles of feldspar and quartz derived from the disintegration of the granitic masses. The existence of particles of feldspar that have remained fairly fresh to the present time appears to afford some indication that the Cambrian climate was not conducive to soil formation or to abundant vegetation. These materials were slightly reworked by the waves into the Scanlan conglomerate, the remnants of which are now usually found resting upon the weathered and reddened surface of the Madera diorite and the granites, here and there separated from the sound rock by several feet of pre-Cambrian granitic saprolite (disintegrated rock in place). The Scanlan conglomerate, or its equivalent, covered the Pinal schist as well as the plutonic rocks. It appears that the region was submerged too rapidly to permit any considerable rounding of the pebbles by wave action or much transportation of material by littoral currents—processes both of which are favored by stability of shore line. The lack of such evidence of long-continued shore action shows that the floor upon which the Cambrian sediments were deposited was in the main due to subaerial erosion and not to marine planation.

Either there were valleys in the old peneplain as much as 200 feet in depth or the region subsided unevenly to an equal extent, for in the Apache Mountains, northeast of Globe, the interval between the pre-Cambrian peneplain and the base of the Pioneer shale, elsewhere occupied by 1 to 6 feet of Scanlan conglomerate, is filled by about 200 feet of hard and varyingly arkosic quartzite.

The Pioneer shale, overlying the Scanlan conglomerate and the lower quartzites of the Apache Mountains, records the accumulation of sandy silt in shallow water. The material of these sediments was in part feldspathic and probably derived from an adjacent land mass, composed largely of granitoid rocks similar to those occurring in the Pinal Mountains. Although there is no direct proof that the rocks of these mountains themselves were reduced to the general level of the peneplain and covered by the Cambrian sediments, yet it seems most probable that they were and that their present elevation and the stripping of their Paleozoic cover are due to later movements and to erosion. It is not likely that there existed any such sharp and local exception to the general unevenness of what must have been at one time an extensive peneplain.

The deposition of the Pioneer shale was followed by that of the Barnes conglomerate. The origin of this conglomerate, which, with its well-rounded pebbles, mostly quartzite, contrasts so strikingly with the reddish sandy shale beneath it, is a puzzling problem. Without any apparent unconformity, the fine silt deposited in quiet waters was succeeded by coarse material that must have been laid down under very different conditions of erosion and deposition. Such coarse material implies the action of strong currents and perhaps of waves, and it is difficult to understand how in these circumstances the underlying silt could have escaped considerable erosion. The pebbles of the conglomerate appear to have come in part from pre-Cambrian quartzites now exposed in the Sierra Ancha and Mazatzal Range, to the north of the region here described. The matrix, however, shows abundant feldspathic detritus, such as might have been supplied by a near-by unsubmerged area of the same pre-Cambrian granitic rocks as are now exposed in the Globe-Ray region. On the whole, the evidence, though far from conclusive, suggests that the Barnes conglomerate is a delta deposit, the work of streams rather than of waves.

Succeeding the deposition of the Barnes conglomerate came the accumulation of quartzose sands now represented by the Dripping Spring quartzite. The thin, somewhat shaly beds near the top of this formation show fossil worm casts or filled borings, ripple marks, and sun cracks. The quartzite was thus, at least in part, laid down in shallow water, and the sandy mud was at times exposed to the air and sun. It also is tentatively regarded as a delta deposit.

The thin-bedded impure dolomitic Mescal limestone, which overlies the Dripping Spring quartzite, marks a decided change in sedimentation. No fossils have been found in this limestone, but it probably is marine and was laid down in shallow water.

The next event in Cambrian time was the eruption of a flow of basalt. Although this flow has nowhere been observed to be much over 100 feet thick, it once covered an area of at least 500 square miles. Whether it spread over a sea bottom or was erupted on land is not known, but the extent and regularity of the flow, taken in connection with its relation to the beds below it, show that the surface covered by it had undergone little if any erosion.

After the eruption of the basalt, which has a vesicular upper surface, the sandy and pebbly sediments now consolidated as the Troy quartzite began to accumulate. The abundant layers of pebbles and the conspicuous cross-bedding of this quartzite are suggestive of a return, during its deposition, to deltaic conditions. The upper beds, however, show lithologic gradation into the Martin limestone, which is considered to be Devonian and is unquestionably marine, as shown by its fossils.

Up to the beginning of the deposition of the Martin limestone the Paleozoic era had been marked by the preponderance of siliceous sediments indicative on the whole of shallow water or alternating land and water. From that point on marine conditions, with apparently increasing depth of water, prevailed.

The geologic record of the region studied is silent as regards Ordovician and Silurian time. No strata of these ages have been recognized, nor, on the other hand, has any unconformity been certainly dectected between the supposed Cambrian and the known Devonian, to account for their apparent absence.

Walcott[59] long ago called attention to the existence of an unconformity between the Devonian beds and the Redwall limestone on Kanab Creek. The same writer[60] also recognized an unconformity between the Cambrian and Devonian beds in the Grand Canyon. It is possible that in spite of the apparently unbroken sequence of beds from the base of the Cambrian to the Devonian there may be an undetected unconformity in the Globe-Ray region. Another possibility is suggested by the fact that approximately the lower half of the Martin limestone and all of the supposed Cambrian are unfossiliferous. Consequently some part of these unfossiliferous beds may prove to be Ordovician or Silurian. In the absence of any paleontologic evidence it has seemed better to adopt the provisional classification employed in this report than to make an arbitrary assignment of certain portions of the stratigraphic series to the two geologic periods that apparently lack representation.

On the assumption that the beginning of deposition of the Martin limestone marked the beginning of Devonian time, the lower beds, consisting in part of calcareous grits, show a pas-

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[58] In the preparation of this section the Globe report (U. S. Geol. Survey Prof. Paper 12) has been freely drawn upon, much of the material being reproduced verbatim. It is believed that the reader will prefer to have the geologic narrative as complete as possible in this place and that there is no gain in attempting to rephrase those portions of the older report in which no changes are demanded by later observations.

[59] Walcott, C. D., The Permian and other groups of the Kanab Valley. Ariz : Am. Jour. Sci., 3d ser. vol. 20, pp. 221-225, 1880.

[60] Walcott, C. D., Pre-Carboniferous strata in the Grand Canyon of the Colorado, Ariz.: Am. Jour. Sci., 3d ser., vol. 26, p. 438, 1883.

sage from shallow water in which terrigenous sediments could accumulate to deeper water in which limestone was deposited.

From Devonian time well into the upper Carboniferous (Pennsylvanian) the region was covered by a sea abounding in animal life and depositing abundant limestone. No unconformity has been found in the Tornado limestone, which carries Mississippian and Pennsylvanian fossils. From time to time during the accumulation of the limestone there were slight incursions of land-derived sediment, and on parts of the sea floor layers of siliceous conglomerates were intercalated in the limestone series. The mass of these layers is unimportant, but they are significant in showing that this part of the Carboniferous sea was probably neither very deep nor far distant from a land mass.

The Pennsylvanian limestone is the latest Paleozoic deposit of which the region preserves any record. If marine conditions continued into the Permian the deposits of that period must have been wholly removed before the strata were broken up and invaded by diabase. Had Permian beds been involved in that structural revolution, some remnants of them would probably have been preserved in the resulting intricate lithologic mosaic.

There are no available means of determining whether or not the region became land and was eroded before the intrusion of the diabase. We know only that the intrusion with its associated faulting occurred after the accumulation of the Tornado limestone and has left unmistakable record of its structural importance. The region was presumably elevated above sea level at the end of the Carboniferous and subjected to erosion. It was extensively dissected, probably in Mesozoic time, by numerous faults, which appear to have been normal in character, to have been usually of moderate throw, and to have had generally northwest and northeast trends. There is ground for supposing that the crystalline massif of the Pinal Mountains escaped much of the intensity of this faulting, as it did that of a later period. The dislocations were followed or accompanied by the intrusion of an enormous quantity of molten diabase magma into the rocks of the region, particularly into those most cut by the faults. If present exposures can be taken as generally indicative of the original proportions, it appears that the intrusive rock fully equaled if it did not considerably exceed in volume the stratified rocks. As the latter were not fused at any point now exposed to observation, it is concluded that room for this great addition of material was effected by mechanical displacement. The dominant form taken by the diabase was that of the intrusive sheet or sill, and had the region been free from faults these sills would probably have been fairly regular, resembling those occurring in the less faulted portions of the general region, such, for example, as those which are well exposed in the canyon of Salt River just below its junction with Tonto Creek or in the Sierra Ancha. As it was, however, the diabase not only forced its way between the beds as sills of varying thickness but found in the faulted rocks the most favorable opportunity for expansion. It occupied the fault fissures and shoved the detached masses of ruptured strata bodily aside, separating them so that they became in many places mere inclusions in a great mass of eruptive rock. All the observed phenomena connected with the faulting and intrusion, as well as the more general geologic considerations outlined in preceding pages, indicate that these events took place comparatively near the surface. The contact metamorphism effected by the diabase is generally slight, and aphanitic facies of the intrusive rock are common near original contacts. The manner in which the blocks of strata were displaced indicates that they were under no great load, and the large increase of volume resulting from the intrusion of the diabase must have produced considerable actual elevation of the surface over the Globe-Ray region. It would seem that when deformation and intrusion were so actively in progress at so slight a depth at least some of the magma must have found its way to the surface and been erupted as basalt. Any such manifestation of volcanic activity as may have existed has, however, since been removed by erosion.

After the intrusion of the diabase the region, having probably gained in elevation, was eroded. As pointed out on page 11 it is not yet determined whether the andesitic volcanic outbursts which have left their products in the southeastern part of the Ray quadrangle and in the region south of Gila River preceded or followed the intrusion of the diabase. The andesitic rocks are associated with coal-bearing late Cretaceous or early Tertiary beds and are believed to be younger than the diabase. This part of the geologic history is still obscure, and much more light will probably be thrown on it when detailed studies are made of the region south and east of that covered by the Globe and Ray quadrangles. It is not unlikely that during late Mesozoic and early Tertiary time the region here described underwent many unrecorded vicissitudes and may have been covered by volcanic rocks and sediments that were afterward stripped away. To this obscure time, following the andesitic eruption, apparently belongs the irruption of the quartz diorite, the Schultze granite of the Globe quadrangle, the granodiorite at Troy, the quartz monzonite porphyry of the Ray district, and the related granitic monzonite and dioritic porphyries of the region. The intrusion of these rocks was probably accompanied and followed by faulting and was the immediate cause of ore deposition.

With the cessation of igneous intrusion, at a time which can not be definitely fixed from present information but which is provisionally considered as coinciding with the earlier or middle part of the Tertiary, the region, characterized by a diversified topography, was apparently dry land and undergoing erosion. Although the surface was probably less rugged, the general conditions as regards climate and erosional activity appear to have been not greatly different from those of the present day. As shown by the accumulation of the Whitetail formation, coarse, rather angular detritus was washed down the slopes and deposited in the more open valleys and gulches. It was during this period of erosion and accumulation of waste that most of the enrichment of the Ray and Miami copper deposits is believed to have taken place.

Over this uneven surface, with its hollows partly filled with the Whitetail conglomerate, was poured, probably in early or middle Tertiary time, an extensive flow of dacite. The greater part of the region here described appears to have been covered by this lava, which issued from a vent or vents as yet undiscovered. As the Whitetail formation in places shows rude stratification and the massive dacite in some localities is underlain by beds of dacite tuff, it is probable that the region contained transient bodies of water, probably in consequence of the disturbance of the drainage by faulting before and during the volcanic activity.

Following closely after the dacite eruption, and possibly as a consequence of it, came the great faulting to which are chiefly due the present structure and less directly the topography of the region. The character of this faulting has been described on page 15. By it much of the country, especially the Dripping Spring Range, was shattered to an extent very imperfectly represented by the great number of small fault blocks outlined on the geologic map of the Ray quadrangle.

In the absence of any satisfactory evidence for connecting with the recognized geologic epochs the events which took place in this district after the Carboniferous period, the postdacitic faulting is rather arbitrarily considered as ending the Tertiary. The provisional nature of this and other post-Carboniferous correlations in this region should not be forgotten. They may be considerably modified when the present geologic work is supplemented and extended by the study of a broader area. The divisions recognized appear to be distinct chapters in the local physical history. They may not, however, be inserted at the correct places in the larger volume of the geologic story of the earth.

The Quaternary was begun by a vigorous erosion of the complex lithologic mosaic resulting from the superposition of the postdacitic shattering upon an earlier structure that was already complex. Great quantities of coarse, rocky detritus were washed down the slopes and deposited as the Gila conglomerate in valleys partly, at least, of structural origin. It has already been shown that the larger conglomerate-filled valleys probably owe their original depression to faulting.

The character of the Gila conglomerate indicates that the climatic conditions of the early Quaternary were not very unlike those of to-day. Prevailing aridity and dominance of mechanical disintegration over rock decay were prominent features, and the precipitation apparently occurred in violent downpours of short duration.

There has been at least one eruption of basalt during the Quaternary period, as shown by the flow intercalated in the Gila conglomerate, south of Gold Gulch, in the northwestern part of the Globe quadrangle, and by smaller masses in the western part of the same quadrangle. The basalt apparently issued from more than one small vent, and its present distribution is not entirely understood.

The early Quaternary erosion that supplied the materials for the Gila formation undoubtedly effected pronounced changes in the topography, but it usually is difficult or impossible to distinguish between such changes and those brought about in late Quaternary time.

More or less faulting has continued throughout the Quaternary, and these later dislocations have had a recognizable effect upon the structure, as shown by the shapes and distribution of the areas of Gila conglomerate.

In late Quaternary time erosion has been active over the whole region, reducing the mountains and dissecting the Gila conglomerate. In some parts of the region, as near Hutton Peak and Needle Mountain, this later degradation appears to have been exceptionally active and has left fragments of the Gila formation, originally a valley deposit, upon the summits of ridges and peaks. Within many areas of conglomerate, however, the present intermittent streams have merely effected an intricate dissection and sculpturing, without exposing the base of the formation save near its margins. This trenching was locally accompanied by the cutting of stream terraces, best seen in the Ray district and along Bloody Tanks Wash in the Globe quadrangle.

ECONOMIC GEOLOGY.

GENERAL CHARACTER OF RESOURCES.

The rough and generally rocky or stony surface of the Ray quadrangle, with its scanty desert vegetation, although utilizable in part for the grazing of cattle and the browsing of goats, offers little inducement to human occupancy or industry. The economic development of the area depends almost entirely upon its mineral resources, and of these copper is supreme. The Ray copper district, which is in the northwestern part of the quadrangle and extends in small part into the adjoining Florence quadrangle, on the west, contains one of the largest deposits of copper ore in Arizona. This ore is being mined on a large scale, and most of it is reduced to metal within the Ray quadrangle. Some copper ore is produced also near Troy and at and near the London-Arizona mine, in the Dripping Spring Range; and on the south side of the Gila, near Kelvin.

The area also contains ores that yield gold, silver, lead, zinc, and vanadium.

HISTORY OF MINING.

Apparently the first mines to be worked in the Ray quadrangle were those which yielded silver-gold ore near Pioneer, in the northeast corner of the quadrangle, and perhaps the Ripsey mine, in the southwest corner. The argentiferous ore of the El Capitan mine, south of Old Baldy, in the Mescal Range, was probably also worked in this early period, during the eighties. Very little definite information is now obtainable concerning these pioneer efforts in what was then a wild and remote region. The Republic mine, at Pioneer, had a mill and apparently was operated successfully for a number of years.

Some mining was done also about 1880 on Mineral Creek, near the site of the present town of Ray. At that time the Mineral Creek Mining Co. built a 5-stamp mill and did some work, presumably on the Mineral Creek claim, north of Copper Gulch. The subsequent history of mining development on the the ground now owned by the Ray Consolidated Copper Co., is given elsewhere.[61]

The Arizona Hercules Copper Co., whose ore-bearing ground is almost inclosed by the claims of the Ray Consolidated Copper Co. and contains the eastward extension of the Ray ore body, began exploration by drilling a little later than the Ray company. The existence of ore was soon ascertained, but it was not until 1916 that active steps were taken to mine it. In that year two shafts were sunk and levels were run preparatory to extensive mining. The shafts were completely equipped with first-class machinery and a coarse-crushing plant was built at the mine, railway connections were made, and at the settlement of Belgravia, 6 miles from the mine, near Kelvin, a 2,700-kilowatt power house and a 1,500-ton concentration mill were constructed in 1917 and 1918. Production of copper on a large scale began in 1918.

Active mining development at Troy began about the year 1900 by the Troy Copper Co., a Boston corporation organized under the laws of Maine and capitalized at $1,000,000. About the same time the Manhattan Copper Co., of New York, capitalized at $1,500,000, entered the field. The Troy company had about 30 claims lying chiefly in the western part of the Troy district and including the '91, Buckeye, Climax, and Alice. The Manhattan had about 15 claims, including the Rattler. Most of the development work appears to have been done between 1901 and 1903. In 1902 the two companies consolidated as the Troy-Manhattan Copper Co., capitalized under the laws of Maine at $3,000,000. A 60-ton smelter, at Riverside, on the Gila, had been completed early in 1901 and was operated intermittently until 1904. In the same period also considerable ore was shipped to El Paso. The Pratt tunnel, the deepest work in the district, was run from the west to undercut the workings of the Alice mine about 500 feet below the collar of the shaft. This tunnel, which is about 2,200 feet long, was a disappointment to its projectors, although the Rattler mine continued productive under a lessee company until about 1907. In that year the Troy-Manhattan Copper Co. transferred its property to the Troy Consolidated Mining Co., capitalized at $4,000,000, which in turn was succeeded by the Troy Arizona Copper Co., the present owners.

PRODUCTION.

The total production of metals in the Ray quadrangle can not be given, as no records of output prior to the extensive mining near Ray are available. The older yield, however, can not have been large.

The production of the Ray or Mineral Creek district from 1905 to the end of 1922 was 25,743,236 tons of ore, from which 9,296.37 ounces of gold, 758,316 ounces of silver, 619,223,035 pounds of copper, and 5,339,185 pounds of lead were saved. The output had a total value of $124,982,876, and most of it was produced by mining disseminated copper ores. The Ray Consolidated Copper Co. produced from April, 1911, to the end of 1922 ore and concentrate containing 620,087,080 pounds of copper.

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[61] U. S. Geol. Survey Prof. Paper 115, pp. 17–19, 1919.

COPPER DEPOSITS.

RAY DISTRICT.[62]

MINING COMPANIES AND CLAIM GROUPS.

By far the strongest and most active company in the Ray district and the one with the largest holdings is the Ray Consolidated Copper Co., which, after acquiring the property of the Gila Copper Co. in 1910, absorbed the Ray Central Copper Mining Co., leaving only the Arizona Hercules Copper Mining Co.[63] as an important outside factor in the development of the disseminated deposits.

The Ray Consolidated Copper Co. is organized under the laws of Maine with an authorized capital of $14,000,000 in shares of $10 par value. It controls also the Ray & Gila Valley Railroad Co., capitalized at $2,500,000.

The land holdings of the Ray Consolidated Copper Co. are large, embracing nearly 2,000 acres in the Ray district, considerable ground in the vicinity of Kelvin, and a tract of 3,750 acres in the vicinity of Hayden, where the concentrator and smelter are situated. (See Fig. 7.)

The Ray Hercules Mines (Inc.) is capitalized at $16,000,000, with shares of $15 par value. It owns about 207 acres of mining claims and a mill site; the most valuable part of the mining ground is inclosed by the claims of the Ray Consolidated Copper Co.

The Ray Hercules Mines (Inc.) was reported in 1921 to have developed nearly 4,000,000 tons of 2.42 per cent ore. The company has carried out extensive underground work and has equipped the mine for production on a large scale. At Belgravia, a settlement just north of Ray Junction and about 6 miles from the mine, there is a concentrating mill with a capacity of 1,800 tons a day. Production began in 1918.

UNDERGROUND DEVELOPMENT.

The general plan of development of the Ray Consolidated Copper Co.'s mines is indicated in Figure 8. This map, however, shows only the main haulage levels and therefore represents but a small part of the actual workings. These at the end of the year 1916 had a total length of about 107 miles, of which about 54 miles had been destroyed by stoping operations. The underground workings driven in 1916 amounted to 66,863 feet. There are three mines, known as No. 1, No. 2, and No. 3.

The plan of the ore body (Fig. 8) shows a marked constriction about 700 feet north of the Pearl Handle shaft, which practically divides the ore body into two parts. No. 1 and No. 3 mines are laid out to work the part of the ore body east and south of this constriction, and No. 2 mine the part west of it. The greater part of the southeast lobe of the ore body, including the ore in the western part of what was formerly the Ray Central ground, is being worked through the No. 1 mine.

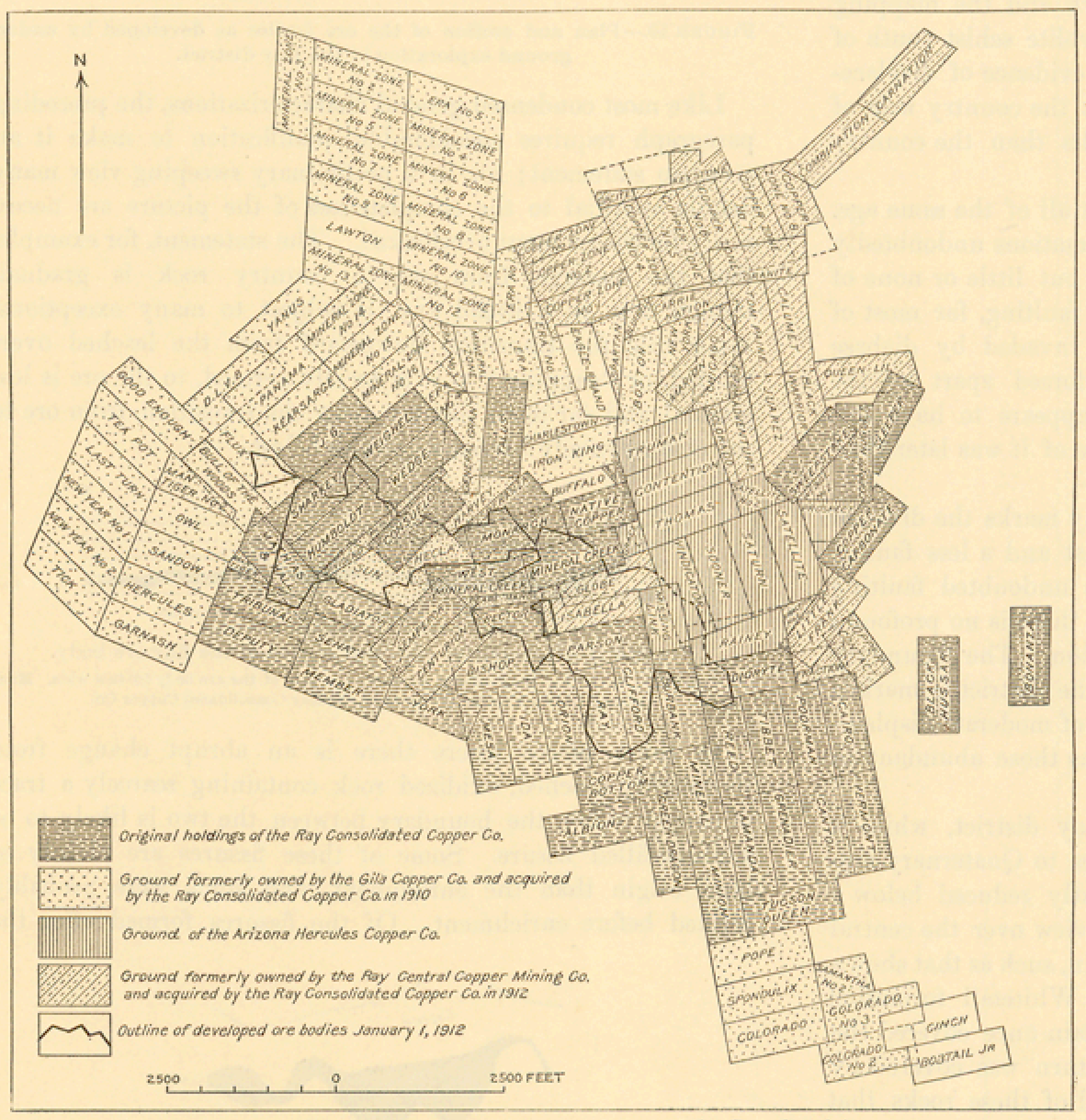

FIGURE 7.—Claim map of the central part of the Ray district.

The comparatively high-grade ore in the eastern part of the former Ray Central ground is worked through the No. 3 mine by methods different from those employed in the two other mines. Between the workings of the No. 1 and No. 3 mines a wall of ground about 100 feet thick is left standing as a precaution against any possible flooding of one mine from the other.

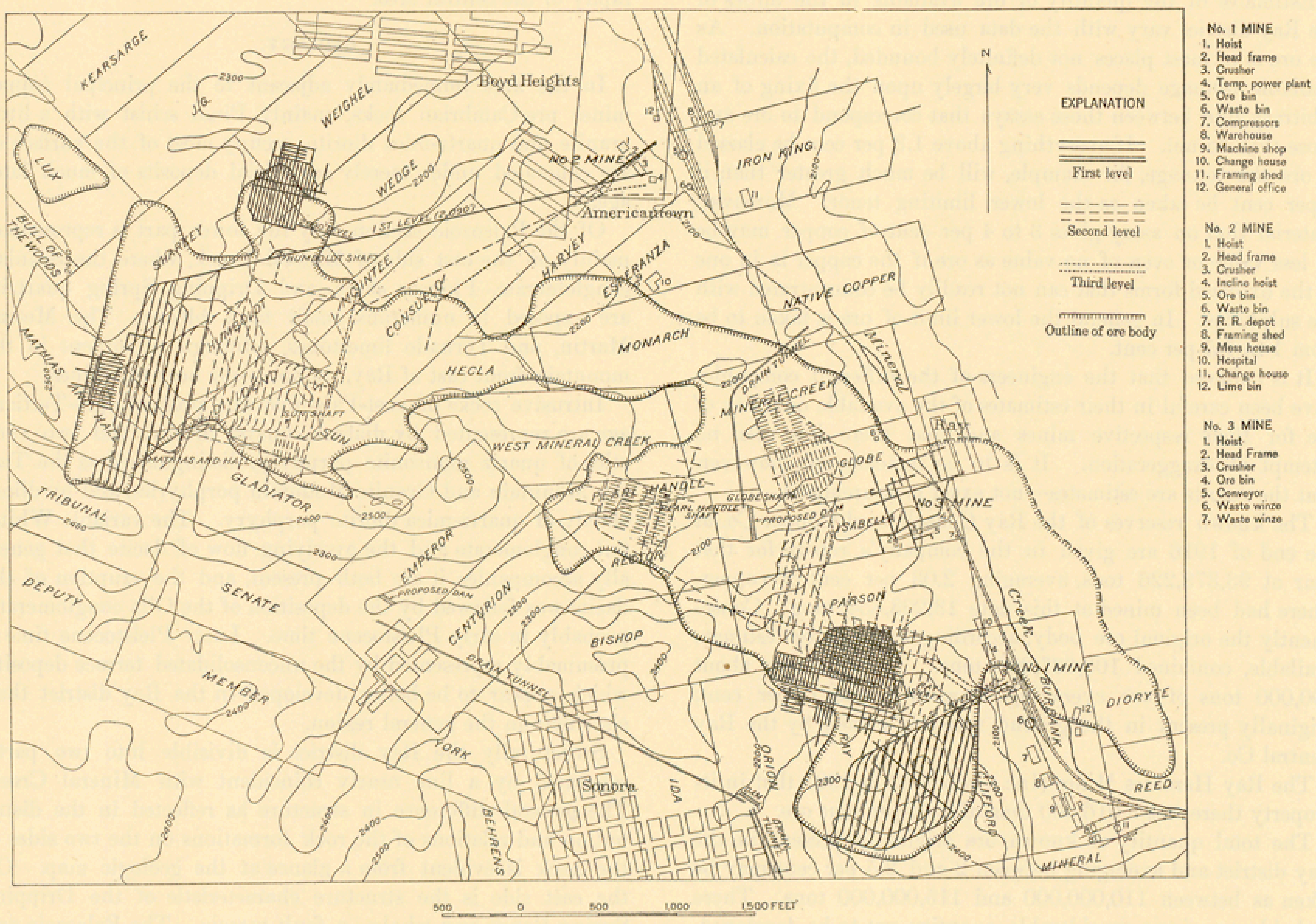

FIGURE 8.—Map showing general plan of development of the Ray Consolidated Copper Co.'s mines on January 1, 1917.

No. 1 shaft and adit are close to Mineral Creek, at the northeast base of Ray Hill. This shaft, 300 feet deep, is used solely for hoisting ore; it is equipped with 12½-ton skips, run in balance by an electric hoist at a speed of 300 feet a minute.

North and east of No. 1 mine is the No. 3 mine, which includes what was formerly the eastern part of the Ray Central mine.

The No. 2 vertical shaft and incline of the Ray Consolidated Copper Co. are three-fourths of a mile nearly northwest of the No. 1 shaft, on the west side of Mineral Creek, just south o the mouth of Sharkey Gulch, and are similar in size, arrangement, and equipment to those of the No. 1 mine.

STOPING.

The general system of stoping adopted in the No. 1 and No. 2 mines at Ray is that commonly known as the shrinkage-stope caving system and has been fully described by Blackner.[64]

Electric locomotives draw the ore in trains of 5-ton cars to the main shafts, where the cars are dumped in tipples. At the surface self-dumping skips deliver the ore to crushers and coarse rolls, from which it is conveyed into capacious steel bins, capable of holding about a week's supply. From these bins are loaded the regular ore trains of thirty-two 60-ton steel cars, for the concentrator at Hayden.

The No. 3 mine is worked by square-set stoping, this relatively expensive method, costing about four times as much as shrinkage stoping, being warranted by the character of the ore.

TREATMENT OF ORE.

At Hayden, 20 miles from Ray (see Fig. 9), the ore is concentrated in a mill designed in accordance with the practice at Garfield, Utah. There are eight sections, each with an originally designed capacity of 1,000 tons. The actual capacity of this mill in 1916, however, was 9,475 tons, and changes were in progress to increase the output still further. At first concentration was effected wholly by running water, but later a flotation section was added.

In addition to the ore milled the company shipped directly to the smelter ore containing the following quantities of copper:

Copper content of ore shipped from Ray directly to smelter, 1913–1922.

	Pounds.		Pounds.
1913	412, 372	1919	724, 429
1914	1, 023, 745	1920	492, 081
1915	1, 425, 682	1921	144, 339
1916	2, 673, 798	1922	432, 419
1917	5, 409, 770		
1918	4, 473, 560		17, 212, 195

The concentrates as a rule contain from 18 to 23 per cent of copper.

Alongside of the concentrator is a smelter built and owned by the American Smelting & Refining Co. on ground leased from the Ray Consolidated Copper Co. This has been described by Vail.[65] It was completed in May, 1912, and has treated all the concentrates from the Ray mill. Since July, 1913, it has smelted also concentrates from other mills.

At Hayden also is a power plant, capable of developing 15,000 kilowatts, which, in addition to operating the concentrator and smelter, supplies the mines at Ray.

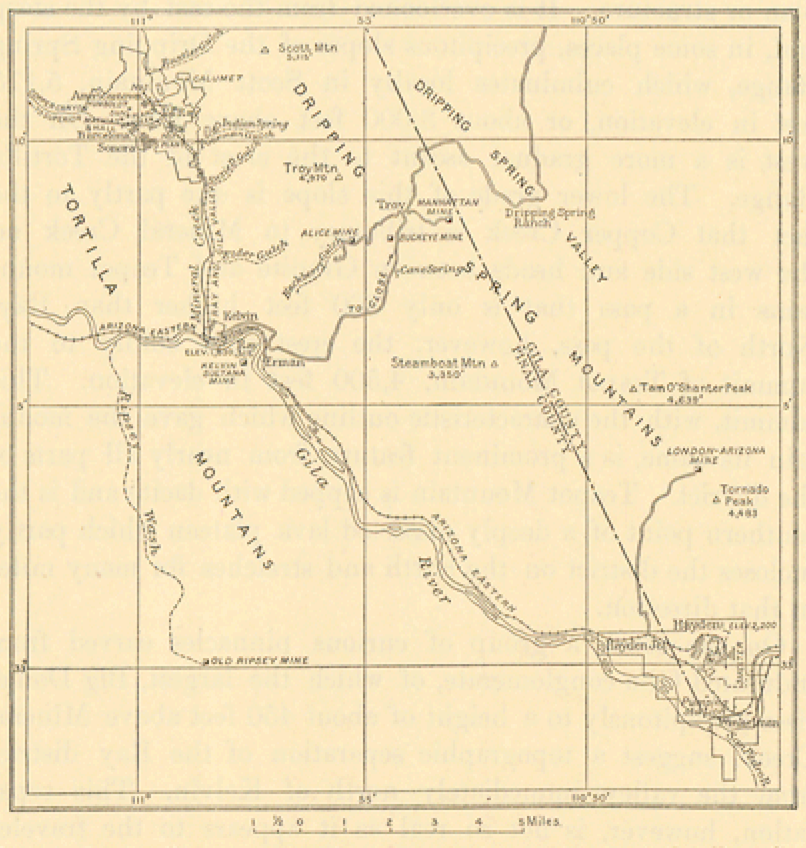

FIGURE 9.—Outline map showing the relative positions of the Ray Consolidated Copper Co.'s mines and mills.

Those who desire more information about the substantial and modern equipment of the Ray Consolidated Copper Co. may find many technical details in the annual reports of the company and elsewhere.[66]

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[62] The copper deposits of the Ray district have been fully described elsewhere (Ransome, F. L., The copper deposits of Ray and Miami, Ariz.: U. S. Geol. Survey Prof. Paper 115, 1919). The description that follows in this folio is an abstract of certain portions of that report.

[63] The ground of this company in 1916 was operated by the Ray Hercules Copper Co. In 1922 it passed into the control of the Ray Hercules Mines (Inc.).

[64] Blackner, L. A., Underground mining systems of Ray Consolidated Copper Co.: Am. Inst. Min. Eng. Trans., vol. 52, pp. 381–422, 1916.

[65] Vail, R. H., Smelting Ray concentrates at Hayden, Ariz.: Eng. and Min. Jour., vol. 98, pp. 553–558, 1914.

[66] Dinsmore, C. A., The Ray Consolidated Copper Co.: Min. and Sci. Press, vol. 103, pp. 282–285, 1911.

(Anon.), Electric hoist at Ray: Min. and Sci. Press, vol. 103, pp. 310–311, 1911.

Herrick, R. L., Ray Consolidated mines: Mines and Minerals, vol. 297, pp. 544–546, 1909.

Edholm, C. L., Ore handling at Ray, Ariz.: Eng. and Min. Jour., vol. 92, pp. 1142–1144, 1911.

Penny, A. N., Mining low-grade copper ore by Ray Consolidated: Eng. and Min. Jour., vol. 99, pp. 767–770, 1915.

Blackner, L. A., Underground mining systems of Ray Consolidated Copper Co.: Am. Inst. Min. Eng. Trans., vol. 52, pp. 381–422, 1916.

Some idea of the magnitude of the task of preparing for mining and treating from 8,000 to 10,000 tons of ore a day may be gained from the statement that the net expenditures of the Ray Consolidated Mining Co. for property and development to December 31, 1911, amounted to $14,635,314.81.

ORE AVAILABLE.

Estimates of the quantity of ore available in the mines of the Ray district vary with the data used in computation. As the ore is in most places not definitely bounded, the calculated available tonnage depends very largely upon the fixing of an arbitrary line between those assays that correspond to ore and those that do not. If everything above 1.3 per cent be classed as ore the tonnage, for example, will be much greater than if 2 per cent be taken as the lower limiting tenor. Moreover, material that on assay gives 3 to 4 per cent of copper may be of less value or even of no value as ore if the copper is in one of the oxidized forms that can not readily be concentrated with the sulphides. In general the lower limit of ore is taken to be from 1 to 1.5 per cent.

It is believed that the engineers of the different companies have been careful in their estimates of the available quantity of ore for their respective mines and that there has been no attempt at exaggeration. It is to be remembered, however, that the results are estimates—not exact measurements.

The known reserves of the Ray Consolidated Copper Co. at the end of 1916 are given in the company's report for that year at 93,373,226 tons, averaging 2.03 per cent of copper. There had been mined at this date 13,293,854 tons. Consequently the original ore body, according to the latest estimate available, contained 106,667,080 tons. This includes about 500,000 tons of ore averaging between 5 and 6 per cent, originally present in the ground formerly owned by the Ray Central Co.

The Ray Hercules Mines (Inc.) estimated in 1921 that in its property there was 3,916,000 tons of 2.42 per cent ore.

The total quantity of known ore originally present in the Ray district and averaging between 2 and 2.5 per cent may be taken as between 110,000,000 and 115,000,000 tons. There probably remains a considerable quantity yet to be developed.

TOPOGRAPHY.

For the first 10 miles of its generally southward course, Mineral Creek traverses a succession of gorges cut in a thick, faulted flow of dacite. About 8 miles north of its mouth, however, the creek emerges from its narrow confines into a more open valley, which continues southward to Gila River. The Ray district, as the name is used in this folio, is situated at the head of this valley, which, although broadly open, contains very little level ground. The district itself is perhaps best characterized as a confusedly hilly area in which the various eminences are distributed without any recognizable plan or structure. It is overlooked from the east by the steep and, in some places, precipitous slopes of the Dripping Spring Range, which culminates locally in Scott Mountain, 5,115 feet in elevation, or about 3,000 feet above Ray. On the west is a more gradual ascent to the crest of the Tortilla Range. The lower grade of this slope is due partly to the fact that Copper Creek is tributary to Mineral Creek on the west side and heads between Granite and Teapot mountains in a pass that is only 800 feet higher than Ray. North of the pass, however, the crest rises boldly to the summit of Teapot Mountain, 4,500 feet in elevation. This summit, with the characteristic outline which gave the mountain its name, is a prominent feature from nearly all parts of the district. Teapot Mountain is capped with dacite and is the southern point of a deeply dissected lava plateau which partly incloses the district on the north and stretches for many miles in that direction.

On the south a group of curious pinnacles carved from indurated Gila conglomerate, of which the largest, Big Dome, rises precipitously to a height of about 450 feet above Mineral Creek, suggest a topographic separation of the Ray district from the valley immediately north of Kelvin. This separation, however, is not so real as it appears to the traveler who approaches the district in the usual way, up the channel of Mineral Creek. A broader outlook over the country, such as may be had from the adjacent mountains, reduces these pinnacles, which are sufficiently imposing near at hand, to their true proportions in the general landscape and shows that there is no constriction of the valley proper.

It thus appears that, as a whole, the district has the aspect of a small hilly basin, traversed from north to south by Mineral Creek and very imperfectly closed on the south. As seen from a moderate elevation the central part of this basin bristles with a huddled assemblage of little rusty sharp-topped hills, of which Humboldt Hill is a type. Most of these hills stand from 300 to 500 feet above the deepest adjacent ravines, or probably from 100 to 300 feet above what may be considered the general level of the district.

The area characterized particularly by this topography is of elongated earlike outline; its longer axis trends a little north of west, and the concave side of the area lies to the south. Its length is about 2 miles, and its greatest width is about three-quarters of a mile. North of this area and to a less extent south of it broad, low, gently sloping spurs, which have evidently been formed by the dissection of superficial layers of stony or gravelly detritus, give to the basin floor a general smoothness which is in marked contrast with the craggy topography of the central area.

GEOLOGY.

In the area immediately adjacent to the principal copper mines pre-Cambrian rocks, mainly Pinal schist with a little granite and quartz-mica diorite, occupy most of the surface or are concealed under merely superficial deposits of much later age.

Of the Paleozoic section only the lower part is represented, mainly on the east side of Mineral Creek, where the Scanlan conglomerate, Pioneer shale, and Dripping Spring quartzite are exposed in numerous small fault blocks. The Mescal, Martin, and Tornado limestones, although prominent in the mountain front east of Ray, do not occur near the mines.

Intrusive rocks of post-Paleozoic but probably pre-Tertiary age are represented by diabase, quartz diorite, and two varieties of quartz monzonite porphyry, distinguished as the Teapot Mountain and Granite Mountain porphyries, and by dikes, chiefly of quartz-mica diorite porphyry. The variable Whitetail conglomerate and the overlying flow of dacite that generally accompanies it are both present, and the eruption of the dacite was followed by the deposition of the Gila conglomerate, probably in early Pleistocene time. Later Pleistocene time is presumably represented by the unconsolidated terrace deposits, which appear to be better developed in the Ray district than elsewhere in the general region.

Structurally the Ray district is divisible into two parts, separated by a line nearly coincident with Mineral Creek. The general difference in structure as reflected in the distribution and relations of the rock formations on the two sides of the creek is evident from a glance at the geologic map. On the east side is the structure characteristic of the Dripping Spring Range as a whole—a fault mosaic. The Paleozoic and older rocks have been intruded by diabase and cut by faults into polygonal blocks, for the most part less than one-fourth of a square mile in area. This displacement of these faults is in general normal. On the west side of the creek is a large area of Pinal schist, invaded irregularly by various intrusive rocks and covered extensively by terrace deposits. This schist is not wholly unaffected by faulting and is doubtless traversed by some faults that, owing to the fact that the same schist occurs on both sides of the fracture, have escaped recognition. On the whole, however, underground work and the mapping of the intrusive masses and the belt of rhyolite schist south of Copper Canyon have brought out little evidence of displacement, and it may safely be concluded that the country west of the creek has been less dissected by faults than the country east of it.

The faults east of Mineral Creek are not all of the same age. Much displacement of the sedimentary formations undoubtedly occurred when the diabase was intruded, but little or none of that displacement is now recognizable as faulting, for most of the fractures formed at that time were invaded by diabase magma, and the blocks of strata were forced apart by the molten material. Most of the faulting appears to have followed the eruption of the dacite, and some of it was later than the deposition of the Gila conglomerate.

Although Mineral Creek in a rough way marks the division between a much faulted region on the east and a less faulted region on the west, and although there is undoubted faulting along the general course of the creek, yet there is no profound fault coincident with this line of division. The boundary between the two structural divisions of the district is marked by comparatively short intersecting faults of moderate displacement and of the same general character as those abundant in the Dripping Spring Range.

The present schist surface in the Ray district, while it undoubtedly owes its topographic features to Quaternary erosion, has not as a whole been very greatly reduced below a surface that existed in Tertiary time. A view over the central part of the district toward Teapot Mountain, such as that shown in Plate VIII, indicates clearly that the Whitetail formation exposed on the steep slopes of the mountain once covered the copper-bearing area. The Whitetail in turn was covered by the dacite. It was only after the removal of these rocks that erosion of the schist could again proceed. To what extent the schist had been uncovered before the deposition of the Gila conglomerate began and how far that conglomerate extended over the present schist area can not be determined. The terrace deposits, more conspicuously developed in the Ray district than elsewhere in the general region, represent a period when the streams were locally overloaded. Whether this was due to an increase in the quantity of detritus to be moved, a change in climate, or a lessening of stream gradients by earth movements is not known. Recent erosion has dissected the terrace deposits and etched out the rough ravines through which storm waters now escape to Mineral Creek.

Although it happens that most of the mining by the Ray Consolidated Copper Co. has been done under two hills, Ray Hill and Humboldt Hill, there apparently is no constant or significant relation between the topographic details of the present surface and the occurrence of ore. The ore is thick under Humboldt Hill, but it is both thick and of comparatively high grade under the lower part of Copper Gulch. In certain details of erosional sculpturing the fact that the rocks contained disseminated pyrite, with its train of chemical consequences, appears to have left its mark. It has not, however, proved possible to determine from the work of erosion at any one place the result of the physical and chemical processes of enrichment directly beneath.

Owing apparently to variation in hardness or induration from place to place, the Gila conglomerate in some localities has been shaped by erosion into forms having little in common with the even-crested branching spurs that flank the Pinal Range. Such exceptional products of erosion are the curious rounded towers that are conspicuous features along Mineral Creek a few miles below Ray. These are residuals of resistant portions of the conglomerate left behind in the general recession of the conglomerate bluffs along the creek.

SHAPE AND GEOLOGIC RELATIONS OF THE ORE BODIES.

FORM AND DIMENSIONS.

The body of disseminated ore in the Ray district may be characterized in general terms as an undulating, flat-lying mass of irregular horizontal outline and of variable thickness. (See Figs. 10, 11.) As a rule the mass lacks definite boundaries. No readily recognizable distinction in color, texture, or general appearance marks it off sharply from the inclosing rock, and closely spaced sampling and assays prove that the passage from ore to country rock is in most places gradual. Consequently, to a greater degree than in most ore deposits of other types, the size and shape of the Ray bodies depend upon the local and current definition of ore.

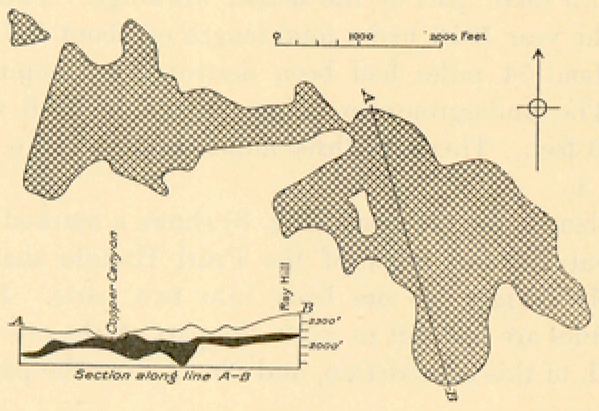

FIGURE 10.—Plan and section of the ore bodies as developed by underground exploration in the Ray district.

Like most condensed general characterizations, the preceding paragraph requires considerable qualification to make it an accurate statement; for in a preliminary sweeping view many details essential to the completeness of the picture are necessarily for the moment overlooked. The statement, for example, that the passage from ore to country rock is gradual, though true in a broad way, is subject to many exceptions. As a rule the transition downward from the leached overburden, or "capping," as it is locally termed, to the ore is less gradual and far more distinct than the transition from ore to the comparatively barren sulphides below.

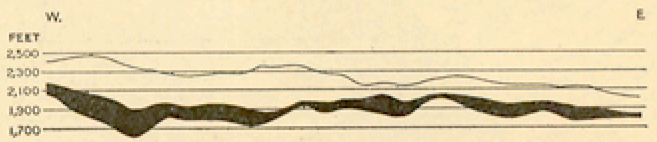

FIGURE 11.—Generalized east-west section of the Ray ore body.

Constructed by averaging the available sections of a strip of the ore body 600 feet wide. Much reduced from a drawing prepared by the Ray Consolidated Copper Co.

In those places where there is an abrupt change from thoroughly leached, oxidized rock containing scarcely a trace of copper to ore, the boundary between the two is likely to be a gouge-filled fissure. Some of these fissures are plainly of later origin than the enrichment, and some were probably formed before enrichment. Of the fissures formed after the enrichment some are associated with displacement; oxidized and leached material has been faulted against ore. Others have probably brought about the observed relation between ore and waste not so much by faulting as by directing the downward progress of oxidation in such a way that the ore on

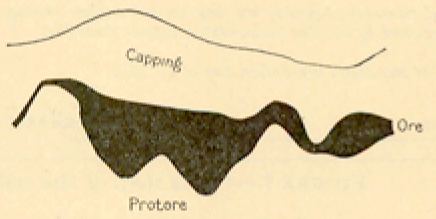

FIGURE 12.—Section across one of the deepest and thickest parts of the Ray ore body.

one side of the fissure was protected, while that on the other was converted to the so-called cap rock. Still a third group of fissures may have been formed before the enrichment and have influenced in the manner just indicated the enriching as well as the leaching and oxidizing processes.

The Ray ore body may range in thickness from 300 feet to 50 feet or less in a distance of 200 to 300 feet. The thicker portions, as seen in section (see Figs. 10, 11, and 12), may be convex below and concave above, double convex, or, more rarely, convex above and concave below. These variations bear no regular relation to the present topography.

RELATIONS OF THE ORE BODIES TO THE SURFACE.

The depth to ore, or the thickness of the overburden, differs widely from place to place; the average thickness of the overburden on the ground of the Ray Consolidated Copper Co. lies between 200 and 250 feet. The range is from about 45 feet to 600 feet, although in very few places does the leached ground extend to depths greater than 500 feet. Drill hole 21 of the Arizona Hercules Copper Co., east of Mineral Creek, is reported to have gone down nearly 900 feet before reaching ore. Possibly other holes drilled on this ground during 1915 and 1916 by the Ray Hercules Copper Co. have also penetrated unusually thick overburden, but full particulars concerning the occurrence of ore in these holes are not available for publication.

LOWER LIMIT OF OXIDATION.

In the Ray district it is exceedingly difficult and perhaps impossible to get from the available data any definite conception of the ground-water surface when mining began; but apparently it was neither coincident with nor closely related to the bottom of the oxidized zone. It has also been shown that in general the layer of oxidized material above the ore is from 45 to 600 feet, the average thickness as calculated by the engineers of the Ray Consolidated Copper Co. being 252 feet.[67]

In general, the bottom of the oxidized zone is a fairly definite but uneven and undulatory surface. If at any time in the history of the deposits this surface was coincident with a ground-water surface which stopped its gradual descent this coincidence is no longer evident. Oxidation appears to have been limited rather by the gradual exhaustion of oxygen from air and rain water as they penetrated downward through the rocks. This being the case, oxidation would extend deeper along certain favorable channels than through the mass of the rock, and as such zones of easier penetration would rarely be vertical, there is little difficulty in accounting in this way for the occasional observed occurrence of oxidized material directly beneath protore or enriched sulphide ore.

RELATIONS TO KINDS OF COUNTRY ROCK.

The rocks intimately associated with the disseminated ores in the Ray district are the Pinal schist, the Granite Mountain variant of the quartz monzonite porphyry of the district, and diabase. By far the greater part of the ore is metallized schist, a relatively small part is metallized quartz monzonite porphyry, and a very much smaller part appears from drill records to be in diabase.

The process of natural enrichment, whereby the protore was changed to ore by generally descending solutions, is described in another publication.[68]

PROTORE, ORE, AND CAPPING.

DEFINITIONS.

That the ore bodies of the Ray district were formed by a process of enrichment acting upon material that originally contained but very little copper is generally recognized. This material is commonly referred to as "primary ore," but of course it is not ore at all in the true sense of that word, nor is most of it likely to become ore by any improvements in mining and milling that can at present be foreseen. To designate this primitive ore stuff concisely and accurately, without using "ore" in an undesirably loose sense, apparently requires a new term, and the word "protore" (first or primitive ore) has been suggested[69] as likely to be a serviceable substitute for the unsatisfactory and periphrastic expressions that have hitherto been current.

In practice it will be sufficiently accurate under present economic conditions to refer to rock carrying less than 1.3 per cent of copper as protore, while that containing 1.3 per cent or more of copper will be classed as ore. Such usage will class with the protore some considerably enriched material, but this will be a small quantity compared to the total bulk of the unenriched rock. The limit here set is not inconsistent with the fact that some material of lower grade goes to the mills, for in mining by a caving system ore is to some extent mixed with waste. The limit, moreover, is not the same in all mines, some calculations of tonnage being based on 1.5 per cent as the lower limit of ore. It also shifts with changes in the price of copper when these exceed the ordinary fluctuations and maintain their departure from the normal over any considerable time.

The choice of the word "capping" to designate the leached, practically barren overburden is simply an adoption of local usage. The term is not ideal, but it does not appear so objectionable as to make the coining of a new word necessary or desirable.

RELATIONS OF HYPOGENE METALLIZATION TO FAULTING.

In the Ray district the hypogene metallization does not appear to have followed regular or systematic zones of fissuring. Some general disturbance and fracturing of the whole rock mass there undoubtedly was, and the many small irregular fissures that resulted were afterward filled with quartz and pyrite and, in much smaller quantity, chalcopyrite and molybdenite. These fillings, however, are what are commonly referred to as stringers or veinlets rather than veins and have little individual persistency.

COPPER CONTENT OF PROTORE.

The average copper content of the wholly unenriched protore is susceptible only of a rough determination from the data available. An examination of all the Ray Consolidated Co.'s drill records leads to the conclusion that below the point where the copper shows any progressive decrease, and presumably therefore below any natural or artificial enrichment, the protore averages from 0.4 to 0.5 per cent of copper. Unenriched diabase at Ray generally contains considerable visible chalcopyrite and appears to be on the whole richer in copper than the schist protore.

SCHIST PROTORE.

The metallized schist does not differ conspicuously in appearance from the normal Pinal schist. On the whole it is perhaps a little lighter in color, and none of it has the bluish tint that is exhibited by some varieties of this rock at a distance from the ore bodies. The features that especially distinguish it are the innumerable veinlets, carrying quartz and pyrite, that traverse the rock in all directions, the presence of pyrite disseminated rather generally through the mass of the schist, and consequently a prevalent rusty hue on weathered surfaces. A few of the quartz-pyrite stringers attain a width of 6 inches or more, but as a rule they are smaller and range from mere films, scarcely visible to the unaided eye, up to little veinlets a quarter of an inch wide. These veinlets have no regularity of arrangement but run in all directions with little or no regard to the planes of schistosity.

Pyrite is by far the most abundant and widespread sulphide of the protore but is generally accompanied by a little chalcopyrite and in some places by molybdenite.

In many samples microscopic examination of the concentrates panned from the crushed material shows more or less chalcocite, usually in very thin dark films on the pyrite.

The chalcopyrite is important, for from the destruction of this mineral probably came nearly all the copper in the present ore bodies, although doubtless some was derived from apparently homogeneous pyrite. As a rule, however, chalcopyrite is present in surprisingly small quantity, and in much of the protore chalcocite is the only cupriferous mineral recognizable. It becomes necessary to conclude that much of the protore, before any enrichment whatever took place, contained exceedingly little copper, certainly less than has been sometimes supposed. The molybdenite is rarely visible in the schist protore but has been identified at a few places and is probably distributed widely through it in small quantity. It is more abundant in the porphyry protore.

The pyrite, chalcopyrite, and molybdenite have been deposited mainly with the quartz in the small fissures, but there is considerable pyrite, generally in very small crystals, disseminated through the substance of the schist. On the whole, however, the commonly applied name "disseminated ore" is likely to be a little misleading unless it is understood that the dissemination is due to the minute and dispersive character of the fissuring and veining much more than to the development of sulphides in isolated grains throughout the rock mass.

PORPHYRY PROTORE.

Like the schist variety, the porphyry protore is traversed by countless small irregular veinlets running in all directions and intersecting at all angles. The walls of these stringers may be fairly sharp, but commonly the adjacent rock is silicified, so that of the once angular fragments into which the porphyry was divided by the fissuring only rounded kernels of comparatively unaltered rock remain. Although these kernels are spoken of as comparatively unaltered, they are by no means fresh. They retain the general porphyry texture, and they are speckled with sparkling and apparently fresh biotite, but the feldspars are dull and decomposed, and the whole kernel is soft and friable. As in the schist protore, the quartz stringers carry pyrite, chalcopyrite, and molybdenite, but the exposures available indicate that both chalcopyrite and molybdenite are more abundant in the porphyry than in the schist. This suggests that, although the bulk of the ore is now in schist, the metallized porphyry was excellent raw material for the enriching process to work upon and in places probably contributed a large quantity of copper to the ore bodies now in the schist. The silicification of the porphyry was accompanied by the development of much sericite and by the dissemination of pyrite and, to a less extent, chalcopyrite and molybdenite through the substance of the altered rock.

The microscope shows that the formation of the sulphides in the granite porphyry has been accompanied by the general conversion of the rock to an aggregate consisting almost exclusively of quartz and sericite. The process has involved considerable recrystallization, and as a rule in rock where the biotite has disappeared the porphyritic quartz and an occasional small zircon are all that remain of the original constituents. Even the quartz phenocrysts have been attacked and partly replaced, some by sericite and some by secondary quartz. Such alteration apparently has required the addition of silica, sulphur, copper, and molybdenum and the subtraction of magnesia, lime, and soda.

Where the biotite has not disappeared much of the altered rock is so fragile that satisfactory thin sections can not be cut from it. Here sericite and in some facies kaolinite are much more abundant than in the harder and more siliceous varieties.

ORE.

GENERAL CHARACTER OF THE SULPHIDE ORE.

The sulphide ore very closely resembles the protore, being in general a pale rock that, were it not for the speckling and veining by chalcocite would be almost white. In texture and structure it is so nearly identical with protore that the description given for that material can be applied to it without change and need not be here repeated.

The essential mineralogic and chemical change effected by the process of enrichment is the more or less thorough substitution of dark-gray chalcocite for yellow pyrite and chalcopyrite, this bringing about some difference in the general tint and appearance of the rock. The body or gangue, if it may be so termed, of the protore, having already been converted into quartz and sericite, a chemically stable aggregate, does not suffer much change in the alteration of protore to ore by the descending cupriferous solutions. Apparently the enrichment was effected by solutions that were neither strongly acid nor of great chemical activity.

GENERAL CHARACTER OF THE PARTLY OXIDIZED ORE.

The partly oxidized ore is readily recognized by its greenish color, resulting from the change of part of the chalcocite to chrysocolla and malachite. This change may be very superficial, giving rise to little more than a brilliant stain, or it may have involved most of the chalcocite, leaving out only small residual kernels of the sulphide. (See Fig. 13.) In part, the malachite and chrysocolla directly replace the chalcocite, but in the process of oxidation a good deal of local migration of copper takes place, and both malachite and chrysocolla with some quartz are deposited in cracks and other small openings in the rock.

FIGURE 13.—Typical pyrite kernels in chalcocite. Schist ore, 1925 level of the No. 2 mine, Ray district.

TENOR OF THE ORE.

In tenor the ore ranges from any lower limit that may be set, usually some figure between 1 and 1.6 per cent of copper, up to about 10 per cent. Occasional assays show ore as high as 12 per cent, but there is no large body of ore of such richness. The general average of all the ore reserves of the Ray Consolidated Copper Co., estimated in the company's report for 1916 at 93,373,226 tons, is given as 2.03 per cent. From the beginning of operations to January, 1917, the company had mined 13,293,854 tons averaging 1.70 per cent of copper. The highest grade of disseminated ore mined at Ray is that of the No. 3 mine, of which it was estimated in 1914 that there was in the ground approximately 540,000 tons of an average tenor slightly above 5 per cent of copper.

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[67] Ray Consolidated Copper Co. Third Ann. Rept., for the year ending Dec. 31, 1911, p. 10.

[68] U. S. Geol. Survey Prof. Paper 115, pp. 169–176, 1919.

[69] Ransome, F. L., Econ. Geology, vol. 8, p. 721, 1913.

OXIDIZED AND LEACHED ROCK.

From the complete oxidation of the protore and ore two general kinds of material result. One is a rock brilliantly colored with malachite and chrysocolla containing approximately as much copper as the ore but in a form not susceptible of satisfactory concentration by the processes applied to the sulphides. In a few places it has been rich enough to mine in a small way and ship to the smelters.

Such copper-stained rock, traversed generally by many little veinlets of chrysocolla, is more abundant in the Miami district than in the Ray district.

The other class of material consists of the leached rock or capping. This in its typical development is in strong contrast with the copper-bearing rock just described, although the materials of the two kinds grade into each other. Its prevalent characteristics are a more or less rustiness of tint and a practical absence of copper. It contains enough iron oxide to give a reddish color to churn-drill sludge, whereas the unoxidized schist and ore give a gray sludge and the material containing much chrysocolla and malachite a greenish-gray sludge.

If it were possible to recognize with certainty a particular variety of cap rock as indicative of ore beneath it, much expensive drilling might be dispensed with, but at present no great reliance can be placed upon visible surface criteria. It may be said, however, that a deep and conspicuous redness of the surface is less propitious than a rather subdued tint of rustiness. The excessive ruddiness generally indicates that the chalcocite zone is thin and that protore will be reached comparatively near the surface. On the other hand, abundant chrysocolla near the surface suggests that erosion may have overtaken the chalcocite zone in its downward progression and have removed some of the ore body. As a rule, the cap rock above an ore body contains abundant small quartz stringers which show, by minute rusty cavities, the former presence of iron sulphide.

The copper tenor of typical leached capping is extremely low, and such material rarely shows any visible trace of the presence of copper-bearing minerals. Assays of capping usually range from a mere trace to about 0.2 per cent of copper, higher results generally being indicative of the presence of a little visible silicate or carbonate of copper—in other words, of material intermediate between typical leached capping and oxidized but unleached ore.

ORIGIN OF THE COPPER DEPOSITS.

INFLUENCE OF IGNEOUS ACTIVITY.

Had no previous study been made of the copper deposits of the western United States and were observation restricted to one only of the two districts here described, the observer might well inquire whether the association of the ores with granitic or monzonitic porphyry is merely accidental or is an illustration of cause and effect. The present state of our information, however, leaves little room for this doubt. Not only at Ray and Miami but at Clifton, Bisbee, and Ajo in Arizona, at Ely in Nevada, at Santa Rita in New Mexico, and at Bingham in Utah, not to mention occurrences outside of this country, copper ores generally similar to those of Ray and Miami are closely associated with monzonite porphyry or with porphyry intermediate in character between monzonite porphyry and granite porphyry. In some of these districts the evidence for an essential genetic relationship between ore and porphyry is plain; in others it is more or less equivocal to anyone who permits himself to realize that some ores, even ores of copper, may occur in localities where there is nothing to suggest any connection between them and igneous activity. Taken collectively, however, the disseminated copper deposits of the southwestern United States present convincing evidence that the monzonitic porphyries, by which they are invariably accompanied, had something to do with their origin.

It is not to be supposed, however, that the now visible parts of these bodies of porphyry contributed in any active way to ore deposition. They, like the neighboring schist, have themselves been altered by the ore-bearing solutions, and, where favorably situated, have been changed into protore just as the schist was changed under similar circumstances. Their significance lies in their testimony to the probable presence of much larger masses of similar igneous material below any depths likely to be reached in mining, and it is from these larger and deeper masses, which must have taken far longer to solidify and cool than the bodies now exposed, that most of the energy and at least a part of the materials were derived to form the protore.

CHARACTER OF THE DEPOSITING SOLUTIONS.

The probable character of the hypogene solutions that deposited a given ore body is ascertainable in part from the observed effects of the solutions on the rocks which they traversed, in part from the study of present-day spring waters, in part from experimental work, and in part from general chemical considerations. On the basis of evidence drawn from the various sources mentioned, fairly general acceptance is given to the view that deposits such as the protore of Ray and Miami are the work of thermal alkali sulphide waters probably carrying some carbon dioxide. It can not be said that these particular deposits very definitely confirm or modify this commonly held view.

On the whole, the hypogene solutions appear to have been of rather feeble chemical activity, and although the quantity of copper which they transported was large in the aggregate, it was small when measured in percentage of the metallized rock mass.

INFLUENCE OF STRUCTURE.

No clear relation has been made out between primary metallization and rock structure. It may be said that such metallization has taken place at or in the vicinity of the contact between schist and granite porphyry, but this is true only in a general way. Typical protore may be found more than 1,000 feet from any known porphyry mass of considerable size. Moreover, it is only along certain parts of the contact region that any deposition has taken place. In the Ray district, for example, the schists near the granite porphyry on Granite Mountain, although showing contact metamorphism, are not noticeably sulphidized, and in the Miami district it is only along the northern border of the north lobe of the Schultze granite that the schists contain much disseminated pyrite and chalcopyrite.

The conditions that determined the ascent of metallizing solutions at any particular place were doubtless complex. Essential ones must have been permeability of the rocks affected and an abundant supply of the active solutions.

Permeability, as shown by a study of the protore, was due in large measure to minute irregular fissuring. This fissuring perhaps accompanied the formation of larger fissures along which faulting took place.

Permeability, it is believed, was favored also by irregularity of the intrusive contact and by the presence of little tongues and dikes of porphyry extending out into the schist. The act of intrusion must have caused some disturbance of the schist, and the presence of such tongues and dikes, by introducing heterogeneity into the rock mass, probably made for further fissuring and to that extent provided communicating channels between the deep-lying igneous material and the zone of sulphide deposition. Some probability is given to this suggestion by the fact that small dikes and irregular protrusions of porphyry are abundant in the metallized ground. This is particularly noticeable about Humboldt Hill, where the ore body attains its greatest thickness. That thickness, however, it should be remembered, is probably due more to enrichment than to protore deposition.

The quantity of mineralizing solutions available at any place in the contact zone probably depended to a large extent also on the shape of the deep-seated mass of magma from which they rose. This mass, however, is entirely beyond our ken, and its form must remain, for the present at least, unknown.

INFLUENCE OF VARIATIONS IN COUNTRY ROCK.

There appears to be no regular or significant difference between schist protore and porphyry protore as regards tenor in copper. Chalcopyrite, however, if not more abundant, is in places a more conspicuous constituent of the porphyry protore than of the schist protore. Molybdenite also seems to be more abundant in porphyry than in schist. At Ray the mineralized diabase as a rule appears to carry more pyrite and chalcopyrite and to assay rather higher in copper than the average schist or porphyry protore. (See p. 21.) This is not surprising when it is remembered that the diabase contains a much larger quantity of iron originally present as oxide and silicate than the other rocks and also, as has been shown in a previous publication,[70] contained originally a little copper. Practically no enriched disseminated ore had been mined in diabase in the Ray district when the field work for this folio was completed, but there appears to be no reason why, under suitable conditions, enrichment of the mineralized diabase should not have taken place, and consequently it would not be surprising if bodies of ore were found in that rock east of Mineral Creek.

RELATION TO THE SURFACE EXISTENT AT THE TIME OF DEPOSITION.

It is probable that at the time the protore was deposited at least 500 feet of rock lay above the present surface, and it is not at all unlikely that the thickness was several times the figure mentioned. The crystallinity of the granite porphyry and the character of the metamorphism that accompanied or followed the intrusion are both indicative of the solidification of the magma under a fairly thick cover. In the Miami district the granite porphyry itself, at the present day, is in places fully 750 feet thick above the ore.

GEOLOGIC AGE.

The deposition of the protore probably followed closely the intrusion of the granite porphyry, but no facts are known that might serve to fix this event definitely in geologic time. The granite porphyry is younger than the diabase, whose intrusion, on general grounds rather than from any definite evidence, is supposed to have taken place at the end of the Mesozoic era. It appears reasonable to regard the intrusion of the granitic porphyries as an early Tertiary event, but it must be admitted that this is little more than conjecture. The deposition of the protore certainly took place after the laying down of the Tornado (Mississippian and Pennsylvanian) limestone and before the eruption of the dacite.

TROY DISTRICT.

The intrusion of the granodiorite of the Troy Basin was followed by pronounced contact metamorphism and by considerable metallization. The granodiorite is closely related to the Schultze granite and the Granite Mountain and Teapot Mountain porphyries and was intruded at about the same time as those rocks. It is associated with many dikes and is surrounded by much fissured rocks, including limestone, which differ in no essential respect from rocks elsewhere ore-bearing in the same general region. In short, Troy would seem to be a decidedly favorable place for ore deposition. Yet those who have acted on this apparently reasonable supposition have thus far been disappointed. There has been extensive prospecting, and some ore has been found, but the returns have not equaled the outlay.

The principal development has been on the Rattler claim, 1 mile in a direction a little south of east of Troy, and on the '91, Buckeye, and Alice claims, one-half, three-fourths, and 1½ miles southwest, respectively, of the now practically abandoned settlement. When the visits were made in 1910 and 1914 the underground workings were only in small part accessible.

The workings of the Rattler mine comprise the Sisson shaft, which is an incline of 65° to the south and 300 feet in depth, connected with three levels, the first of which is an adit. The levels run nearly east-northeast and west-southwest and open a section of ground about 700 feet long. A second shaft, east of the Sisson, extends only about 50 feet below the adit level. There is no vein, the ore occurring as bunches and lenses that follow more or less closely the bedding of the Mescal limestone in which it occurs. The limestone at the Rattler mine is an inclusion in diabase, the original igneous contact being modified in some places by faulting. Granodiorite was not seen in the workings, but as shown on the geologic map it is not far away and has effected considerable contact metamorphism in the diabase, which sparkles with secondary biotite. The ore zone dips 20° S. 15° W. and from a point in the main tunnel about 100 feet in has been followed in an inclined winze for about 95 feet to a point where it appears to be cut off by a rather obscure fault. There is apparently no large quantity of ore available. The Sisson shaft appears to be entirely in diabase below the first level.

The ore of the Rattler mine is chiefly a dark fine-grained aggregate of magnetite and chalcopyrite with varying quantities of silicate minerals derived by metamorphism from the inclosing limestone. With increasing proportions of these silicates the ore grades into the metamorphosed limestone. Analyses of the ore recorded in the books of the Troy Arizona Copper Co. and its predecessors show from 3 to 3.7 per cent of copper, a maximum of 0.04 ounce of gold and 0.7 ounce of silver per ton, from 27 to 30 per cent of silica, about the same proportion of iron, about 1 per cent of calcium oxide, and 20 per cent of magnesium oxide.

Very little could be seen of the '91 mine, as the shaft had caved in. It apparently is about 150 feet deep, and the maps show three short levels. The little copper ore that was found in this mine appears to have occurred, as at the Rattler, as small lenticular bunches in the Mescal limestone. The wulfenite in the '91 mine, concentration of which was at one time attempted, occurs in joints in fractured Dripping Spring quartzite.

The Buckeye mine is situated on a nearly east and west branch of the same porphyry dike complex on which is the Alice mine, at a point where the dike complex cuts through Dripping Spring quartzite, Mescal limestone, and Troy quartzite. These stratified rocks appear to be underlain and overlain by intrusive sheets of diabase. The dump of the shaft, which is apparently about 150 feet deep, with three levels, is chiefly diabase. These levels trend generally west-northwest. The first level has a length of about 1,000 feet, but each of the other two is less than 300 feet. The Buckeye at one time had a little oxidized copper ore near the surface and alongside of the porphyry dike. This ore was reduced in a small furnace at the mine.

The Alice mine was worked through a shaft inclined at 45° with three levels, the lowest of which is about 200 feet vertically below the collar. As shown by the mine map the general trend of the levels is northeast and the length of the block of ground explored by them about 350 feet. The shaft is sunk on a porphyry dike at a point where Tornado limestone on the north is faulted down against Martin limestone on the south. A few small bunches of ore were found in limestone near the dike, but the mine did not pay expenses. It could not be entered when the geologic field work on which this folio is

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[70] U. S. Geol. Survey Prof. Paper 12, p. 12, 1903.

based was in progress. The mine maps show that connection was made with the Pratt tunnel by an inclined raise of about 200 feet vertical height.

Since the last visit the Troy Arizona Copper Co. has done additional prospecting and is reported to have sunk a 500-foot shaft on the Climax claim, about three-quarters of a mile west-southwest of Troy, and in 1917 some ore was being shipped.

On the Renfro group of 47 claims, about 1½ miles east-southeast of Troy, considerable ore was visible in 1912 in the lower part of the Martin limestone at a point near the crest of a steep spur where the limestone beds, which dip at a low angle to the east, are stepped down toward the south by four or five small faults the throw of which is apparently nowhere over 40 to 50 feet. The ore, mostly chrysocolla and carbonates, occurs as irregular layers 6 inches in maximum thickness, which lie parallel with the bedding of the limestone and occur as small replacement masses near fissures. From the ravine to the west of these exposures of ore on the ridge, and about 400 feet below them, a tunnel 900 feet in length had been driven in 1912 entirely in diabase, which here underlies the Troy quartzite and Martin limestone of the crest of the ridge. The tunnel follows a nearly vertical fissure and runs southeast. No ore had been found in this tunnel in 1912. Since that year the ground has been worked by the Pinal Development Co., which began production in 1917. The ore shipped is oxidized and presumably comes from the replacement deposits in limestone previously mentioned. The main tunnel is stated[71] to be 1,600 feet long and to connect with about 2,500 feet of underground workings with a maximum depth of 600 feet.

OTHER COPPER DEPOSITS.

London-Arizona mine.—The London-Arizona mine is in the southeastern part of the quadrangle, about 4 miles north of Hayden, on the north side of Tornado Peak.

The lowest rock exposed in the canyon, in which are the mine buildings, is diabase, apparently in a sheet several hundred feet thick, which was intruded at approximately the horizon of the Mescal limestone. Overlying the diabase in succession are the Troy quartzite, the Martin limestone, and the Tornado limestone. All these rocks are cut by dikes and small intrusive masses of quartz diorite porphyry. The diabase in the vicinity of the mine buildings is conspicuously metamorphosed by the porphyry and in places is a sparkling dark biotitic schist, generally containing disseminated pyrite and chalcopyrite.

On the south side of the ravine the lower part of the Devonian Martin limestone, as at other places in the quadrangle, shows metallization by copper, especially near dikes of quartz diorite porphyry, and since the time of visit considerable oxidized copper ore has been shipped to the Hayden smelter from flat-lying lenticular deposits in this limestone. In 1913 about 1,000 tons of 16 per cent ore was sent to the smelter and in 1916 about 6,000 tons of 4½ per cent ore. This ore was probably mined through tunnels or inclines on the south side of the ravine. A few thousand tons of lead ore was also mined. In 1910 exploration was in progress from the Curtin shaft, which was sunk in the Tornado limestone south of the ravine in order to reach the ore-bearing zone in the Martin limestone or to cut any ore bodies that might possibly occur at higher horizons in the limestones near one of the porphyry dikes. The shaft at that time was 270 feet deep, and no ore had been found in the workings connected with it.

Christmas deposits. — The interesting contact-metamorphic deposits at Christmas, although they lie in the adjoining Christmas quadrangle, about 4 miles east of the London-Arizona mine, may be briefly referred to here. The ore bodies, which consist of chalcopyrite generally rather finely disseminated through altered limestone and associated with yellow-brown garnet, magnetite, and sphalerite, occur as gently inclined tabular or lenticular replacement masses in certain beds of the limestone near quartz diorite porphyry dikes. Their occurrence is illustrated by the north and south section through the No. 1 shaft of the Christmas mine, based on the work of Mr. S. H. Sherman, who in 1910 was the engineer for the Gila Copper Sulphide Co., the owner of the deposits. A little bornite and chalcocite have also been reported in the ores.

Production began in 1905, and the total yield to the end of 1910 was 113,222 tons of ore, from which were won 4,484,374 pounds of copper, 27,062 ounces of silver, and 784 ounces of gold. This ore was reduced in a 150-ton water-jacket furnace. Since 1916 the mine has been worked under a contract with the American Smelting & Refining Co., the ore going to that company's Hayden smelter. The ore as mined prior to 1911 generally contained from 3 to 6 per cent of copper, 22 to 40 per cent of silica, 5 to 40 per cent of lime, 14 to 33 per cent of iron, and a maximum of 30 per cent of sulphur. Much of the ore first mined was oxidized and contained very little or no sulphur. An average of the analyses of eight samples of ore from the Las Novias stope above the 300-foot level, taken in September, 1910, as recorded in the company's books, is as follows:

Average of eight analyses of ore from Las Novias stope of Christmas mine.

	Per cent.
Cu	3.3
S	10.0
Fe	20.2
CaO	17.4
SiO_2	35.6

Schneider group.—The Schneider group of claims lies north and west of the ground of the London-Arizona Co. No work was in progress on these claims at the time of visit late in 1910, but operations have since been conducted by the Gila Canon Consolidated Copper Co.

The principal development in 1910 was what was known as the No. 1 tunnel, on the north side of the London-Arizona ravine. This tunnel runs north for about 600 feet, then bends to the east, and at that time continued about 200 feet farther. It is chiefly in diabase but cuts a few dikes of quartz diorite porphyry. Small irregular stringers of pyrite, chalcopyrite, and quartz were observed to be fairly abundant, but no body of ore had been found at that time.

Since then considerable additional work has been done. In 1917 the main tunnel was 1,800 feet long, and about 2 cars of ore were shipped weekly.[72] The mine is credited with a yield of about $200,000 to the end of 1917.

Kelvin-Sultana mine.—The Kelvin-Sultana mine, owned by the Kelvin-Sultana Copper Co., is on the south side of Gila River, nearly opposite Ray Junction. The main shaft is 550 feet deep, and the total underground workings are approximately 10,000 feet in length.

The shaft is sunk in an irregular mass of diabase that is intrusive into pre-Cambrian granite and is itself cut by a quartz diorite porphyry dike and by five or six fissure zones that trend nearly east and west. These fissure zones are vertical or dip south at high angles. Most of them show a little oxidized copper ore near the surface, and some small shipments, amounting to about 500 tons, were made from one of these zones on the William J. Bryan No. 2 claim from old workings, now abandoned, 200 feet deep. The present main shaft is about 800 feet north of these old workings.

At the time of the first visit, in April, 1912, the 200-foot was the bottom level of the main shaft and consisted of a crosscut to the south perhaps 500 feet in length. This working cut the porphyry dike and three or more of the east and west fissure zones but showed no ore.

At the second visit, in December, 1914, the mine was idle, although it was being kept free from water by pumping about 1,000 gallons a day. A 200-ton concentrator had been built, and a wire-rope tramway had been constructed across the river A power plant had also been erected on the north side of the river.

The mine has since produced a little ore but apparently has not been in continuous operation.

GOLD AND SILVER DEPOSITS.

Pioneer mines.—In the northern part of the quadrangle, at the south base of Pioneer Mountain and close to the stage road from Kelvin to Globe, dumps of considerable size testify to underground work done in the eighties at the now abandoned settlement of Pioneer. The principal mine appears to have been the Republic, but it is now entirely inaccessible. The shaft was started in diabase but evidently went into quartzite below, and the ore apparently occurred in quartzite.

Fragments from the dump show galena, sphalerite, quartz, and barite, but rich secondary silver minerals are reported to have occurred near the surface. Just northeast of the shaft narrow stopes, 3 to 4 feet wide, come to the surface and show the existence of a branching fissure, which strikes generally N. 60° E. and dips 75° NW. The main fissure apparently coincides with a normal fault on the northwest of which the beds are slightly downthrown.

El Capitan mine.—The El Capitan mine is on the north side of Silver Creek, in the Mescal Mountains, 1½ miles south-southwest of Old Baldy Mountain, and is accessible only by trail. The lode is a well-defined zone of crushing in Dripping Spring quartzite. It strikes N. 65° E. and dips 70° to 75° NW. It is opened by a tunnel at least 250 feet long, from which ore has been stoped to the surface. A winze from this tunnel is reported to be 150 feet deep and, as shown by the dump, went into diabase which underlies and almost surrounds the block of quartzite in which most of the underground work has been done.

The El Capitan mine is reported to have been first worked 40 years ago, when the now abandoned Government road through El Capitan Canyon was the main stage route between Fort Thomas and Florence.

Barbarossa mine.—At a locality known as the Barbarossa mine, 2¼ miles southeast of Troy, free gold to the value of a few thousand dollars, probably from $2,000 to $3,000, has been obtained by dry washing the soil and loose detritus on the Troy quartzite. One nugget is reported to have weighed about 22 ounces. The nuggets showed little rounding and presumably were supplied by the disintegration of some small vein close at hand.

Miller & Nissen mine.—The Miller & Nissen group of claims is at Cane Spring, on the road from Kelvin to Troy. At this point a nearly east and west dike of quartz diorite porphyry cuts diabase and Dripping Spring quartzite. At the mine the dike is about 15 feet wide, with diabase on the south side and diabase and quartzite on the north side. The ore, which is all oxidized, occurs along the north side of the dike and consists of free gold in a rusty matrix of vein quartz and crushed quartzite. At the time of visit no production was being made, although it was stated by Mr. Miller that a few tons of the ore had been worked in an arrastre. The workings in 1912 consisted of a tunnel a few hundred feet long and a 60-foot winze.

Lavell mine.—The Lavell mine, owned by the Lavell Gold Mining Co., has been opened since the geologic work on the Ray quadrangle was done. It is 6 miles north of Hayden and just north of the London-Arizona ground. The ore occurs as flat-lying lenses along bedding planes, apparently in Martin limestone, and near quartz diorite dikes.[73] Shipments to the middle of 1918 are given as 365 tons of ore, valued at $10,004. Although mainly gold the ore also carries silver, copper, and lead.

Cow Boy mine.—The Cow Boy mine is nearly 1¼ miles south-southeast of Dripping Spring Ranch, in the Dripping Spring Range, on a nearly eastward-trending porphyry dike, which has a maximum width of 50 feet and which cuts diabase and Mescal limestone. The mine was idle at the time of visit and was not examined in detail. The workings consist of two shafts, apparently about 50 and 75 feet deep, with a 150-foot tunnel and unsystematic shallow pits and burrows. The vein material is porous quartz stained with oxides of iron and manganese and showing a little carbonate of copper. The quartz is bunchy and apparently occurs partly in the Mescal limestone and partly in the porphyry. Free gold to the value of $12,000 was reported to have been taken from small bunches of ore near the surface.

Since the date of visit the mine has been operated in a small way and has yielded a maximum of about $3,000 in gold annually. According to Mr. C. W. McGraw, the owner and operator, much of the gold is in coarse wire form and occurs erratically in pockets, particularly where the vein is in limestone. A sample of concentrate sent by Mr. McGraw to the Geological Survey shows the presence of a lead vanadate, probably descloizite. The total output of the Cow Boy mine to the end of 1918 is estimated at about $25,000 in gold, with a little silver and lead.

Ripsey mine.—The Ripsey mine is in the southwest corner of the quadrangle and at the time of the writer's visit in 1911 had evidently been long idle. The Ripsey vein strikes N. 70° E. and dips 45°–50° S. The granite in the vicinity of the shaft—an incline on the vein—is cut by many intrusive masses of diabase, some of which rock appears in the hanging wall of the vein at the collar of the shaft. Nothing could be learned of the character or extent of the now inaccessible underground workings. Fragments of ore picked up on the dump show chalcopyrite, pyrite, sphalerite, and galena in a matrix consisting of a finely crystalline aggregate of quartz and calcite. This vein material may be a much altered dike rock. Although this ore might be successfully concentrated if a large quantity of it were available, it is apparently too low in grade to be worked on a small scale, and presumably the past operation of the mine was based on the former presence of material near the surface which had a larger content of gold and silver than is apparently present in the ore examined.

LEAD-SILVER DEPOSITS.

In the vicinity of Haley's cabin, about 2¼ miles east of Ray and 2,225 feet higher than that town, occur deposits of lead ore from which small shipments had been made from time to time prior to 1912, the ore being brought down to Ray on burros. The country rock of this ore, so far as could be seen from openings accessible in 1912, is the Devonian Martin limestone.

The principal work at that time had been done on the Cincinnati claim, a short distance northwest of the cabin. Here a thin sheet of diorite porphyry in Devonian limestone is cut by fissures that strike nearly east and west. The ore, chiefly cerusite together with some anglesite and residual galena, associated with abundant hematite and some limonite, occurs in the fissures and has replaced certain beds of the limestone for a few feet from the fissures. A considerable fault, which has dropped the Martin limestone against the Troy quartzite, passes just southwest of the cabin and curves to the west to its intersection with two other faults. (See the geologic map.) The fissures in which the ore occurs lie just north of this fault and presumably are subsidiary fractures that were opened at the time of the faulting. The workings in 1912 consisted of a small tunnel with branch drifts and had probably nowhere attained a depth of over 100 feet.

Since the visit on which the foregoing description is based was made the Ray Silver Lead Mining Co. has been shipping ore from this locality and apparently from the Cincinnati

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[71] The Mines Handbook, vol. 14, p. 313, 1920.

[72] The Mines Handbook, vol. 14, p. 194, 1920.

[73] The Mines Handbook, vol. 14, pp. 195–196, 1920.

claim. It is reported[74] that production began in 1917 and that in the middle of 1918 shipments were averaging about 750 tons a month. The ore was brought down to Ray by pack burros and at that time was shipped to the Empire Smelting & Refining Co., at Deming, N. Mex. This smelter is understood to be no longer in operation.

A short distance east of the cabin on the San Francisco claim a tunnel about 200 feet long has been run on a strong fissure that strikes N. 70° W. and dips 60° S. The tunnel is mostly in the Martin limestone, but the fissure for a part of its course follows a decomposed diorite porphyry dike. A seam of iron oxide, chiefly hematite, lies along the hanging wall, and in places some sandy cerusite lies under the hematite. No galena was seen. The hematite is not confined to the fissure but occurs in rather bunchy masses along a bed from 15 to 20 feet above the base of the Martin limestone, especially where the limestone has been fissured.

The Crown Point claim on the west slope of the main ridge, about three-quarters of a mile west of the cabin, is located on a fissure that strikes nearly east and dips about 72° N. The country rock is Devonian limestone. A shaft, 150 feet deep in March, 1912, had been sunk on this fissure and showed gouge, abundant oxide of iron, and a little cerusite. The zone of soft oxidized material is in places 5 feet wide. The main fissure appeared to be that of a normal fault with a throw of 50 to 100 feet. There are at least two nearly parallel fissures north of the one explored by the shaft.

MISCELLANEOUS MINERAL RESOURCES.

Vanadium.—The vanadium prospects of Mr. J. J. Sullivan, afterward taken over by the United States Vanadium Development Co., are 4 miles in a straight line east-northeast of Kelvin and about 2 miles nearly due south of Troy. The principal development in 1912 was on the south side of a narrow steep-walled ravine in diabase. Here a small mass of Mescal limestone, shown on the geologic map, is included in the diabase and is cut by a fissure that strikes N. 80° E. and dips 80°-85° S. A shaft 40 feet deep had been sunk on the fissure, which had also been explored by a few short tunnels. The ore occurred in the fissure and also extended out from the fissure for short distances along some of the bedding planes of the limestone. It consisted of vanadinite (lead chlorvanadate, $3Pb_3V_2O_8.PbCl_2$) and descloizite (basic vanadate of lead, zinc, etc., $(Pb, Zn)_2(OH)VO_4$), associated with galena, cerusite, wulfenite, and quartz. The vanadates are younger than the galena, as in places they occur as veinlets in that mineral. They are older, however, than some of the quartz.

About 600 feet south of the main workings a small open cut on a fissure in diabase exposed a little vanadinite in 1912. On the north side of the ravine and northeast of the main workings a strong fissure between diabase and Mescal limestone also contains a little vanadinite, and small quantities of the mineral were observed in other shallow prospecting cuts in the vicinity.

Although it is understood that a mill was built subsequently to the time of visit, there has been no recorded production of vanadium concentrates from this locality.

Limestone.—The Ray quadrangle contains abundant limestone, and a plentiful supply for the manufacture of lime or cement might be quarried from nearly every one of the numerous areas of Tornado limestone.

Building stone.—Some of the tuffaceous beds that constitute the lower part of the Gila formation north of Ray are easily quarried and dressed and furnish a soft but fairly durable building stone that has been used in some of the buildings in Ray and vicinity.

A harder stone that can be dressed into rough-surfaced blocks may be obtained from certain beds of the dolomitic Mescal limestone. This material has not been utilized, so far as known, within the Ray quadrangle, although it was employed in the masonry of the Roosevelt dam.

A tough, dark, hard stone in small blocks might be quarried in many places from the areas of diabase, and the granodiorite of the Troy basin would perhaps yield building stone of good quality, although probably not in large blocks.

Concrete materials and road metal.—Crushed stone suitable for concrete or for macadam could be obtained near at hand in almost any part of the quadrangle. The hardest and toughest rock could probably be had from the diabase, although the quartzites, limestones, granite rocks, and intrusive porphyries would yield excellent material for certain purposes. Sand and gravel can be obtained in abundance along the lower courses of the arroyos in the areas within which the Gila formation is the surface rock.

Water.—Abundant water may be obtained anywhere along the alluvial valley bottom of the Gila from wells below the surface of the river, and somewhat deeper wells in the Dripping Spring Valley would probably also tap an underground flow near the base of the alluvium. Mineral Creek carries surface water along parts of its course throughout the year, and a large part of the water used in the vicinity of Ray comes from a reservoir formed by a dam on this stream, above Ray, although the drinking water for that settlement is obtained from springs in the Dripping Spring Range. Small springs of good water are fairly abundant in this range and in the Mescal Range.

September, 1923.

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[74] The Mines Handbook, vol. 14, p. 326, 1920.

DEPARTMENT OF THE INTERIOR
ALBERT B. FALL, SECRETARY
U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

TOPOGRAPHY

ARIZONA
RAY QUADRANGLE

R.B. Marshall, Chief Geographer.
T.G. Gerdine, Geographer in charge.
Topography by Pearson Chapman, C.F. Eberly,
and reduced from map of Ray and Vicinity.
Control by T.M. Bannon and Thos. Winsor.
Surveyed in 1907-1908.

APPROXIMATE MEAN DECLINATION, 1922.

Scale $\frac{1}{62500}$

Contour interval 50 feet.
Datum is mean sea level.

Edition of Feb. 1910, reprinted 1922.

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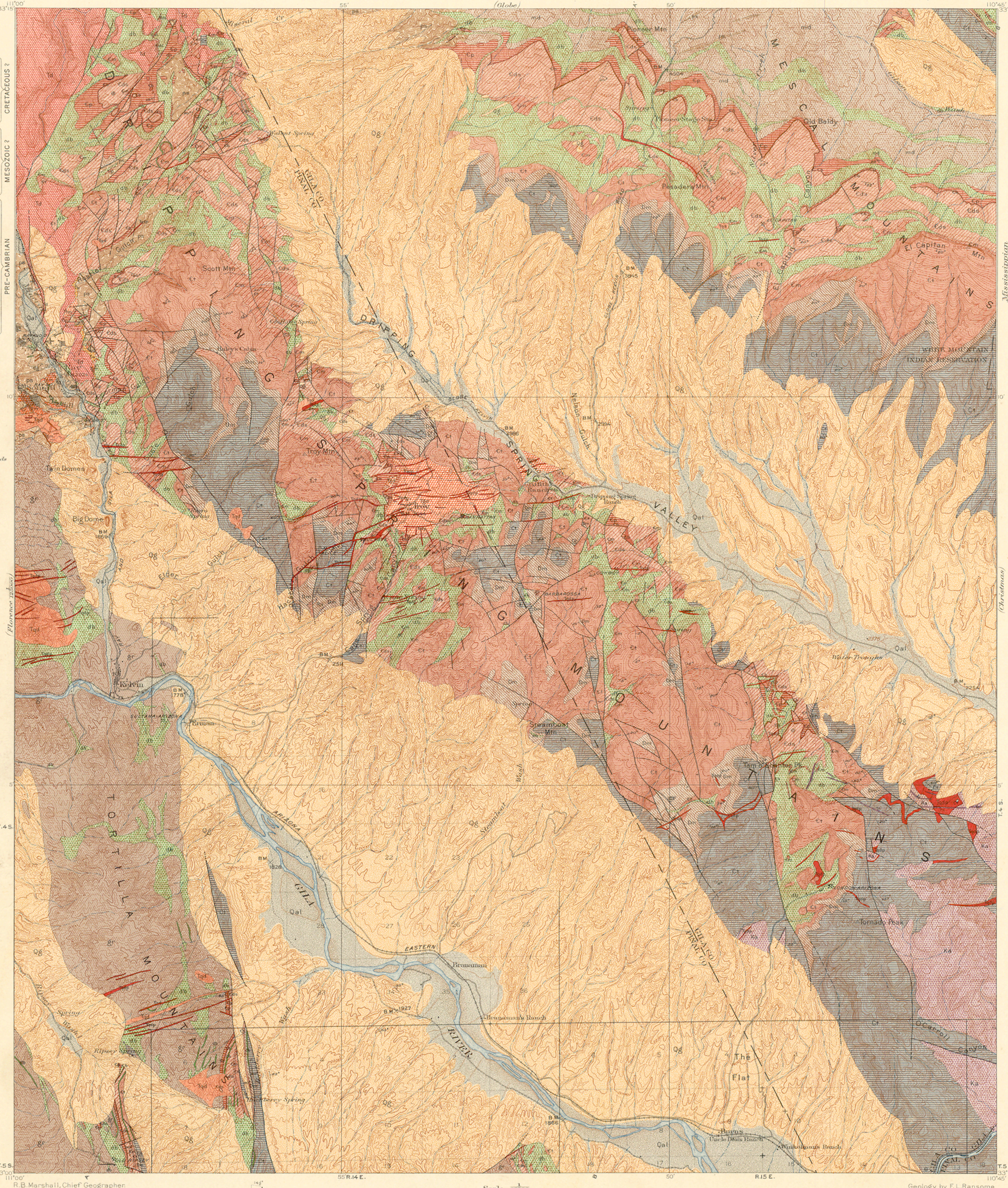
AREAL GEOLOGY

ARIZONA
RAY QUADRANGLE



EXPLANATION

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)

QUATERNARY

Recent

Qal **Alluvium**
(gravel, sand, and silt along present stream ways)

Pleistocene

Qg **Gila conglomerate**
(Fluviatile conglomerates, coarse in places near the mountains, grading into fine silts, probably in part lacustrine, in wide valleys; includes some beds of tuff and infusorial earth)

UNCONFORMITY

TERTIARY

Tw **Whitetail conglomerate**
(subangular fragments chiefly of diabase and limestone accumulated by streams and hillside wash)

UNCONFORMITY

CARBONIFEROUS

Mississippian and Pennsylvanian

Ct **Tornado limestone**
(light-gray limestone thick-bedded in lower part, thinner bedded in upper part. Fossils abundant in upper beds)

DEVONIAN

Dm **Martin limestone**
(thin-bedded, yellowish to dark-gray, somewhat magnesian limestone; upper part fossiliferous, some yellow arenaceous beds in lower half)

UNCONFORMITY?

CAMBRIAN AND POSSIBLY ALSO ORDOVICIAN AND SILURIAN

Apache group (Christmas)

€t **Troy quartzite**
(cross-bedded pebbly quartzite, chiefly thick-bedded, but thin, flaggy beds, marked with worm casts, in upper portion)

€m **Mescal limestone**
(thin-bedded, white to buff limestone, in part dolomitic, with abundant knotty layers of chert. Includes, as mapped, an overlying flow of vesicular basalt)

€ds **Dripping Spring quartzite**
(fine grained, ripple-marked and sun-cracked, arkosic quartzite, much of it banded dark red and gray)

€b **Barnes conglomerate**
(coarse, well-rounded, quartzose pebbles in arkosic matrix)

€p **Pioneer shale**
(dark, reddish-brown, spotted with yellow, arenaceous shale, grading into arkosic quartzite at base. Includes, as mapped, underlying thin Scanlan conglomerate)

GREAT UNCONFORMITY

PRE-CAMBRIAN

Metamorphic rocks

ps **Pinal schist**
(chiefly fine-grained quartz-sericite schist, metamorphosed fine arkosic sediments. Includes some metamorphosed grits and a little schistose igneous material)

IGNEOUS ROCKS

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

LATE TERTIARY ?

Td **Dacite**
(thick extensive flow with a little tuff at base, in northwestern part of quadrangle)

EARLY TERTIARY ?

Tr **Rhyolite porphyry**
(rhyolite porphyry dikes east of Tam o' Shanter Peak)

Tqdp **Quartz diorite porphyry**
(dikes and small intrusive masses, particularly abundant near Troy and Tornado Peak)

Tgd **Granodiorite**
(intrusive mass in Troy Basin)

Ttm **Teapot Mountain porphyry**
(dikes and irregular intrusive masses of quartz monzonite porphyry near Ray)

Tgm **Granite Mountain porphyry**
(irregular intrusive masses of quartz monzonite porphyry near Ray)

Tqd **Quartz diorite**
(dikes and comparatively small intrusive masses)

Explanation is continued on the left margin.

IGNEOUS ROCKS
(continued)

CRETACEOUS ?

Ka **Andesite tuff and breccia**
(chiefly consolidated pyroclastic material with contemporaneous dikes; possibly includes some lava flows)

MESOZOIC ?

db **Diabase**
(typically a medium-grained, ophitic, olivinitic diabase or dolerite. Irregular sills with many cross-cutting connections; intruded especially in the Mescal limestone)

PRE-CAMBRIAN

md **Madera diorite**
(quartz-mica diorite, apparently grading locally into granodiorite or quartz monzonite; in places gneissoidal. Irregular batholithic intrusions in the Pinal schist of the Pinal Range)

gr **Granite**
(biotite granite, generally coarsely porphyritic and crumbling. Batholithic intrusive mass extensively exposed in the Tortilla Range)

— Known fault

- - - Probable fault

······ Concealed fault
(covered by younger deposits)

Dip of fault plane

Overthrust side of thrust fault

Strike and dip of stratified rocks

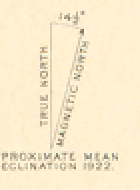
Strike of vertical beds

● *Horizontal beds*

⚒ *Mine*

x *Prospect*

R.B. Marshall, Chief Geographer.
T.G. Gerdine, Geographer in charge.
Topography by Pearson Chapman, C.F. Eberly, and reduced from map of Ray and Vicinity
Control by T.M. Bannon and Thos. Winsor.
Surveyed in 1907-1908.



APPROXIMATE MEAN DECLINATION 1922.

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

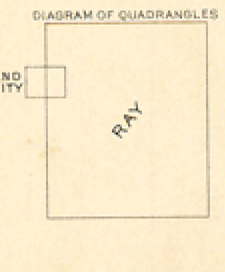
1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 50 feet.

Datum is mean sea level.

Edition of Oct. 1922

DIAGRAM OF QUADRANGLES

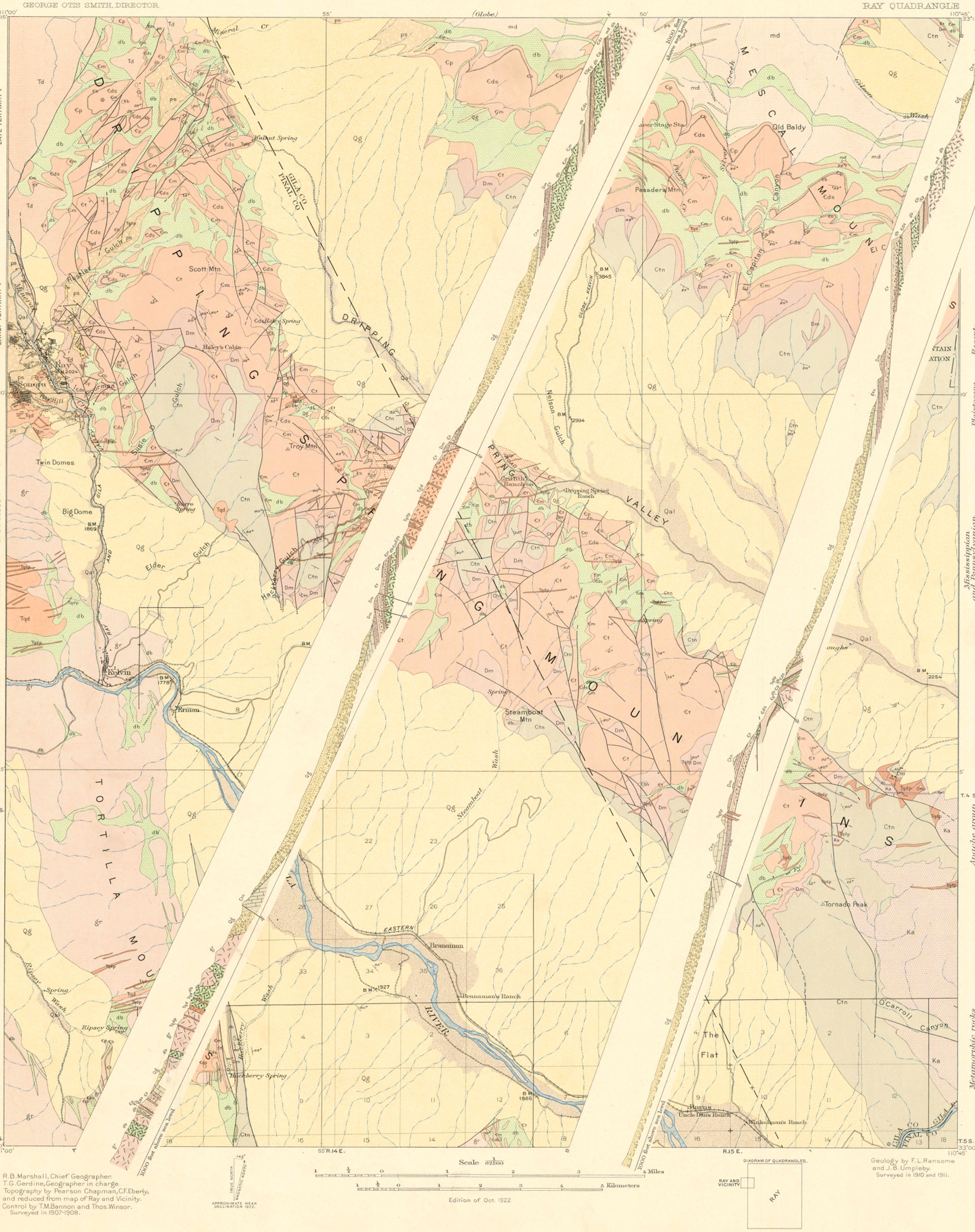


Geology by F.L. Ransome and J.B. Umpleby.
Surveyed in 1910 and 1911.

DEPARTMENT OF THE INTERIOR
ALBERT B. FALL, SECRETARY
U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

STRUCTURE SECTIONS

ARIZONA
RAY QUADRANGLE



EXPLANATION
(continued)

IGNEOUS ROCKS

SHEET SYMBOL	SECTION SYMBOL	Name	Age
Td		**Dacite** *(thick extensive flow with a little tuff at base; in northwestern part of quadrangle)*	LATE TERTIARY ?
	Tr	**Rhyolite porphyry** *(rhyolite porphyry dikes east of Tam o' Shanter Peak)*	EARLY TERTIARY ?
Tqdp	Tqdp	**Quartz diorite porphyry** *(dikes and small intrusive masses, particularly abundant near Troy and Tornado Peak)*	
Tgd	Tgd	**Granodiorite** *(intrusive mass in Troy Basin)*	
Ttm		**Teapot Mountain porphyry** *(dikes and irregular intrusive masses of quartz monzonite porphyry near Ray)*	
Tgm		**Granite Mountain porphyry** *(irregular intrusive masses of quartz monzonite porphyry near Ray)*	
Tqd	Tqd	**Quartz diorite** *(dikes and comparatively small intrusive masses)*	
Ka		**Andesite tuff and breccia** *(chiefly consolidated pyroclastic material with contemporaneous dikes; possibly includes some lava flows)*	CRETACEOUS ?
db	db	**Diabase** *(typically a medium-grained, ophitic, olivinitic diabase or dolerite. Irregular sills with many cross-cutting connections; intruded especially in the Mescal limestone)*	MESOZOIC ?
md	md	**Madera diorite** *(quartz-mica diorite, apparently grading locally into granodiorite or quartz monzonite; in places gneissoidal. Irregular batholithic intrusions in the Pinal schist of the Pinal Range)*	PRE-CAMBRIAN
gr	gr	**Granite** *(biotite granite, generally coarsely porphyritic and crumbling. Batholithic intrusive mass extensively exposed in the Tortilla Range)*	

Known fault

Probable fault

Concealed fault
(covered by younger deposits)

Dip of fault plane
Overthrust side of thrust faults
Strike and dip of stratified rocks
Strike of vertical beds
Horizontal beds

EXPLANATION

SEDIMENTARY ROCKS

SHEET SYMBOL	SECTION SYMBOL	Name	Epoch / group	Period
Qal		**Alluvium** *(gravel, sand, and silt along present stream ways)*	*Recent*	QUATERNARY
Qg	Qg	**Gila conglomerate** *(Fluviatile conglomerates, coarse in places near the mountains, grading into fine silts, probably in part lacustrine, in wide valleys; includes some beds of tuff and infusorial earth)*	*Pleistocene*	
		UNCONFORMITY		
Tw		**Whitetail conglomerate** *(subangular fragments chiefly of diabase and limestone accumulated by streams and hillside wash)*		TERTIARY
		UNCONFORMITY		
Ctn	Ctn	**Tornado limestone** *(light-gray limestone thick-bedded in lower part, thinner bedded in upper part. Fossils abundant in upper beds)*	*Mississippian and Pennsylvanian*	CARBONIFEROUS
Dm	Dm	**Martin limestone** *(thin-bedded, yellowish to dark-gray, somewhat magnesian limestone; upper part fossiliferous; some yellow arenaceous beds in lower half)*		DEVONIAN
		UNCONFORMITY ?		
€t	€t	**Troy quartzite** *(cross-bedded pebbly quartzite, chiefly thick-bedded, but thin, flaggy beds, marked with worm casts, in upper portion)*	*Apache group*	CAMBRIAN AND POSSIBLY ALSO ORDOVICIAN AND SILURIAN
€m	€m	**Mescal limestone** *(thin-bedded, white to buff limestone, in part dolomitic, with abundant knotty layers of chert. Includes, as mapped, an overlying flow of vesicular basalt)*		
€ds	€ds	**Dripping Spring quartzite** *(fine-grained, ripple-marked and sun-cracked, arkosic quartzite, much of it banded dark red and gray)*		
€b	€b	**Barnes conglomerate** *(coarse, well-rounded, quartzose pebbles in arkosic matrix)*		
€p	€p	**Pioneer shale** *(dark, reddish-brown, spotted with yellow, arenaceous shale, grading into arkosic quartzite at base. Includes, as mapped, underlying thin Scanlan conglomerate)*		
		GREAT UNCONFORMITY		
ps		**Pinal schist** *(chiefly fine-grained quartz-sericite schist; metamorphosed fine arkosic sediments. Includes some metamorphosed grits and a little schistose igneous material)*	*Metamorphic rocks*	PRE-CAMBRIAN

Explanation is continued on the left margin.

R.B.Marshall, Chief Geographer.
T.G.Gerdine, Geographer in charge.
Topography by Pearson Chapman, C.F.Eberly,
and reduced from map of Ray and Vicinity.
Control by T.M.Bannon and Thos.Winsor.
Surveyed in 1907-1908.

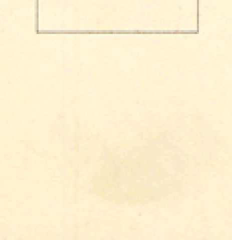
TRUE NORTH
MAGNETIC NORTH
14½°
APPROXIMATE MEAN DECLINATION 1922.

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Edition of Oct. 1922

DIAGRAM OF QUADRANGLES.


Geology by F.L.Ransome
and J.B.Umpleby.
Surveyed in 1910 and 1911.

DEPARTMENT OF THE INTERIOR
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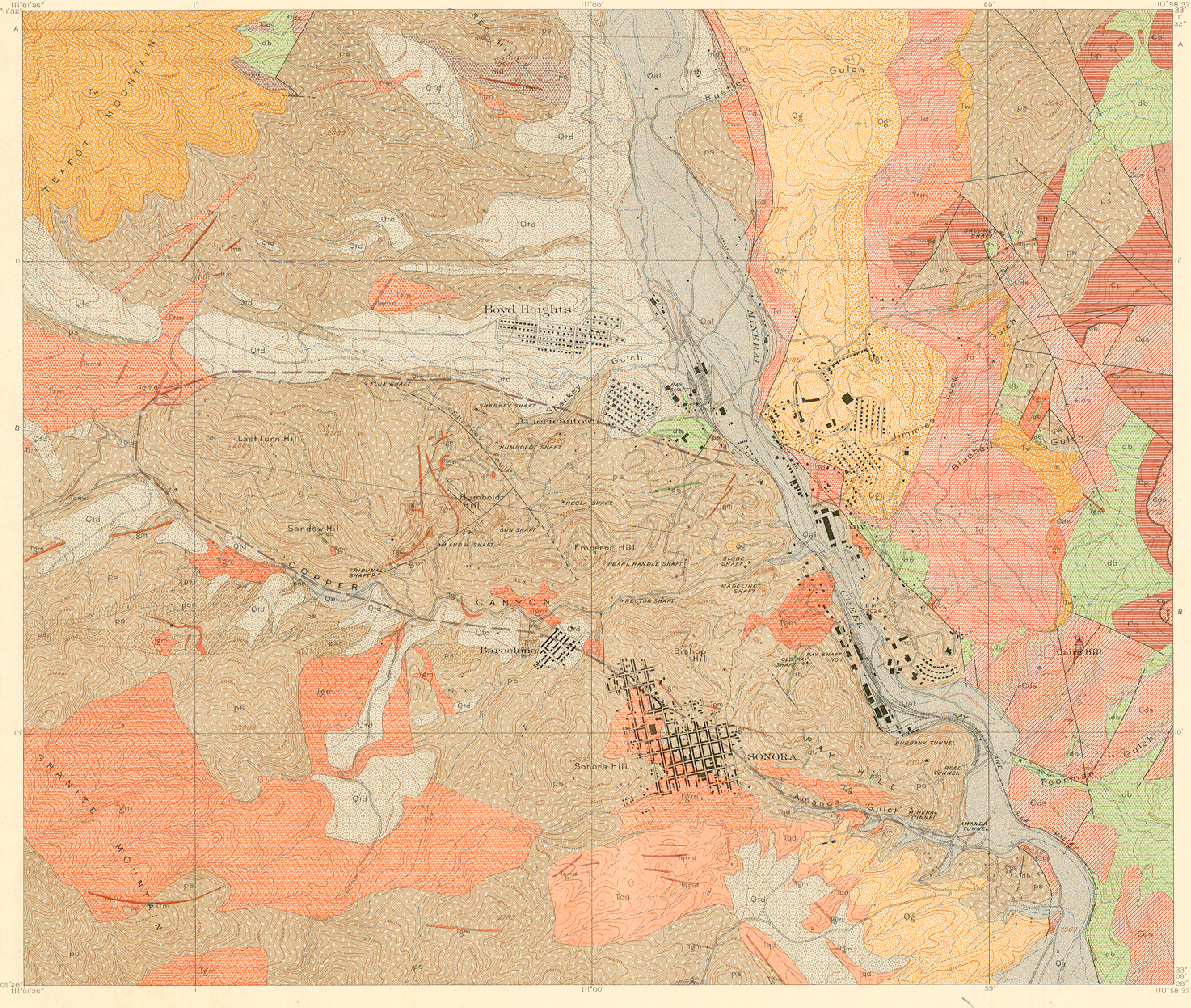
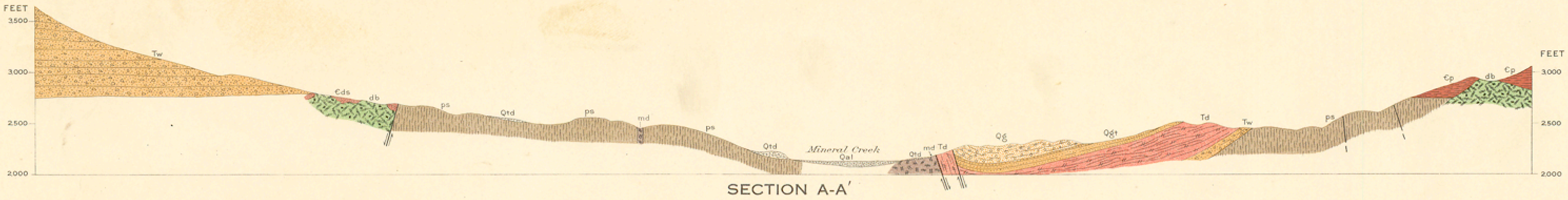
GEORGE OTIS SMITH, DIRECTOR

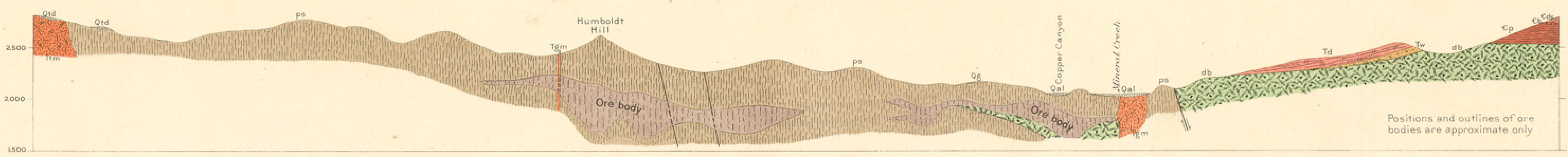
ECONOMIC GEOLOGY

ARIZONA
(PINAL COUNTY)
RAY AND VICINITY





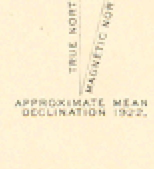
SECTION A-A′



Positions and outlines of ore bodies are approximate only

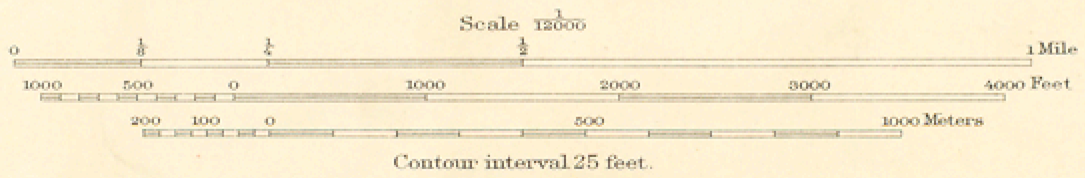
SECTION B-B′

R.B. Marshall, Chief Geographer.
T.G. Gerdine, Geographer in charge.
Topography by W.M. Beaman.
Control by T.M. Bannon and Thomas Winson.
Surveyed in 1910.
Culture revised in 1917 by W.M. Beaman.



APPROXIMATE MEAN DECLINATION 1922.

Scale $\frac{1}{12000}$



Contour interval 25 feet.
Datum is mean sea level.
Edition of April 1922.

Geology by F.L. Ransome
and J.B. Umpleby.
Surveyed in 1910 and 1911.

EXPLANATION

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)

QUATERNARY

Recent

Qal
Alluvium
(gravel, sand, and silt along present stream ways)

Qtd
Terrace deposits
(unconsolidated angular and gravelly detritus derived from adjacent hill slopes and dissected by present streams)

Pleistocene

Qg
Qgt
Gila conglomerate
(Fluviatile conglomerates, coarse in places near the mountains, grading into fine silts, probably in part lacustrine, in wide valleys; local basal portion of well-stratified tuff and pumiceous beds, Qgt)

UNCONFORMITY

TERTIARY

Tw
Whitetail conglomerate
(subangular fragments chiefly of diabase and limestone accumulated by streams and as hill-side wash)

UNCONFORMITY

CAMBRIAN AND POSSIBLY ALSO ORDOVICIAN AND SILURIAN

Apache group

Ct
Troy quartzite
(cross-bedded pebbly quartzite, chiefly thick bedded, but thin, flaggy beds, marked with worm casts in upper portion)

Cds
Dripping Spring quartzite
(fine-grained, ripple-marked and sun-cracked, arkosic quartzite, much of it banded dark red and gray)

Cb
Barnes conglomerate
(coarse, well-rounded, quartzose pebbles in arkosic matrix)

Cp
Pioneer shale
(dark, reddish-brown, spotted with yellow; arenaceous shale, grading into arkosic quartzite at base. Includes, as mapped, underlying thin Scanlan conglomerate)

GREAT UNCONFORMITY

PRE-CAMBRIAN

Metamorphic rocks

ps
psr
Pinal schist
(chiefly fine-grained quartz-sericite schist; metamorphosed fine arkosic sediments. An uncommon variety, probably an altered rhyolite, psr)

IGNEOUS ROCKS

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

LATE TERTIARY ?

Td
Dacite
(thick extensive flow with a little tuff at base)

EARLY TERTIARY ?

Tqmd
Dikes of quartz monzonite porphyry and quartz diorite porphyry

Ttm
Teapot Mountain porphyry
(dikes and irregular intrusive masses of quartz monzonite porphyry)

Tgm
Granite Mountain porphyry
(irregular intrusive masses of quartz monzonite porphyry)

Tqd
Quartz diorite
(intrusive mass)

MESOZOIC ?

db
Diabase
(typically a medium-grained, ophitic, olivinitic diabase or dolerite. Irregular sills with many cross-cutting connections)

PRE-CAMBRIAN

md
Madera diorite
(quartz-mica diorite, apparently grading locally into granodiorite or quartz monzonite; in places gneissoidal. Irregular batholithic intrusions in the Pinal schist of the Pinal Range)

gr
Granite
(biotite granite, generally coarsely porphyritic and crumbling. Batholithic intrusive mass extensively exposed in the Tortilla Range)

Approximate outline of ore-bearing area

Known fault

Probable fault

Concealed fault
(covered by younger deposits)

Dip of fault plane
Overthrust side of thrust fault
Strike and dip of stratified rocks

Mine shaft
Mine tunnel
Prospect

ILLUSTRATIONS

PLATE I.—VIEW LOOKING NORTHEASTWARD ACROSS DRIPPING SPRING VALLEY TO THE MESCAL RANGE.

Shows intricately dissected valley fill of Gila conglomerate.

PLATE II.—BARNES CONGLOMERATE ON EL CAPITAN CREEK, MESCAL RANGE.

PLATE III.—VIEW LOOKING NORTHWESTWARD TOWARD PIONEER CREEK, MESCAL RANGE, SHOWING DIP SLOPE ON DRIPPING SPRING QUARTZITE TO RIGHT.

PLATE IV.—TYPICAL HILLSIDE EXPOSURE OF THE CHERTY MESCAL LIMESTONE IN THE DRIPPING SPRING RANGE, 2 MILES SOUTH OF DRIPPING SPRING RANCH.

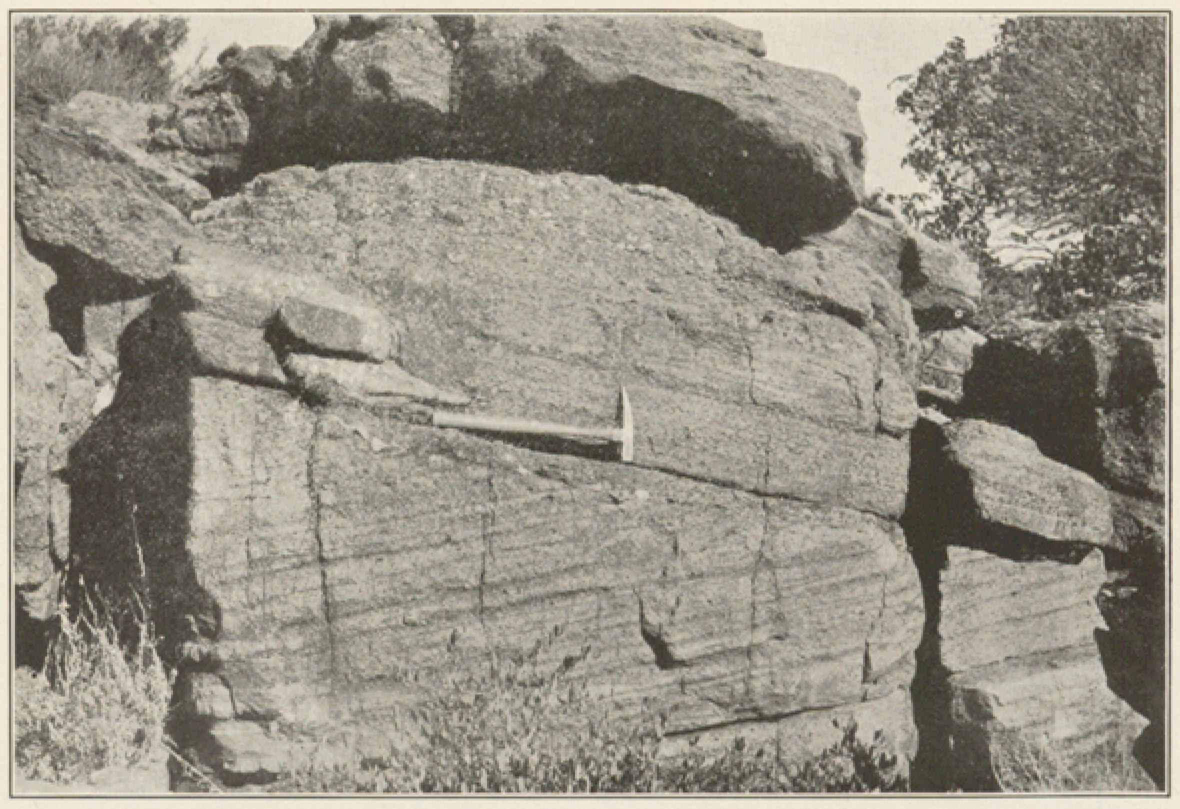


PLATE V.—CROSS-BEDDED PEBBLY TROY QUARTZITE, DRIPPING SPRING RANGE.

PLATE VI.—TYPICAL HILLSIDE EXPOSURE OF THE DEVONIAN ON EL CAPITAN CREEK, MESCAL RANGE.

The Devonian limestone forms the smooth slope between the bluff of Troy quartzite in the middle ground and the cliffs of Tornado limestone above.

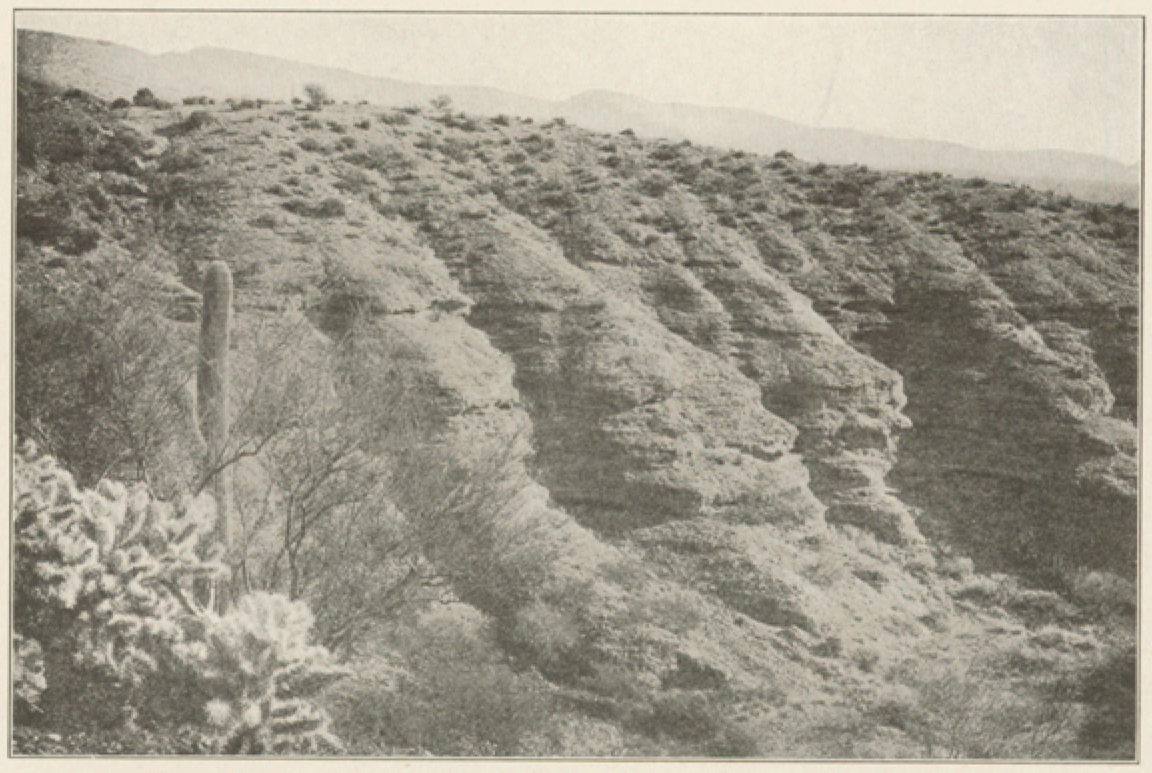


PLATE VII.—TYPICAL EXPOSURE OF THE GILA CONGLOMERATE, SHOWING CHARACTERISTIC EROSION.

About 2½ miles east-southeast of Dripping Spring Ranch.

PLATE VIII.—GENERAL VIEW OF THE RAY DISTRICT LOOKING NORTHWESTWARD FROM THE EAST SIDE OF MINERAL CREEK.

On the left, across the creek, is the No. 1 mine of the Ray Consolidated Copper Co. To the right are the head frame, crusher house, and ore bin of the No. 2 mine, and still farther to the right, nearly in line with the tall cactus, are the corresponding structures of the No. 3 mine. The prominent peak near the middle of the view is Teapot Mountain. The lighter-colored, indistinctly stratified rock under the dark dacite capping the mountain is the Whitetail conglomerate.

AGE OF THE FORMATIONS.

Geologic time.—The larger divisions of geologic time are called *periods.* Smaller divisions are called *epochs,* and still smaller ones are called *stages.* The age of a rock is expressed by the name of the time division in which it was formed.

The sedimentary formations deposited during a geologic 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.*

As sedimentary deposits accumulate successively the younger rest on the older, and their relative ages may be determined by observing their positions. In many regions of intense disturbance, however, the beds have been overturned by folding or their relations to adjacent beds have been changed by faulting, so that it may be difficult to determine their relative ages from their present positions at the surface.

Many stratified rocks contain *fossils,* the remains or imprints of plants and animals which, at the time the strata were deposited, lived in bodies of water or were washed into them or were buried in surficial deposits on the land. Such rocks are said to be fossiliferous. A study of these fossils has shown that the forms of life at each period of the earth's history were to a great extent different from the forms at other periods. Only the simpler kinds of marine plants and animals lived 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 forms that 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. If two sedimentary formations are geographically so far apart that it is impossible to determine their relative positions the characteristic fossils found in them may determine which was deposited first. Fossils are also of value in determining the age of formations in the regions of intense disturbance mentioned above. The fossils found in the strata of different areas, provinces, and continents afford the most effective means of combining local histories into a general earth history.

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

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

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

Each symbol consists of two or more letters. The symbol for a formation whose age is known includes the system symbol, which is a capital letter or monogram; the symbols for other formations are composed of small letters.

The names of the geologic time divisions, arranged in order from youngest to oldest, and the color and symbol assigned to each system are given in the subjoined table.

Geologic time divisions and symbols and colors assigned to the rock systems.

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

DEVELOPMENT AND SIGNIFICANCE OF SURFACE FORMS.

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

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

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

THE GEOLOGIC MAPS AND SHEETS IN THE FOLIO.

Areal-geology map.—The map showing the surface areas occupied by the several formations is called an *areal-geology map.* On the margin is an explanation, which is the key to the map. To ascertain the meaning of any color or pattern and its letter symbol the reader should look for that color, pattern, and symbol in the explanation, where he will find the name and description of the formation. If he desires to find any particular formation he should examine the explanation and find its name, color, and pattern and then trace out the areas on the map corresponding in color and pattern. The explanation shows also parts of the geologic history. The names of formations are arranged in columnar form, grouped primarily according to origin—sedimentary, igneous, and crystalline of unknown origin—and those within each group are placed in the order of age, the youngest at the top.

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

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

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

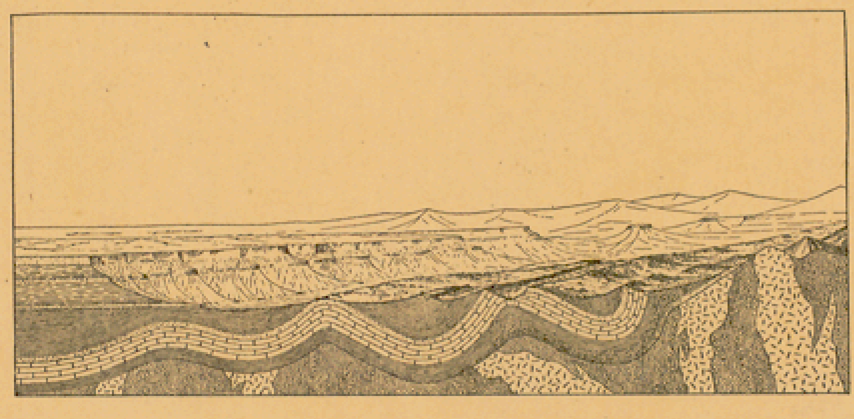
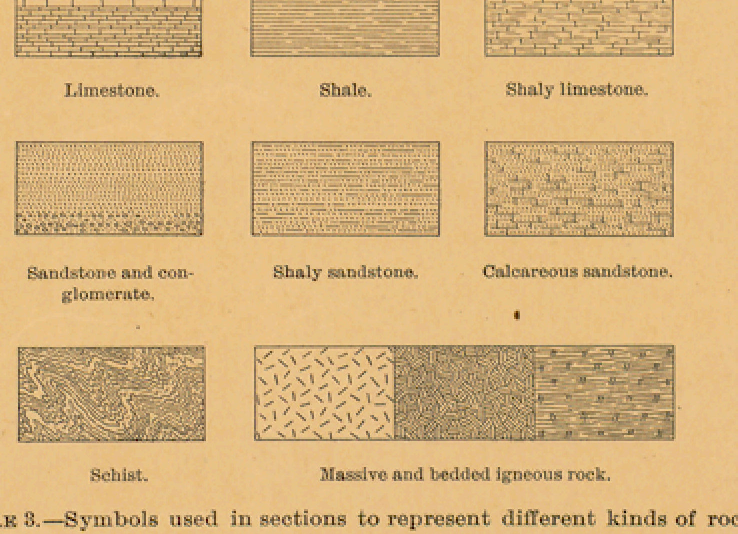


FIGURE 2.—Sketch showing a vertical section below the surface at the front and a view beyond.

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



Limestone. Shale. Shaly limestone.

Sandstone and conglomerate. Shaly sandstone. Calcareous sandstone.

Schist. Massive and bedded igneous rock.

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

The plateau shown at the left of figure 2 presents toward the lower land an escarpment, or front, made up of sandstone, which forms the cliffs, and shale, which forms the slopes. The broad belt of lower land is traversed by several ridges, which, as shown in the section, correspond to the outcrops of a folded 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 beds appear at the surface their thickness can be measured and the angles at which they dip below the surface can be observed, and by means of these observations their positions underground are inferred. The direction of the intersection of the surface of a dipping bed with a horizontal plane is called its *strike.* The inclination of the bed to the horizontal plane, measured at right angles to the strike, is called its *dip.*

In many regions the beds are bent into troughs and arches, such as are seen in figure 2. The arches are called *anticlines* and the troughs *synclines.* As the materials that formed the sandstone, shale, and limestone were deposited beneath the sea in nearly flat layers the fact that the beds are now bent and folded shows that forces have from time to time caused the earth's crust to wrinkle along certain zones. In places the beds are broken across and the parts have slipped past each other. Such breaks are termed *faults.* Two kinds of faults are shown in figure 4.

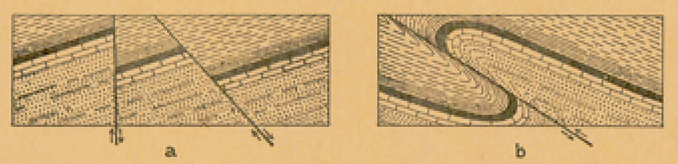


FIGURE 4.—Ideal sections of broken and bent strata, showing (a) *normal* faults and (b) a *thrust* or *reverse* fault.

At the right of figure 2 the section shows schists that are traversed by igneous rocks. The schists are much contorted, and the form or arrangement of their masses underground can not be inferred. Hence that part of the section shows only what is probable, not what is known by observation.

The section also shows three sets of formations, distinguished by their underground relations. The uppermost set, seen at the left, is made up of beds of sandstone and shale, which lie in a horizontal position. These beds were laid down under water but are now high above the sea, forming a plateau, and their change of altitude shows that this part of the earth's surface has been uplifted. The beds of this set are *conformable*—that is, they are parallel and show no break in sedimentation.

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

The horizontal beds of the plateau rest upon the upturned, eroded edges of the beds of the middle set, as shown at the left of the section. The beds of the upper set are evidently younger than those of the middle set, which must have been folded and eroded between the time of their deposition and that of the deposition of the upper beds. The upper beds are *unconformable* to the middle beds, and the surface of contact is an *unconformity.*

The lowest set of formations consists of crystalline schists and igneous rocks. At some period of their history the schists were folded or plicated by pressure and intruded by masses of molten rock. The overlying beds of the middle set have not been traversed by these intrusive rocks nor have they been affected by the pressure of the intrusion. It is evident that considerable time elapsed between the formation of the schists and the beginning of the deposition of the beds of the middle set, and during this time the schists were metamorphosed, disturbed by the intrusion of igneous masses, and deeply eroded. The contact between the middle and lowest sets is another unconformity; it marks a period of erosion between two periods of deposition.

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

Columnar section.—Many folios include a *columnar section,* which contains brief descriptions of the sedimentary formations in the quadrangle. It shows the character of the rocks as well as the thickness of the formations and the order of their accumulation, the oldest at the bottom, the youngest at the top. It also indicates intervals of time that correspond to events of uplift and degradation and constitute interruptions of deposition.

THE TEXT OF THE FOLIO.

The text of the folio states briefly the relation of the area mapped to the general region in which it is situated; points out the salient natural features of the geography of the area and indicates their significance and their history; considers the cities, towns, roads, railroads, and other human features; describes the geology and the geologic history; and shows the character and the location of the valuable mineral deposits.

GEORGE OTIS SMITH,

January, 1922. *Director.*

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