DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

126

GEOLOGIC ATLAS

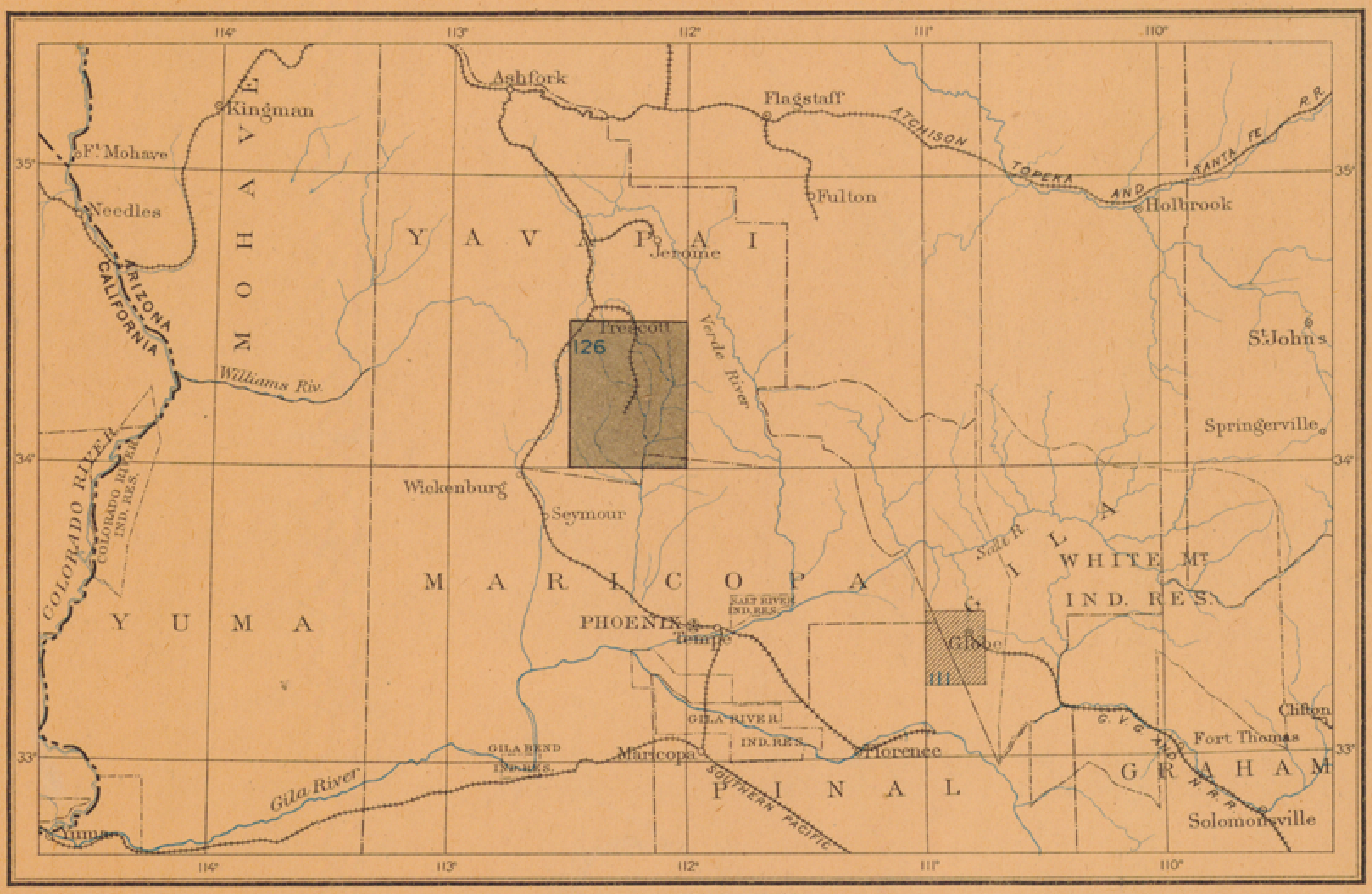
OF THE

UNITED STATES

BRADSHAW MOUNTAINS FOLIO

ARIZONA

INDEX MAP



SCALE: 40 MILES=1 INCH

BRADSHAW MOUNTAINS FOLIO

OTHER PUBLISHED FOLIOS

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

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EOLOGIC AND TOPOGRAPHIC ATLAS OF UNITED STATES.

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

THE TOPOGRAPHIC MAP.

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

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

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

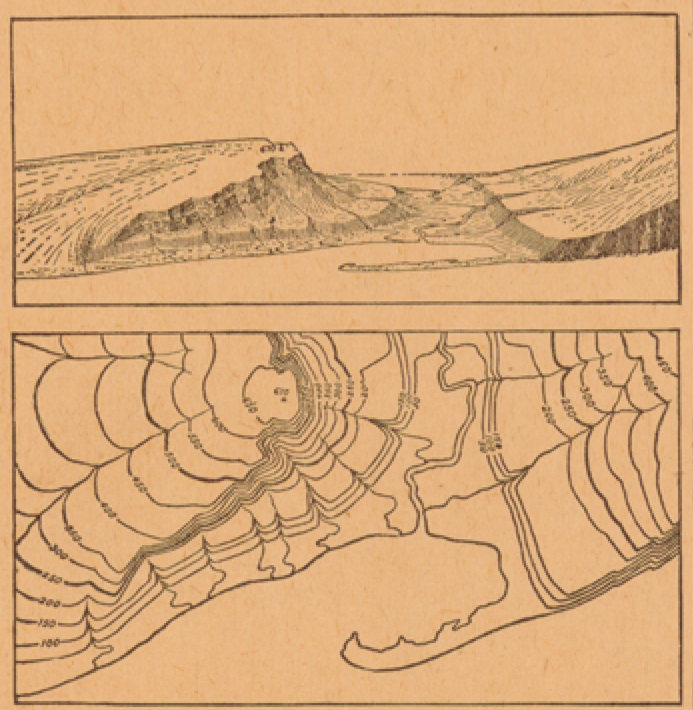


Fig. 1.—Ideal view and corresponding contour map.

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

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

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

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

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

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

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

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

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

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

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

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

THE GEOLOGIC MAPS.

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

KINDS OF ROCKS.

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

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

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

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

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

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

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

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

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

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

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

FORMATIONS.

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

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

AGES OF ROCKS.

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

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

(Continued on third page of cover.)

DESCRIPTION OF BRADSHAW MOUNTAINS QUADRANGLE.

By T. A. Jaggar, Jr., and Charles Palache.

INTRODUCTION.

Location.—The Bradshaw Mountains quadrangle lies between parallels 34° and 34° 30′ north latitude and meridians 112° and 112° 30′ west longitude. It measures approximately 34.5 miles from north to south and 28.6 miles from east to west, and covers 986 square miles. The quadrangle is in the southeastern part of Yavapai County, Ariz., and includes a very small part of Maricopa County in its extreme southeast corner; a portion of the Prescott Forest Reserve occupies the western half—a mountainous region including all the higher summits of the Bradshaw Range. The city of Prescott is 2 miles north of the northwest corner of the quadrangle, and Jerome, a mining town, is 17 miles north of the northeast corner. The only settlements at the time of the survey were small mining camps and scattered ranches. On the north the Prescott and Eastern Railroad enters the quadrangle near Valverde Smelter and terminates at Mayer station. The eastern third of the quadrangle consists largely of low-lying desert land and basaltic mesas.

Topography.—The Bradshaw Mountains form a natural divide through the quadrangle from north to south, culminating in Mount Union, which rises 7971 feet above tide. Several other peaks on the west and northwest reach altitudes near 7000 feet, and southward the higher summits range from 4000 to 6000 feet. Across the Agua Fria Valley to the southeast the New River Mountains rise to heights of 6000 feet, but north of them the flat-topped mesas and desert waste from Stoddard to Squaw Creek average only 4000 feet, and the general aspect of the country is relatively low and flat. The lowest part of Agua Fria Canyon is here 1800 feet above sea level, making the maximum range of relief within the area over 6000 feet. Bigbug Creek flows though a wide, flat lowland in the region about Mayer, where here and there salient reefs of metamorphic quartzite project like black combs, or walls, above the general surface. The Bradshaw Mountains have bare, rocky surfaces in the wilder southern range, and wooded spurs in the northern peaks, with gentle slopes and rounded eminences. Characteristic phases of the topography are shown in figs. 1 to 4 on the illustration sheet.

Drainage.—The principal streams are Agua Fria River on the east, into which flow Turkey, Poland, and Bigbug creeks, which drain the eastern slopes of the mountains. The Hassayampa and its branches drain the western slopes. The valleys of these watercourses vary from open, pine-clad basins in the high mountains to deep gulches and box canyons in the slopes of the range. Where the streams emerge into the open desert country they usually sink away and their courses are dry, stony bottoms, which fill with water only after heavy showers in the mountains. Such showers are common in summer, and the sudden rush of a mud flood is sometimes a menace to human life. Agua Fria River cuts a deep trench in the basalt sheets of Black Mesa, producing a table-land topography, in marked contrast to all the other topographic features of the Bradshaw Mountains quadrangle.

General geologic structure.—The higher peaks near Prescott, which culminate in Mount Union, are composed of gneissic granites and schists. Such rocks, which have in general a north-northeast trend, control the topographic forms and geologic structures of the Bradshaw Mountains.

The schists are variously hornblendic, quartzose, argillaceous, or micaceous, and include many members of unquestionable sedimentary origin. Here and there intrusive quartz-diorite bodies occur in the high pine-clad mountain basins, and frequently sulphide ores are found along their contacts; other igneous rocks occur as dikes or stocks.

The main Bradshaw Range, in the middle of the southern half of the quadrangle, consists largely of massive coarse granite which has split the schists apart as a great intrusive wedge and, under the wearing action of atmospheric erosion, stands in high relief as a resistant rock.

The schists farther north, near Mayer, have weathered to low relief, forming a wide valley, where the quartzite combs are traceable for many miles by their prominence above the general level.

Agua Fria River skirts the edge of horizontal basalt flows interbedded with agglomerates, which extend to the east beyond the quadrangle, and similar volcanics, but of less basic character, lie in the trough of the Hassayampa Valley and outcrop along the western and southern boundaries of the quadrangle. The lavas lie in the hollows of an irregular topography carved in the old schists and crystallines, and no sedimentary rocks of intermediate age are here present.

Precipitation and vegetation.—The rainfall, here as elsewhere in Arizona, is much greater on the higher lands than in the wide dry valleys that separate the mountain ranges. The Bradshaw Range receives a higher precipitation than Prescott, 2 miles to the north (altitude 5500 feet above sea level), where the average annual rainfall for ten years has been 15.18 inches and the average temperature is 58° F. At Phoenix, a city farther south in the Gila Valley, at an altitude of 1100 feet, the average temperature is 70°, and the rainfall 7.21 inches, or less than one-half the above. In the Bradshaw Mountains quadrangle the difference between the rainfall on the summit of Mount Union and that of the Agua Fria Valley is probably as great as between these two cities. Heavy thunder showers occur over the mountains almost daily during portions of July and August, and the winter rainy season lasts four months, from December to March inclusive, when the mountains are frequently covered with snow.

The heaviest timber grows in the mountain basins at altitudes of from 5000 to 6000 feet, and consists largely of the yellow pine (*Pinus ponderosa*) and its varieties. These forests are especially noteworthy in the basins of Groom Creek, Crown King, and Minnehaha, where the soil is in each case of dioritic origin. Along the upper Agua Fria and its tributaries the river bottoms contain mesquite, cottonwood, willow, alder, hackberry, and aspen; the mountain spurs are frequently covered with a close and impassable mat of shrubs and small trees, pin oak, nut pine, greasewood, and juniper; toward the southern half of the quadrangle the desert shrubs become more abundant, including giant cactus, prickly pear, and other cacti, ocotillo, acacia, yucca, and agave.

Population.—The population is that of a mountainous mining district, with scattered camps incessantly changing. In 1901, when this survey was made, there were about 1000 persons in the quadrangle. Crown King was reported in 1899 as having a population of 500; McCabe, 300; Mayer, 200. The chief occupations are prospecting and mining; some farming and cattle raising are carried on in the Agua Fria Valley.

Reports on the region.—In the reports of the Governor of Arizona to the Secretary of the Interior, beginning 1896, are references relating to the geology of Arizona. The reports of the Territorial geologist, W. P. Blake, in these volumes, are valuable, and also the map and text on "The Mining Region around Prescott, Arizona," by J. F. Blandy, published in Trans. Am. Inst. Min. Eng., vol. 11, 1883, p. 286.

Field work.—The topographic map of the quadrangle was made in the autumn and winter of 1900–01. The geologic work was done in 1899 and 1901, under the general direction of Mr. S. F. Emmons. Mr. Emmons made a reconnaissance of the district in 1899; in the summer of 1901 the authors completed the geological field work, using the manuscript report of Mr. Emmons as a guide to field operations. The petrography and economic geology are by Mr. Palache; the general geology is by Mr. Jaggar. Changes occasioned by the opening of mines since 1901 are not here considered.

DESCRIPTIVE GEOLOGY.

STRATIGRAPHY.

The Bradshaw Mountains include sedimentary, metamorphic, and igneous rocks. Excluding the recent alluvium, the sediments are of pre-Cambrian and presumably Algonkian age, no representatives of the Paleozoic, Mesozoic, or Tertiary being known. The metamorphic and sedimentary rocks are here so intimately related that they are discussed together. The igneous rocks include intrusives of uncertain age and effusives of probably Tertiary age.

Sedimentary and Metamorphic Rocks.

ALGONKIAN SYSTEM.

According to the present usage of American geologists, formations that lie unconformably beneath the Cambrian and consist chiefly of sedimentary rocks are assigned to the Algonkian. Owing to the fact that in some regions scattered sediments have been found in Archean rocks otherwise chiefly igneous, there is some confusion in the nomenclature of the ancient schists. The schists of the Bradshaw Mountains are considered by the authors to be (1) pre-Cambrian and (2) in great part sedimentary, for the following reasons:

(1) The nearest Paleozoic section is exposed at Jerome, 17 miles northeast of the northeastern quarter of the quadrangle. The rocks are there flat-lying sandstones, shales, and limestones, and are outliers of the great mass of horizontal Paleozoic and Mesozoic sediments which form the high plateau region of northern Arizona and New Mexico. The escarpment which marks the edge of this plateau district, 5 miles northeast of Jerome, extends in a northwest direction across the valley of Verde River. Ninety miles north of the Verde Valley at this point is the Grand Canyon of the Colorado River, where the whole plateau section is trenched through and the underlying schists are exposed. The Grand Canyon section, as described by Walcott (Jour. Geol., vol. 3, 1895, p. 312), shows metamorphic sandstones, mica-schists, and granite dikes and veins at the bottom of the canyon (Vishnu terrane, Algonkian). These have a vertical structure and north-northeast trend. Unconformably above them are terranes carrying scanty organic remains (Grand Canyon series) referred by Walcott to the upper Algonkian. Still higher, and separated from the Grand Canyon series by a profound unconformity, occur sandstones (Tonto) of Cambrian age; above these the Paleozoic section is continuous to the surface of the plateau.

The schists of the northern part of the Bradshaw Mountains are continuous, so far as known, with certain schists invaded by granite and diorite at Jerome. The latter have a similar northerly trend, and underlie the Paleozoic rocks unconformably at Jerome. The Wheeler Survey (U. S. Geog. Surv. W. One Hundredth Mer., vol. 3, 1875, pp. 207–208) determined these rocks to be Paleozoic, with the Tonto sandstone recognized at their base a few miles north of the present site of Jerome. This correlation is the basis of the opinion expressed here that these schists are pre-Cambrian. Furthermore, the extension of this correlation under the Paleozoic sediments of the plateau to the Grand Canyon leads to comparison with the two Algonkian series of Walcott. On structural and lithologic grounds the schists of the Bradshaw Mountains are believed to be the equivalents of the lower or Vishnu series, as they have an accordant strike and dip, contain granites and indurated sandstones, and are schistose.

(2) The determination of the sedimentary origin of a great series of schists rests upon field and laboratory evidence. Field exploration shows what rock types in the series are most abundant, and microscopical work determines whether those types contain waterworn sands and pebbles. The type rock most widespread in the schist belts of the Bradshaw Mountains is a sericitic phyllite with occasional rounded quartz grains. From the great abundance of this rock and of variations, which are on the one hand true clay slates and on the other sandstones and conglomerates, the authors conclude that the schist series is in the main sedimentary. Confirmation of this conclusion is found in the sequence at certain points from coarse littoral sediments to finer off-shore types across the strike, the finer rocks occurring in greater abundance, as would be expected. Even in those belts where the schists are hornblendic and otherwise highly metamorphosed (as along Black Canyon, east of the southern Bradshaw Range) the constant recurrence of quartzites in the series points to a sedimentary origin for the greater part of the rocks. This was recognized by Prof. W. P. Blake, Territorial geologist of Arizona (Report of the Governor of Arizona, 1899, p. 139), who wrote that from the Tiger mine eastward "the granite is succeeded by slates, sandy and siliceous, with traces of pebbly beds forming a part of an extensive development of distinctly sedimentary rocks which form great hills, and extend over eastwardly to and beyond Humbug Creek."

These schists are therefore considered pre-Cambrian and largely sedimentary; hence they are assigned to the Algonkian. There may be unconformities and faults within the series, and Archean rocks may exist within the Bradshaw Mountains quadrangle. No strong evidence, however, of large masses of igneous or gneissic rocks older than the schists has been found, and such unconformities as are indicated (see pp. 2 and 7) separate undifferentiated members of the Algonkian. No formations have been discovered in any way resembling the Grand Canyon series of Walcott. Future exploration may show that some of the granite masses are not intrusive into the schists, but are rather the source of the pebbles in the conglomerates. Such granites should properly be called Archean. They have not been discovered in this region by the authors of this folio.

YAVAPAI SCHIST.

General character.—The most abundant rock in the schist is an argillaceous phyllite varying to slate, mica-schist, and chlorite-schist, but the formation as mapped locally includes gneisses, granulites, hornfels, and epidote- and hornblende-schists.

Within the schist areas are conglomerate and sandstone bands and lenses, and zones of intense metamorphism where the rocks are amphibolitic and contain epidote, garnet, zoisite, tourmaline, andalusite, and mica in various amounts. These variations of the normal schist have been mapped separately, and are discussed under separate headings.

The typical phyllite as developed in the great body of Yavapai schist which occupies the northern half of the center of the quadrangle is a finely foliated, blue or silvery schist consisting chiefly of quartz and the form of muscovite-mica known as sericite. The foliation is pronounced, but the surfaces of the partings are not plane, so that nowhere are truly cleavable slates found. The rock seems soft owing to the abundance of mica scales on all its surfaces, but when studied with the microscope it is found to consist largely of quartz in angular grains, closely interlocking, producing a structure that may be termed mosaic-granular, the sericite being woven in between the grains or forming layers wrapped about individual grains. Occasionally single large rounded grains of quartz are seen, their edges granulated and the mica plates curving like flow structures about them. Grains of plagioclase feldspar occur very sparsely mingled with the quartz in most specimens, and calcite, epidote, zoisite, pyrite, and magnetite are often found in scattered grains. The present structure of these rocks is almost wholly the result of recrystallization; there is reason to believe, however, that the larger rounded quartz grains have their original form of water-rounded pebbles and that their occurrence is positive evidence of the sedimentary nature of the schists. This derivation is confirmed by the occurrence in the series of extensive lenses of quartzite which are conformable in attitude with the schist and differ from it in composition solely in the much greater preponderance of quartz.

On the other hand, facies of the schist series were noted which in general conform to the above description, but show abundance of feldspar, partly in the mosaic groundmass, partly in relatively large crystals with partly preserved crystal form. The feldspar is both microcline and albite, and is sufficient in amount and of such a form as to indicate that the schists containing it were probably derived from acid igneous rocks, such as granite-porphyry or the like. The fact that such feldspathic facies of the schists are rare strengthens the conviction gained in the field that the great bulk of the phyllite formation is of sedimentary origin.

The following section across the Yavapai formation illustrates the variety and nature of its constituents. In this section widths of surface exposure are given, rather than thicknesses, because the whole series varies in dip east or west of the vertical and occurs in closely appressed folds, so that actual thicknesses can rarely be determined.

Generalized section for 10 miles from west to east, from Mount Davis to Copper Mountain.

	Width of exposure across strike.
Bigbug Creek:	
Banded and argillaceous green mica-slate, more or less fissile; strike N. 33° E.; dip west nearly vertical	1.7 miles.
Amphibolite	.25 mile.
Massive banded green schist, in part uralite-diabase, lamination vertical; trend north-south	1.1 miles.
Grapevine Creek:	
Ledge of gneiss; trend north-south; dip E. at an angle of 80°	40 feet.
Green phyllites	2.5 miles.
Quartzite	50 feet.
North of Mayer:	
Ferruginous and siliceous schist with white quartz veins and hematite parallel to the banding; small veins of onyx marble cutting the schists	1.3 miles.
Rapid alternations of various schists — hornblendic, silvery, ferruginous, siliceous; trend N. 15° E. vertical	1 mile.
Fissile green phyllites; trend N. 9° E.; dip east at an angle of 66°; containing basic breccias and eruptives and quartzite ledges	.75 mile.
Copper Mountain:	
Siliceous schist decomposed on surface, greenish with copper carbonates; trend N. 10° W.; dip west at an angle of 67°; gray rhyolite-porphyry dike	1.3 miles.
Massive gray quartz	300 feet.

Thickness.—The changes of dip in this section indicate an anticlinal structure on the west, in the vicinity of Grapevine Creek, and a synclinal structure in the region west of Copper Mountain. If these folds are projected southward along the strike they match similar ones indicated north of Brady Butte and in Cedar Canyon. Assuming that the strata are essentially vertical, the approximate thickness of the Yavapai formation above the conglomerate on Bear Creek may be estimated by taking one-half the distance beteen the axes of two folds of like kind (see section C–C on structure-section sheet). Measured in this way the Yavapai schists above the conglomerate-sandstone series have a thickness of from 5000 to 7000 feet.

In structure section C–C the attitude of the conglomerate on either side of Brady Butte is hypothetical. The schists between the granite and the conglomerate may have a synclinal structure unless the conglomerate represents the base of a formation unconformable on other schists. That such unconformity exists in the region is indicated by the fact that pebbles of schist and quartzite occur within the conglomerate. The sequence is probably interrupted by overthrust and normal faults, but the structure is too complex for such faults to be in evidence. Whatever the structure, one-half the distance between separate conglomerate bands will give a very moderate minimum thickness to the schist series. If the Ticonderoga Gulch and Bueno outcrops of conglomerate are considered as representing the same band, and the granite belt of Mount Union is disregarded, four conglomerate belts appear, separated by nearly equal intervals of about $2\frac{1}{2}$ miles. One-half of this distance makes the thickness 6600 feet. To such an extent as the dip departs from the vertical this figure would be reduced, but the greater part of the schists are essentially vertical. The estimate, while approximate only, is made on the best available data, and is deemed worthy of record.

Conglomerate lenses.—Conglomerate beds occur in the Yavapai schist in widely scattered localities. They contain well-rounded pebbles in some places, more angular ones in others, and are interbedded with sands and grits. Their occurrence and association afford the strongest evidence of the sedimentary origin of the greater part of the schists. The conglomerate retains its original character where finer sediments are highly metamorphosed, as near the Senator mine; at another place it occurs in the midst of phyllitic rocks; at a third place it appears to be basal and shows gradations in coarseness from the base upward. The transition to sandstones, slates, and limestone successively across the strike is illustrated east of Battle Flat.

Along the road from Battle Flat to Bear Creek the conglomerate outcrops in contact with granite; it dips S. 70° E. at an angle of 55° and contains pebbles of granite, schist, quartz, and quartzite. Farther east, near the mouth of Peck Canyon, vertical phyllites contain interbedded conglomerate bands. The pebbles of the conglomerate are waterworn into roundish shapes, and these again have sometimes been flattened and stretched by the successive periods of pressure that folded the beds, closed the folds, and so compressed the strata as to produce the schistose structure found in the Algonkian rocks. A short distance up Peck Canyon there are limestone lenses.

The presence of pebbles of schist and quartzite in the conglomerate shows that there were more ancient rocks, probably of sedimentary origin, from which some of the recognized conglomerates were themselves derived by sedimentary processes. This indicates that there are unrecognizable unconformities within the Algonkian, and the granite pebbles may have been derived from Archean granites which still exist but have not been differentiated.

The conglomerate outcrops without conspicuous relief in five localities, all of which are in the northwest quarter of the quadrangle. These outcrops are on Bear Creek (already mentioned), near Brady Butte, at Bueno, in Ticonderoga Gulch at the Dividend mine, and at the head of Hassayampa Creek in and near the Senator mine. East and west of Brady Butte the conglomerate dips away from the granite core, suggesting anticlinal structure, the granite being everywhere apparently intrusive. Such structure is further indicated at the northernmost end of the granite of Brady Butte, where the phyllite shows marked folds and an anticline is exposed in the creek bed pitching to the northeast. (See section C–C on structure-section sheet.)

The relation of the conglomerate to the sandstones and phyllites is indicated by the following examples: On both sides of the granite of Brady Butte a wide series of slates and schists occurs beyond the conglomerate, suggesting that the latter is below sediments, which become finer-grained in the higher beds. In the outcrops of conglomerate at the head of Hassayampa Creek the pebbles are sometimes angular and the bedding has been upturned to a vertical position. The nearest metamorphic sandstones occur south of Mount Tritle, and to the west in the vicinity of the Blue Dick mine. On Ticonderoga Gulch the exposures are poor; at Bueno, south of the conglomerate, is a contorted ferruginous quartzite, in part altered to jasper and iron ore, and east and west of the conglomerate there are phyllites and sandstones. The structure of the whole series is isoclinal. A syncline is indicated in the southwest part of Hackberry Creek basin.

There is no evidence regarding the character of the old land on which these ancient sediments were deposited except that afforded by the pebbles. The thickness of the conglomerate-sandstone member on Bear Creek is not less than 900 or 1000 feet. This series has apparently no definite upper limit, but shows a gradual transition to phyllites and bluish slates.

In all the specimens studied under the microscope the clastic structure is distinct. The rounded or subangular grains consist chiefly of quartz, with some feldspar, mostly orthoclase and microcline. The grains and pebbles show evidence of mashing, their long axes being parallel and the points of the fragments often granulated. The cementing matrix is granular quartz and sericitic mica, with some small areas of micropegmatitic quartz-orthoclase aggregates. Needles of tourmaline had developed between the quartz grains in one specimen.

In specimens from the Senator mine were pebbles of red jasper in which, as in the cementing material, were cubes of pyrite.

Quartzite lenses.—Throughout the schist areas and especially in the Hackberry basin occur upright ledges, resistant to erosion, composed of metamorphic sandstone or of very siliceous schist full of quartz veins and lenticles. A conspicuous ledge exposing 300 feet of massive gray quartz occurs at Stoddard and is prolonged southward into the eminence of Copper Mountain. Throughout the Bigbug district these ledges trend from north-south to northeast-southwest with the schists, and they may be traced southward to the Crazy basin, where they diverge about the northern end of the Bradshaw Mountains granite mass, some of the ledges there trending southwest-northeast, and others south-southeast and north-northwest, on opposite sides of the granite mass.

The quartzite ledges are more abundant in the schist belts than the conglomerates, and as has been shown above, their association with conglomerate on the one hand and phyllite on the other goes far to prove the sedimentary origin of the schists. Their microscopic structure is sometimes positively sedimentary, in other cases obscure. Some of the ledges in the field, however, notably near the Bueno iron ore and east of Battle Flat, are unmistakable sandstones. The occurrence of such sandstone beds, moreover, in parts of the schist remote from the conglomerate gives evidence of sedimentary origin in many places where the other rocks are obscure or highly metamorphosed.

The question of the relation of the quartzite lenses to the quartzite pebbles in the conglomerate of Bear Creek is not clearly answered by any evidence yet found. Just as some of the granites may be pre-conglomerate, so may some of the quartzites be members of an older series of Algonkian or pre-Algonkian rocks, separated from the quartzite-bearing conglomerates by an unconformity. Such unconformities, if they exist, have not been recognized because of the close compression of the whole schist series.

The quartzite is typically a dense, fine-grained rock of gray, bluish or greenish white color, often distinctly laminated and cut in every direction by minute veins of white quartz. It contains so much iron, either in the form of films of shining specular hematite or of rusty limonite that the name "iron dike" is commonly applied by the miners to the outcrops. Under the microscope the rock generally shows a uniformly fine grain with a distinctly clastic character, the quartz grains of which it is chiefly composed being often separated by films of sericite or chlorite. Hematite is disseminated in specks and scales, and a very little feldspar could be determined either in roundish grains like the quartz or in larger oval areas. The contorted banded iron ore occurring south of Bueno probably represents an altered form of this quartzite. It is a quartz mosaic of fine, uniform grain with small amounts of granular garnet and epidote, and has a banded appearance produced by magnetite grains abundant in some layers and failing in others.

A section of the schist containing quartzite in Blue Bell Hill, south of Hackberry Creek basin, from Cedar Canyon westward, is as follows:

Section in Blue Bell Hill, from Cedar Canyon westward.

	Width of exposure on surface.
At Cedar Canyon, slaty schist, vertical, trending N. 23° E.	
Light-colored slates and phyllites	.6 mile
Dark ferruginous quartzites, contorted; dip westerly at angles of from 75° to 80°; strike N. 40° E.; white quartz veins	.7 mile
Upper part of this series forms a belt of salient copper-stained silvery siliceous phyllite or sericite-schist. Pockets 1 foot to 3 feet in diameter have been weathered out and show malachite. Trend here is N. 43° E.; dip west at an angle of 72°. There is a zone of these corrosion cavities associated with quartz-mica veins. At the Blue Bell mine the sericite-schist belt is bounded on both sides by a quartzite ledge, and the trend of the ore body (copper) is N. 30° E., its thickness increasing with depth, and averaging 25 to 30 feet, while its length is about 400 feet	150 feet
Hornblende-schist and quartzite ledges, white quartz and white calcite veins, one of latter 1 foot thick	.6+ mile.

As these rocks are nearly vertical, surface widths are given, rather than thicknesses; closed folds probably occur frequently.

The individual quartzite beds vary in thickness from 5 to 50 feet. The section west from Mayer is a characteristic one, as follows:

Section west of Mayer.

	Width of exposure on surface.
Green and red slate and mica-schist	.6 mile.
Reddish-white quartzite, vertical and trending N. 28° E.	5 feet.
Schist	
Two hard dike-like beds, each 50 feet thick, of hematitic quartzite, containing white quartz lenses and dipping N. 65° W. at an angle of 18°	100 feet.
Schist	.75 mile.
Gray quartzite and green mica-schist in a ledge containing much white quartz	20 feet.
Silvery siliceous light-green mica-schist, followed by amphibole-schist and some black eruptive rocks within the schist series	300+ feet.

The quartzite within this succession between Mayer and the eastern edge of Bigbug Mesa illustrates the general character of the quartzite lenses.

The succession shown in Black Canyon from east to west, at the eastern face of the Bradshaw Mountains, between the main range and Bumblebee, is as follows:

Section in Bradshaw Mountains near Bumblebee.

	Width of outcrop on surface.
Diorite of Bland Hill	
Sericitic and argillaceous schists, trending N. 15° W., and dipping west at an angle of 64°	1.2 miles.
Variable schists with numerous quartzite ledges, trending north-south	.3 mile.
Ferruginous quartzite with some amphibole and mica-schist, vertical, or nearly so, with westerly dip	.5 mile.
Bradshaw granite	

Outcrops of quartzite occur throughout the Bigbug district, near Bueno, west of Mount Tritle, northeast of Cordes, and south of Silver Mountain, in addition to the localities already mentioned.

Hornblende-schist phase of Yavapai formation.—The highly metamorphic members of the Yavapai schist, characterized by the development of hornblende and other distinctive minerals, are here collectively described under the above title. The hornblende-schist phase varies in different places in coarseness, schistosity, mineral composition, and origin. The belts shown on the geologic map occur principally in contact with granite or quartz-diorite bodies. Thus the western and eastern contacts of the Groom Creek quartz-diorite body are largely with hornblende-schists. A belt of such schist extends south from Bigbug Mesa, follows the edge of the granite of Mount Union and of the eruptives farther south, and occurs along the borders of the large granite stock that forms the main chain of the southern Bradshaw Mountains.

The width of the metamorphosed belts averages 1 mile, but it becomes greater in those places where igneous bodies occur on opposite sides of a single schist belt, as in Silver Mountain or Spruce Mountain.

The topographic relief of these schists is great and is exceeded only by that of the Bradshaw granite; thus the greater part of Spruce Mountain, Mount Tritle, and portions of Tuscumbia Mountain and Silver Mountain are formed of these indurated and metamorphosed beds.

The transition from the metamorphosed belts to the normal Yavapai schist can not be said to be definite in all cases, and the contacts of schist with granite or diorite do not always show pronounced metamorphism. Thus the schists on the flanks of the Mount Elliott and Brady Butte granite masses do not show any marked amphibolitization. This can not, however, be used as an argument for the Archean age of these granites, for the same granitic masses farther south in each case show a hornblende-schist belt on their flanks. Moreover, the changes wrought in the schist of the hornblendic belts are probably not wholly due to contact action of intrusive plutonic magmas. There are many local occurrences of highly metamorphic rock which are not near igneous contacts. The case cited below, of the transition in the zone surrounding the great southern Bradshaw granite stock, appears to be a definite case of "contact metamorphism." The continuity of even this zone, however, is interrupted in two places, and it is remarkable that the long diorite belt bordering the granite of Bland Hill, and parallel to the eastern contact of the southern Bradshaw stock across Black Canyon, has apparently exerted very little metamorphosing action on the schist. Further exploration is necessary before these problems in this complex field can be solved.

A characteristic section of the hornblende-schist phase is shown on the west flank of Spruce Mountain, where, east of the quartz-diorite of Groom Creek basin, is a region of massive hornblendic epidote hornfels characterized by foothill and canyon topography, as distinct from the pine-clad flat land of the quartz-diorite. Farther east, in the vicinity of the Monte Cristo mine, are ore-bearing quartz veins in a country rock of massive black amphibolite changing to banded hornfels, which strikes N. 25° E. and dips at high angles to the west. Hornfels and hornblende-schists are continuous to the diorite at the summit of the mountain. Streaks of diorite and acid porphyry dikes are common in many places throughout these schists, and granite or pegmatite lenses occur in the vicinity of granite contacts.

Along Crazy Basin Creek, northeast from Blanco Springs, the succession of exposures parallel to and near the granite contact is as follows:

Exposures along Crazy Basin Creek.

Mica-schist with granite and pegmatite veins.

Mica-schist containing quartz and tourmaline, cut by granite veins and two small porphyry dikes.

Small dike of camptonite; trend N. 35° W.

Staurolite, garnet, and mica-schist.

Green schist and breccia, containing quartz; dip north at an angle of 70°; strike N. 82° E. (Here the schist changes its strike to the east to conform to the curve of the great intrusive body of granite.)

Mica-schist; strike N. 65° E.; dip northwest at an angle of 43°.

The change of dip in these schists conforms to a steady flexure, well illustrated in the eastern spur of the conspicuous hill of metamorphic schists which rises north of Crazy Basin Creek; on ascending the spur from southeast to northwest the strike changes from east-west to northeast-southwest, and the dip from relatively low angles (55°) where the schists are buckled about the northern end of the granite, to the more normal higher angles (68°); in the same space the rock changes from staurolite-schist, characteristic of the contact metamorphic zone, to mica-schist.

Petrographically the hornblende-schist phase is a complex of extremely varied rocks. It includes, as its principal members, (1) typical hornblende-schists; (2) amphibolites; (3) mica-schist; and, as subordinate members; (4) epidote-, zoisite-, garnet-, and tourmaline-schists; (5) hornfels; (6) uralitic diabase.

(1) The hordblende-schist includes highly laminated rocks consisting principally of hornblende and quartz. The hornblende is green or greenish blue in color and is generally in confused fibrous aggregates; epidote and biotite almost invariably accompany it in more or less abundance. The quartz presents aggregates having mosaic or cataclastic structure, with occasional grains of ill-defined plagioclase feldspar. A typical occurrence of these rocks is seen in the belt west of the granite of Tuscumbia Mountain, along the Crown King road.

(2) The amphibolites differ from the rocks above described chiefly in the absence of lamination and the greater abundance of hornblende. They are very massive and tough, and occur as local phases of the schist and as independent masses.

The original character of these two groups of rocks is uncertain. The schists may represent the complete recrystallization of siliceous ferromagnesian limestones; they may equally well, and the amphibolites more probably, be derived from basic igneous rocks. The evidence is inconclusive.

(3) The mica-schists include coarsely crystalline foliated muscovite- and biotite-schists. They are highly quartzose rocks; the quartz occurs in patches with mosaic-granular structure or in isolated grains wrapped about by the mica plates. Accessory minerals are green hornblende, garnet, epidote, tourmaline, and staurolite; magnetite is always present also. These accessory minerals are locally so abundant as to dominate the normal constituents. The chief occurrence of these schists is in the zone surrounding the great southern stock of Bradshaw granite, from Silver Mountain on the southwest, northeastward to Crazy basin, and thence southward along the eastern boundary of the granite, nearly to the southern line of the quadrangle. The schists show a gradual change as one approaches the granite across the strike. From finely crystalline phyllites one passes, by gradual increase in the degree of crystallization, to fine and then coarse mica-schist; near the granite staurolite, garnet, and tourmaline appear abundantly. At the immediate contact quartz veins containing andalusite are found and pegmatite veins with abundant tourmaline become extremely numerous. The derivation of the mica-schists from the phyllites of the Yavapai formation, which are regarded as altered sediments in large part, is held to be clearly demonstrable.

(4) Epidote-, zoisite-, garnet-, and tourmaline-schists are recognized as local members of the schist in which one of the four minerals named is predominant. They are foliated and generally fine-grained rocks, the mineralogical nature of which is revealed only by microscopical examination.

(5) Hornfels is here used to include certain contact rocks found locally at the immediate boundary of granite and schist. They are black or gray, extremely dense and hard rocks of exceedingly fine grain, in many cases hardly resolved by high powers of the microscope. The structure is granular, but has poor definition—the feldspar grains, hornblende-biotite scales, and magnetite particles of which they are chiefly composed being mingled in a confused aggregate. In a specimen from near the Tiger mine the hornfels occupies a narrow, sharply defined zone at the contact and is marked by an abundant development of andalusite. It is regarded as a local metamorphic phase of the phyllites.

(6) The uralitic diabase comprises dense black rocks showing little schistose structure and composed of minute needles of green uralitic hornblende and indeterminable plagioclase feldspar laths. This rock, which is developed in two considerable masses—north of the Senator mine on Hassayampa Creek, and east of the Crown King mine—is regarded as undoubtedly derived from an igneous rock, probably originally a diabase.

Name.—The county name, Yavapai, is applied to the great body of schists of which the greater part are clearly of sedimentary origin. Blake (Report of the Governor of Arizona, 1899, p. 139) was the first to describe these schists, and spoke of them as a slate formation extensively developed in Arizona, lithologically resembling the Taconic slates of Massachusetts. He named them the "Arizonian" slates. This name is not retained because lack of correlation with other parts of Arizona makes it necessary to adopt a name of more limited geographic significance.

QUATERNARY SYSTEM.

The principal formation representing Quaternary time in the quadrangle is the alluvium of the modern streams. Certain spring deposits may also be conveniently discussed here, though there are some reasons for correlating them with the Tertiary volcanic agglomerates.

ONYX MARBLE.

There are two hot-spring deposits in the quadrangle, the principal one being the onyx marble which occurs near Mayer. This deposit covers an oval area about three-quarters of a mile long by less than half a mile broad, to a depth which varies from a fraction of a foot to upward of 25 feet. The deposit consists of a very compact limestone, distinctly banded in layers that are horizontal, inclined, or undulating. The thickest bands, which may be as much as a foot thick, consist of fibrous aragonite, the fibers being faintly radial and transverse to the banding. The main mass of the material is, however, calcite, varying in color from white or pale green to deep brown or red where the small amount of iron carbonate contained in it has been decomposed into iron oxide.

The onyx rests directly on the upturned edges of vertical schists, and the lowest layer of the onyx is generally a breccia of schist fragments and other rock débris cemented by calcite (see fig. 5). At several points, moreover, this breccia occurs in vein-like masses passing downward into the schist. These undoubtedly were the outlets of springs, probably hot, which brought up the calcium carbonate in solution, and the precipitation of calcite or aragonite from the hot waters flowing over the surface first took place in the mantle of loose rock covering the ground. Terrace-like masses were then deposited with more or less regular banding, the greater thickness of the deposit accumulating in depressions of the surface.

The appearance of the onyx deposit strongly suggests a recent formation formed on the present surface after the lavas which must formerly have covered this region had been removed by erosion. Study of similar deposits elsewhere in the quadrangle throws doubt on this conclusion. On Agua Fria Creek at its junction with Sycamore Creek, 10 miles southeast of Mayer, is a considerable extent of magnesian travertine lying directly beneath the basalt and on the granite. It is a compact to slightly porous, cryptocrystalline, dull-white rock that is harder than limestone and frequently contains bands of chert. It does not dissolve in cold acid like limestone, but must be powdered and heated before solution takes place; it is found to contain both magnesium and calcium carbonates besides small amounts of silica and alumina. Although this travertine is clearly a spring deposit, it merges horizontally by insensible gradations into a volcanic agglomerate with calcareous cement, and since the agglomerate is older than the basalt the same age is naturally assigned to the spring deposit. If the onyx is correlated with this travertine, as seems natural from their similarity of origin, it must be assumed that the onyx was formed before the outpouring of the basalts which undoubtedly at one time extended over the area between the eastern lavas and Bigbug Mesa, and that it has been revealed as now seen by the subsequent removal of these lavas by erosion. There is a further argument for the assumption that the onyx has been at one time buried beneath a great weight of lava in the compactness of its present texture, which is quite unlike the porous texture of ordinary surface hot-spring deposits of limestone. The travertine as first formed may well have been recrystallized to the compact onyx form under the influence of the heated waters moving under great pressure beneath the lava. Or it is possible that both deposits, instead of having been deposited before the basalt outburst, were formed beneath the lava as they now occur. It is, however, difficult to understand how such slight and nonresistant deposits as these could survive a period of erosion capable of removing from wide areas several hundred feet of hard basalt. The problem of the age and origin of the onyx is therefore not yet satisfactorily solved.

ALLUVIUM.

The oldest surficial deposits in this region are gravels, associated with the lavas. In some cases these have been rearranged by recent washing, but all such deposits are here included under volcanic agglomerate (see page 6). The only Quaternary deposits shown on the map are the larger alluvial bottom lands, most numerous along the course of Agua Fria and Bigbug creeks. Agua Fria Creek flows through an open basin north of the quadrangle, and south of Valverde has deposited loam and gravel to the depth of 30 feet along its bottom. This deposit has been trenched by the stream and sections with horizontal bedding are exposed. South of this area the creek flows across schist in a canyon, from which it emerges at the edge of the basaltic deserts east of Copper Mountain. Here occur alluvial deposits, which give place to another canyon in the basalt farther down the stream. Materials scoured out of this canyon form bottom lands where the creek emerges on the granite east of Cordes. This process is repeated at Richinbar, where the stream (here known as Agua Fria River) enters a third canyon in granite and basalt At Goddard's, where the river leaves the basalt, another wide flood plain has been deposited, and below this point another canyon has been cut in schists. This is a continuation of Black Canyon, which extends far to the north along the eastern contact of the Bradshaw granite and schist, following the course of the softer schists, which are bordered on both sides by eruptives.

Bigbug Creek, like Agua Fria Creek, shows evidences of trenching in old alluvial gravels above Mayer. Such deposits are to be expected where a stream emerges from high land into the flat, open country, and the sudden mud floods from cloudbursts on the mountains promote the process of accumulation.

Igneous Rocks.

INTRUSIVES.

The intrusive rocks of the Bradshaw quadrangle occur as large stocks of irregular form with dimensions measured usually in miles, and as dikes filling fractures of elongate form, the width of which is usually measurable in feet. In some cases—notably that of the Crooks complex—intrusives of different kinds are mingled together in an irregular banding which strongly resembles the banding seen in the schists, with the difference that the rocks are all igneous and crystalline. Frequently the banding of the igneous rocks is transverse to that of the schists, as in Crooks Canyon.

BRADSHAW GRANITE.

Character.—The Bradshaw granite is a coarse plutonic rock which has in places a gneissic and in places a coarse granular structure, and which frequently shows zones where the rock becomes highly schistose and would more properly be called a mica-gneiss. The normal type is a coarse biotite-granite with rare green hornblende. Petrographic study of specimens from different parts of the Bradshaw Mountains quadrangle indicates that there are certain distinct primary variations, and other secondary changes due probably to pressure, which are more pronounced in some places than in others.

The primary phases or varieties are of four kinds: The normal granite, the coarse pegmatitic varieties, the transition to the Crooks complex, and the transition to diorite. The last two will be described under their respective headings. The normal granite occurs in the Mount Union Range at Indian Creek and near Prescott, at Minnehaha, at Bland Hill, and in the granitic hills north of Richinbar. Coarse-grained or pegmatitic forms of granite are abundant in the southern Bradshaw Mountains, in the mountains along the southwest border of the quadrangle from Cellar Spring southward, and in Tuscumbia Mountains.

Petrographic description.—The Bradshaw granite is normally a coarse granitic aggregate of quartz, orthoclase, and microcline in about equal amounts, with a little acid plagioclase (oligoclase), biotite, and magnetite, and occasionally some green hornblende. The more or less distinct gneissic structure visible in most outcrops of the rocks is scarcely visible in the microscopic structure, but the influence of strains is clearly seen in the universal granulation or wavy extinction of the quartz and occasionally of the feldspar. Alterations of the latter to sericite or a mixture of sericite and calcite are widespread in all phases of the rock. The dark constituents of the granite are small in amount, the biotite being often bleached or altered to chlorite. As rarer constituents, apatite, zircon, and orthite were noted in some slides.

Variations from this type, both structural and mineralogical, are numerous. The mass of Tuscumbia Mountain consists of a granite much coarser than the normal, and one large dike on its northeastern slope is coarsely porphyritic with large, distinct Carlsbad twins of microcline in a pinkish groundmass of ordinary texture. Distinctly gneissic facies are also found, especially toward the contacts with the schists and amphibolites into which it has been intruded. Pegmatitic facies are extremely abundant in the great southern stock, particularly along the eastern contact, where extensive areas, practically all of pegmatite, are found. Mineralogical variations are chiefly of a more basic character, and will be described under the heading "Diorite" (p. 4).

The granite has the normal granitic structure at the headwaters of Crooks Canyon at the southern base of Mount Union, in the high mountain east of Cordes, in the extreme northwest corner of the quadrangle on Indian Creek, and at many other places. A specimen (No. 358) from Crooks Canyon was made the basis of a partial analysis which resulted as follows:

Partial analysis of granite from Crooks Canyon.

	Per cent.
SiO_2	74.62
CaO	1.06
Na_2O	3.99
K_2O	3.90

The molecular alkali-silica ratio calculated from these figures is 0.085, and corresponds to that of liparose or toscanose, which are considered the equivalent of granite. (See Iddings, Prof. Paper U. S. Geol. Survey No. 18, 1903.)

Metamorphism.—The secondary changes in the Bradshaw granite were produced in connection with pressure, which has developed the wavy extinction that is seen when the quartz and feldspar are viewed in polarized light and which has caused sericitic zones or bands in places where the rock has been sheared. These places are found along the contacts with schist in the border zone of the great southern Bradshaw stock and are also numerous in the granitic phases of the Crooks complex.

It is probable that the belts of schist indicated on the map within the large southern stock are more continuous than is there shown. Detailed exploration would be necessary to determine this point. The presence of such included bodies of the schist a mile or more in length and of varying width indicates that as the granite magma welled upward the schist isoclinals were probably split and there was possibly some fusion or resorption of the masses broken apart. Geologists have no accurate knowledge as yet of the dynamic conditions which govern granitic intrusion. In such a region as the Bradshaw Mountains the granites represent only one manifestation of the metamorphosing agents which have produced such marked mineral and chemical changes in the sediments. The development of gneissic structure along the borders of the granite indicates that the plutonic rock itself was compressed either during its intrusion, when it was a very stiff or viscous mass, or at some later period, after its solidification, when the whole mountain range was subjected to regional stresses. The dàta at hand are insufficient to determine which of these conditions was dominant in producing the gneissic structure observed in the granites of the Bradshaw Mountains.

It should be further observed that some chemical changes probably took place within the granite magma locally along its contact with schist, for the transition to basic phases (diorite) is apparent in some places, though absent in others. Such a change is evident along the western flank of Bland Hill and on the eastern contact of the schist belt north and south of that point. Without detailed field studies it is not possible to account satisfactorily for this greater basicity of the granite along certain contacts. There is no such border of diorite around the great Bradshaw Mountains stock or the granite masses of the northwest and west. These granites and the Crooks complex, which is largely a mixture of granite and diorite, in places show local transitions to diorite. The Bland Hill diorite zone may have been caused by any one of the three following processes: (1) Endomorphic differentiation in the granite, (2) a local change in composition of the granite magma due to solution of materials from the schist, (3) a later intrusion of diorite along the contact of granite and schist while the granite was still in a semi-fluid condition.

Age.—With the exception of such metamorphic eruptives as may be contained in the Yavapai schist, the Bradshaw granite is the oldest intrusive rock in the region. It is younger than the schists and is intrusive into them, this being shown along the contacts by lenses and dikes of granite in the Yavapai formation, and by included bodies of schist frequently found within the granite-gneiss.

Distribution.—The Bradshaw granite is much the most widespread cartographic unit in the quadrangle, occupying at least one-half of the area and extending beneath the lavas on either side for an indefinite distance.

The granite forms the higher mountain summits, including the southern Bradshaw Range, the southwestern range, the Mount Union group of peaks, Brady Butte and the heights south of it, Bland Hill and the high hills east of Cordes, and part of the mountains at the head of Yava Wash.

The largest stock of granite forms the main southern range of the Bradshaw Mountains. The rock is alternately pegmatitic, gneissic, and schistose. The Yavapai schist to the north appears to have been split apart and suffused with the fluids which crystallized as granite; throughout the granite are found schist belts and fragments that frequently preserve their original trend. The formation varies from porphyritic granite-gneiss to a coarse, weathered, reddish granite or a muscovite-pegmatite with much white quartz and very large feldspars. On the east slope of Horsethief Canyon the schist is filled with granite intrusions which in the stream beds both cut across the banding of the schist and interpenetrate the laminæ.

In the exposures on the Mount Union Range the Bradshaw granite is much weathered and on the corners and edges of the joint blocks has a characteristic bright-red rusty stain which frequently serves to distinguish this formation from quartz-diorite. These two rocks are in contact east of Walker on the road from Lynx Creek to Bigbug Creek. Few ore deposits have been found within the Bradshaw formation, but they occur along its contacts with included or peripheral schist.

Name.—The Bradshaw granite is named from the mountains in which it is so conspicuously displayed.

CROOKS COMPLEX.

General character.—The Crooks complex is closely associated with the Bradshaw granite, but differs from it in that it is marked by alternations of diorite, aplite, gabbro, schist, and granite. It is largely igneous and the trend of its bands is often transverse to adjacent schists. The complex merges into the Bradshaw granite south of Mount Union, west of Minnehaha, and north of Squaw Creek. Included schist is not abundant. Ore bodies are almost wholly wanting in this formation.

A characteristic section of the Crooks complex may be seen on the southwestern spur of the high peak west of Bueno, between Crooks Canyon and Blind Indian Creek.

Section of Crooks complex on peak west of Bueno.

	Width across surface exposure. Miles.
Broad band of diorite followed by similar one of granite	.3
Four alternations granite and diorite	.4
Coarse diorite	.15
Diorite-gneiss, schist, and granite	.3
Miscellaneous gneisses and schists; lamination vertical, trend N. 4° W.	.5
Strips of diorite in granite trending N. 20° W. and east-west; some diorite breccia in a granite matrix occurring as a band trending N. 22° E.; hornblendic and quartzitic schists trending N. 8° W.	.5
Granite, diorite, diorite breccia, and olivine-gabbro	.3
Nearly all gneissic granite, lamination trending northeast, muscovite-mica on joint surfaces; one dike of olivine-gabbro	.65
A strip of diorite in granite; lamination in latter trends N. 18° E. and the rock weathers in upright slabs like gravestones	.2
Chiefly granite	.6

This complex is mapped as a single formation, but is really a mixture of the diorite-granite and schist units in bodies too small to be differentiated on the folio map. Its distinctive feature is the alternation of these units in bands. Small stocks of diorite or granite undoubtedly occur at places in the complex, cut by dikes of aplite and lamprophyre. Where brecciation has taken place the matrix is granite and the pyroclastic fragments are diorite or gabbro. The granite of the complex is identical with the Bradshaw granite, and the diorite is identical with the diorite which is described under the next heading as occurring elsewhere and which is independently mapped. The petrographic description of the rocks therefore is omitted in this place because all the types described under the headings "Diorite" and "Bradshaw granite" occur in the Crooks complex. In its relation to the Yavapai schist the complex has the same metamorphosing effect east of Crooks Canyon as has the granite farther north. In that region also it merges into both granite and diorite on the north, and the same is true of a banded igneous complex having precisely the same characteristics which occurs northwest of the New River Mountains and passes into undifferentiated granite on the north and diorite on the west.

Origin.—The origin of the banded structure of the Crooks complex is one of the many obscure problems presented by the Bradshaw quadrangle. The contacts between the separate acid and basic bands appeared to be igneous in all cases observed, and inclosed belts of schists are numerous. The banding may have been occasioned by contemporaneous intrusion, by segregation during intrusion, by intrusion of one magma into parallel fissures in the already solidified material of the other, or by the intrusion of parallel dikes originally guided by thin schist belts. The breccias of basic material in an acid matrix, contrasted with the diorite dikes found elsewhere in granite, show that contemporaneous intrusion or local segregation is the most probable explanation of the phenomena observed. In many places these phenomena strongly suggest the alternation observed in composite dikes, but on a much greater scale. The inclusions of schist in the Crooks complex have the same character as those found in the Bradshaw granite. The marked transverse character of the banding of the complex in the Crooks Canyon district shows that this igneous banding is there due to a cause different from that which produced the banding of the schists, though in other places it conforms closely to the banding of adjacent schists. The Crooks complex is in miniature an epitome of many of the complex relations of granite, diorite, and schist, shown on a larger scale on the geological map.

Name.—The complex is named from Crooks Canyon, in the northwestern part of the quadrangle, where it is well displayed.

DIORITE.

The rocks indicated on the map as diorite comprise two groups of somewhat different character. In the one the diorite may be regarded as a basic, border phase of the Bradshaw granite and is found chiefly on the borders of large masses of that rock along its contacts with the Yavapai schists. This group includes quartz-diorites of coarse granitic structure, similar to the granite in appearance but darker colored owing to greater abundance of hornblende and mica and with more soda-lime feldspar. Quartz is present in small amount and, as in the granite, shows pronounced strain effects—a character which serves to distinguish these diorites from the younger quartz-diorite of similar composition. The first group also includes phases in which quartz is practically absent—typical diorites with abundant hornblende.

The most conspicuous area of these diorites is in a belt extending south from Cordes to Gillette and beyond, and lying between the granite of Cordes Mountain and the schists to the west. Here the rock is partly massive and partly schistose; south of Bumblebee the diorite is seen clearly to grade into the granite and contains occasional bands of schist and white or blue quartz veins, the parallel structure being sufficiently marked to give a gneissic character to the formation.

North of Richinbar a nearly circular area of quartz-diorite, which is bounded by granite on three sides and may be in contact with schists on the west, where the older rocks are concealed by agglomerate, shows a gradual transition into the granite, so that no sharp line can well be drawn between them. Toward the granite quartz increases, orthoclase increases relative to lime-soda feldspar, and the bisilicates become less abundant. The line drawn on the map is largely arbitrary owing to the regularity of this gradation.

On the high mountain west of the head of Yava Wash the diorite takes on a peculiar phase through the alteration of its feldspar to zoisite. The contact of the diorite with granite is here marked by an extensive development of the same breccias, showing resorption of the fragments, as described in the Crooks complex.

The second group of dioritic rocks comprises more basic forms than those described above, and occurs chiefly as small stocks intruded in the schists and not in general in evident connection with granite bodies. They are dark, heavy hornblendic rocks free from quartz, the texture varying from massive granular to porphyritic. Such stocks occur on Mount Tritle, on Spruce Mountain at the head of Bigbug Creek, on Agua Fria Creek northwest of Stoddard, and on Towers Mountain.

In most of the cases observed the diorite occurs either along a schist contact, indicating that it is the product of differentiation of the granite along cooling walls, or as an intrusion wholly within schists, or as a member of the Crooks complex. The possibility is, however, not excluded that the basic diorites of the stocks where connection with granite is not evident may have an independent origin and represent another period of intrusion, but evidence was not available for satisfying the authors on this point.

Ores sometimes occur within the diorite, which forms the country rock of the quartz veins in the Poland mine, and forms the west wall of the United Verde ore body at Jerome, north of the Bradshaw Mountains quadrangle.

The diorites of the western belt described above as presenting distinct gradations into the Bradshaw granite are coarse-grained rocks of granitic appearance, but darker colored than the associated granite. A typical occurrence near Badger Spring, north of Richinbar, is composed of abundant green hornblende and greenish white feldspar with inconspicuous quartz. Under the microscope the somewhat idiomorphic albite or albite-oligoclase is found to be largely altered to sericite, zoisite, and calcite. The hornblende is in anhedra, brown to dark green where fresh, bordered in part by blue-green fibrous hornblende, in part altered to chlorite. The little interstitial quartz is strained as in the granite. Accessories are apatite, magnetite, and epidote. This type may be termed a quartz-diorite.

The diorites of the northwestern stocks are much more basic rocks. At the Bland mine and the summit ledges of Mount Tritle they are heavy blue-black rocks, fine to coarse grained, rarely with porphyritic feldspar development. The hornblende is green to brown in color and sometimes has a fibrous uralitic appearance, but no augite cores were observed. The feldspar varies from acid oligoclase to acid labradorite and is generally fairly well preserved, epidote, zoisite, and calcite being the ordinary alteration products. In one porphyritic phase the very fresh idiomorphic labradorite crystals were extraordinarily shattered, with intricate penetrations along the cracks of the felted green hornblende groundmass.

Quartz is absent and apatite and magnetite are abundant.

A partial analysis of diorite-porphyry (No. 306) gave the following result:

Partial analysis of diorite-porphyry.

	Per cent.
SiO_2	61.68
CaO	3.28
Na_2O	4.40
K_2O	2.15

The alkali-silica ratio calculated from these figures is 0.090, and corresponds in general to that of tonalose, an equivalent of diorite.

Gabbroid facies of this type are characterized by more basic plagioclase and the presence of augite more or less completely changed to uralite-hornblende.

The diorite from Yava Wash mentioned above, in which the plagioclase has been entirely altered to zoisite, has the appearance of granite. Under the microscope it is found to be a granular rock composed of zoisite and pale-green actinolite. The zoisite is a confused aggregate with definite boundaries representing the original feldspar; occasionally it occurs also in large crystals. The hornblende is slightly altered to chlorite. Interstitial quartz and feldspar in small amount and a little leucoxene complete the constituents. Owing to the unusual completeness and definiteness of the alteration the rock was analyzed by Mr. George Steiger, with the following result:

Analysis of diorite from Yava Wash.

	Per cent.
SiO_2	45.73
Al_2O_3	19.45
Fe_2O_3	5.28
FeO	3.18
MgO	6.24
CaO	13.86
Na_2O	.64
K_2O	.32
H_2O-	1.57
H_2O+	3.56
TiO_2	.23
Co_2	.28

The mineral composition, calculated on the basis of this analysis, was found to be:

Mineral composition of altered diorite from Yava Wash.

	Per cent.
Zoisite	47
Actinolite	17
Quartz	7
Orthoclase, Albite	7
Chlorite	7
Kaolin	8
Magnetite	4

MONZONITE-PORPHYRY.

South of Bueno the greater part of the basin within the mountains known as Battle Flat is occupied by a gray porphyritic rock, gneissic in part, of peculiar petrographic character, which appears to be intermediate to the older and younger quartz-diorites. The basin-like character of the area which this rock occupies suggests that it is related to the quartz-diorites, but its pronounced gneissic structure allies it more directly with the older rocks. It is traversed by dikes of diorite and camptonite and is in contact on the northwest and southwest with Yavapai schist, and on the east with a fine-grained granite-porphyry which merges into the Bradshaw granite.

Hand specimens of the rock show a rather uniform fine grain, the most conspicuous minerals being needles of shining black hornblende, irregular grains of an unusually bright blue, vitreous quartz, and occasional feldspars. The gneissic banding is not distinct in small specimens and is noticeable only in varieties containing rather more biotite than the average.

In thin section it appears porphyritic, with numerous phenocrysts of bipyramidal quartz, shattered, strained, and deeply embayed, hornblende in sharp prisms, biotite crystals, and sparse orthoclase crystals vaguely bounded and crowded with inclusions of mica. The groundmass is granular and indistinctly gneissic, consisting of quartz and oligoclase feldspar in about equal amounts, with shreds of hornblende and mica. Over considerable areas the quartz-feldspar aggregate appears to be embraced in vague outlines, as though large feldspars had been recrystallized without wholly losing their individuality. Magnetite and apatite are present, and much secondary chlorite and calcite. The rock has the appearance of a hornblendic monzonite-porphyry much affected by dynamic metamorphism.

The results of a chemical analysis (by Mr. George Steiger) are shown in the following table:

Analysis of monzonite-porphyry.

	Per cent.
SiO_2	60.39
Al_2O_3	13.94
Fe_2O_3	4.07
FeO	2.91
MgO	2.39
CaO	5.17
Na_2O	2.68
K_2O	1.88
H_2O-	1.11
H_2O+	2.76
TiO_2	.41
CO_2	2.10
P_2O_5	.07
MnO	.08
Total	99.96

The rock, as may be seen from this analysis with over 2 per cent CO_2, is far from fresh, and this was expected from the appearance in thin section, although so large an amount of calcite was not in evidence. The calculation of the norm gives the following result:

Mineral composition of monzonite-porphyry.

	Per cent.
Quartz	23.46
Orthoclase	11.12
Albite	22.63
Anorthite	20.29
Diopside	4.42
Hypersthene	5.32
Magnetite	5.80
Ilmenite	0.76
Water	3.87

This composition leads to the classification of the rocks as tonalose.

The name monzonite-porphyry is employed notwithstanding the somewhat low content of potassa and consequently of orthoclase indicated by the analysis, because of the recognition of orthoclase as a constant and considerable constituent of the rock in all the thin sections examined.

QUARTZ-DIORITE.

The youngest plutonic igneous rock occurring in the quadrangle is quartz-diorite, which forms stocks of considerable extent at Crown King, in the basin of Groom Creek, at Walker, and near the head of Bigbug Creek. The typical quartz-diorite is a medium-grained, light-gray rock of granitic appearance, composed predominantly of snow-white triclinic feldspar together with more or less interstitial quartz and a variable amount of hornblende and biotite, the latter sometimes wholly replacing the hornblende. The rock is noticeably free from banded or gneissic structures and, as shown by microscopic study, its constituents are free from evidence of unusual strains; and these characters serve to distinguish it quite sharply from the older Bradshaw granite and its quartz-diorite phases. Its most marked characteristic as noted in the field, however, is the way in which it weathers into spheroidal forms, the bowlders of disintegration lying loose on the surface amid the sandy soil into which it finally passes. It moreover yields to the agencies of erosion more readily than any of its neighboring formations, so that its outcrops always occupy basins, generally thickly pine clad and recognizable from a distance by the bowldery outcrops. This well-defined topographic character of the quartz-diorite is especially well shown by the Groom Creek area, which is the largest stock, and by that surrounding Crown King.

The quartz-diorite is known to be the youngest plutonic intrusive in the region because it was observed at various points in igneous, intrusive contact with Yavapai schists, both of normal type and in the form of hornblende-schist, with Bradshaw granite, with diorite, and with members of the Crooks complex.

The principal mines of the quadrangle occur along its contacts, showing that mineralization of the older rocks and infiltration of ore-bearing solutions accompanied or followed the intrusion of this latest magma.

The structure of the rock is medium to coarse granular with a tendency toward idiomorphic development of the dark constituents. Oligoclase feldspar is the dominant constituent and is generally fresh and unaltered. Fresh green-brown hornblende and chloritized biotite are about equally abundant, much subordinate to the plagioclase. Small amounts of quartz, orthoclase, and microcline are present in all slides as filling of interspaces of other constituents. The accessory minerals are titanite, which is abundant in relatively large, envelope-shaped crystals, apatite, and zircon. The absence of the strain effects so common in the older granite and diorite is a noticeable feature of this rock and emphasizes its younger character as determined by field relations.

Two local variations of this rock were observed. At the south base of Towers Mountain, on the Crown King road, at the contact of the quartz-diorite with the massive basic diorites that constitute the summit of that peak, a contact breccia is developed and the quartz-diorite takes on a markedly porphyritic character. The large, sharply idiomorphic feldspars are bytownite, and these with biotite plates and green hornblende prisms up to three-quarters of an inch long are embedded in a groundmass of quartz-orthoclase micropegmatite with plagioclase microlites, rounded quartz grains, and shreds of biotite and hornblende. Titanite and apatite are abundant. In the narrow breccia zone are angular fragments of the normal quartz-diorite, of darker basic rocks, and of this monzonitic porphyry in a dark-colored matrix of minutely fragmental plagioclase, quartz, orthoclase, hornblende, and abundant magnetite. (See fig. 6 on the illustration sheet).

The other variation is found in parts of the stock at the head of Bigbug Creek. It is here an alkali granite composed essentially of quartz and albite. It is much more altered than the normal form, the hornblende almost wholly replaced by epidote and chlorite, singly and mixed with pyrite, and the albite opaque from formation of sericite. Apatite and abundant zircon were noted.

Partial analyses were made of two phases of the quartz-diorite, a typical specimen from Walker (No. 19), and a porphyritic phase from the foot of Towers Mountain (No. 120).

Partial analyses of quartz-diorite.

	No. 19. Per cent.	No. 120. Per cent.
SiO_2	63.22	64.23
CaO	4.46	4.07
Na_2O	4.32	4.90
K_2O	2.53	2.44

The figures show the rocks to be essentially identical in composition. The molecular ratios of combined alkalies to silica are 0.091 and 0.098—ratios that correspond in general to that of yellowstonose, an equivalent of quartz-diorite.

BASIC DIKES.

Dark-colored dikes of basic composition occur chiefly in association with the plutonic igneous rocks and consist of diorite, augite-diorite, diabase, gabbro, and camptonite.

Composite dike.—On the road leading north from the Jersey Lily mine, at the west end of the Mount Tritle Range, there occurs in the Yavapai schist a 70-foot dike of olivine-gabbro trending north-south with aplite on both sides. The gabbro weathers to rough black spheres. Such composite dikes are not uncommon, but sometimes the medial member is acid and the borders are basic.

Diorite dikes.—Dikes of diorite and diorite-porphyry were noted near Hassayampa Creek on the Jersey Lily road, at Cash mine, on the divide between Indian and Granite creeks, and on Agua Fria River above Little Squaw Creek, near the Mitchell ranch. Petrographically they resemble the diorite of the stocks already described, being dark basic rocks consisting of hornblende, andesine to oligoclase feldspar, with very little quartz, abundant titanite and magnetite, and much secondary epidote, zoisite, and calcite.

Augite-diorite dikes.—Dikes of augite-diorite were seen on lower Lynx Creek, northwest of Stoddard, and at Henrietta mine, where they form wall rocks. They are similar in appearance to the diorites, differing from them chiefly in the presence of augite in greater or less abundance in the place of hornblende. Some of them are vesicular, the vesicles being filled with calcite and epidote.

Diabase dikes.—Dikes of gray ophitic diabase were found on the Jersey Lily road at Indian Creek, at Blue Dick mine, at Blue Bell mine, on the west side of Battle Flat, and on the divide between Hackberry and Wolf creeks. The feldspar of these rocks is andesine, or more basic in composition, and is largely altered to calcite and sericite. Grains of colorless or pink augite fill the network of feldspar laths and are partly changed to fibrous uralite, partly to chlorite and serpentine. Some original brown hornblende is present, and in the first-mentioned rock alone some olivine, much serpentinized. Magnetite is abundant in all.

Gabbro dikes.—Gabbro was found in but two dikes, near together on the Jersey Lily road near Hassayampa Creek. These are coarse, black, poikilitic rocks showing chiefly augite and biotite in hand specimens. In thin section these two minerals predominate, the former in partly idiomorphic reddish crystals, altered in places to uralite. Olivine, in large grains surrounded by serpentine and magnetite derived from it, is but little less abundant than augite. The sparse feldspar is basic labradorite and is well preserved. Magnetite and apatite are the chief accessories.

Hornblendite dikes.—Dike-like masses of a peculiar hornblende rock were found on the hilltop southwest of Battle Flat and on the summit ridge west of Crooks Canyon. The rock is coarse gabbroid in texture and consists almost wholly of a pale-green or white amphibole between actinolite and tremolite in composition. The amphibole is in large individuals and has been altered in part to pale-green chlorite, in part to a secondary hornblende in parallel growths on the ends of the older crystals, paler in color and with slightly differing extinction angle. Dusty magnetite is present throughout and secondary talc, chlorite, and limonite are more or less abundant.

Camptonite dikes.—Dikes of camptonite occur in Battle Flat, at Creek mine, northwest of Goodwin, and in a number of localities in the zone of staurolitic mica-schists east of Alexandra. At the Crooks mine the camptonite dike follows the quartz vein for some distance and the rock is almost wholly altered to calcite and sericite. On the ridge west of Crooks Canyon is a composite dike, the center of which, 5 feet in width, is camptonite, with large hornblende phenocrysts; the borders, 12 and 15 feet wide, of a coarse diorite, the whole cutting mica-granite. The coarser form of the camptonite is a rock of striking appearance, with black hornblende and biotite crystals up to three-fourths inch across and large fragments (apparent inclusions) of labradorite, in a fine greenish-black crystalline groundmass. Under the microscope the hornblende phenocrysts present a remarkable structure due to partial resorption. They are broken up into a lozenge-shaped network by separation of magnetite grains along parallel lines, the centers of the lozenges being occupied either by a fresh brown hornblende substance or by a fine granular feldspar aggregate, apparently orthoclase, charged with magnetite dust. The borders of the hornblendes are deeply embayed, and there is sometimes a bordering zone either of hornblende having color and extinction different from those of the main mass or of augite in parallel orientation with the hornblende.

The most abundant constituent of the groundmass is biotite in hexagonal plates, although in some forms hornblende exactly like the large crystals also appears as a second generation. Colorless augite in rough crystals or anhedra is abundant. The feldspar of the groundmass is lath shaped, and almost wholly altered to sericite and calcite. It appeared to consist about equally of orthoclase and a soda-lime feldspar, probably andesine, and was about equal in amount to the bisilicates.

A chemical analysis of this rock was made which confirmed the determination above given, but so much alteration was revealed that it seemed unnecessary to reproduce the figures of the analysis.

ACID DIKES.

Dikes of siliceous porphyry occur scattered throughout the Bradshaw Range, following in general belts of schist. They cut all the other intrusive bodies, and consist chiefly of rhyolite-, syenite-, and monzonite-porphyry. Their trend varies, but is usually north-northeast, parallel to the schistose or gneissic structure. They frequently occur in association with ore bodies.

The two most conspicuous dikes in the quadrangle are a thick one on the northwest flank of the New River Mountains and a very long one which extends from Silver Mountain to Peck Canyon, more than 13 miles. The former is a conspicuous topographic feature forming a series of steep foothills in a straight line trending N. 34° E.; the dike has an actual thickness of over 1000 feet, and owing to a northwesterly dip of 48° has a much greater width on the surface. The rock is a fine-grained white rhyolite-porphyry, frequently quite flinty in texture. The second dike mentioned is not topographically so conspicuous, varies in thickness from 50 to 150 feet, and while crossing various formations maintains, at a distance of 2½ miles, a striking parallelism to the western contact of schist and the larger southern stock of Bradshaw granite. The dike rock here is a coarser rhyolite-porphyry and parallel to it are other dikes.

The rock of the great dike in the New River Mountains is dense and flinty looking, with glassy sanidine phenocrysts in a micrographyric groundmass of quartz and feldspar. It differs but little from the rhyolite flows of the same region.

The rock of the long dike described is typical of a large number of smaller rhyolite-porphyry dikes throughout the quadrangle. It is a dull-white porphyry, with quartz and feldspar phenocrysts up to half an inch across rather abundantly scattered through it. The quartz is bipyramidal and deeply embayed; the feldspar is partly orthoclase in Carlsbad twinning, partly plagioclase, too much altered to sericite and calcite to be determinable. Plates of muscovite of a peculiar shredded appearance, filled with sagenitic webs of rutile, are sparingly present. The groundmass is a fine aggregate, granophyric in part, of quartz, feldspar, and sericite plates. Apatite and zircon were noted occasionally.

Similar dikes were found at the head of Lynx Creek, in the Stoddard and Mudhole mines, in the Whale tunnel at Middleton's, and in Rockwall Gulch.

Syenite- and monzonite-porphyry dikes were found in Peck Canyon, on Lynx Creek, in Pine Flat, south of Tucker's ranch, abundantly on the Mayer road above Crown King, and west of Horsethief Gulch. They are gray rocks speckled with snow-white feldspar and greenish chlorite patches. The feldspar of the phenocrysts is chiefly oligoclase, often very fresh, and orthoclase. Quartz was sparingly present in some sections. The chlorite patches are pseudomorphs after both biotite and hornblende, both of which occur rarely unaltered. The groundmass is generally microgranophyric and consists of some quartz and abundant feldspar, both orthoclase and plagioclase, the latter largely sericitized, with greenish hornblende needles, plates of mica and chlorite, occasional bytownite grains, magnetite, and apatite.

RHYOLITE-PORPHYRY.

Rhyolite-porphyry occurs in the form of black or greenish porphyritic obsidian or pitchstone in the vicinity of Prescott, a few miles outside of the northwestern corner of the Bradshaw Mountains quadrangle, and also in the New River Mountains, in the extreme southeastern corner of the quadrangle and beyond its limits. Very little is known at present concerning these rocks. They show flow structures and occur as fragments in great abundance in the agglomerate and loose gravels on the summit of Squaw Creek Mesa.

The pitchstones are black to green and purple in color, porphyritic with small feldspars and occasional mica plates, and show pronounced flow lines. In thin section the feldspars are seen to be plagioclase, apparently near albite in character, but so altered to sericite that their exact determination is difficult; some crystals of doubtful orthoclase were also seen. Both muscovite and biotite are sparingly present. The groundmass is partly a minutely granular devitrified glass, partly granophyric with indistinct spherulitic structures, composed of quartz and orthoclase. Inclusions of microlitic glassy lava were noticed in one specimen.

The New River Mountains were approached from the head of Little Squaw Creek and from the head of Moore Gulch. From Squaw Creek Mesa the section was examined to the higher peaks of the New River Mountains. After crossing a characteristic development of the Crooks complex in the foothills, a remarkable dike or band of white fine-grained rhyolite-porphyry was crossed, which forms a conspicuous and continuous topographic eminence for 5 miles along the base of this mountain range. The mountains themselves appear to be largely made up of the dark-colored pitchstone, and without doubt the pebbles of this rock found so abundantly on Squaw Creek Mesa were derived from these mountains in an early period of erosion. The thick dike-like mass of white porphyry was found again in a reconnaissance along Moore Gulch, and the drainage northwestward off the flanks of the New River Mountains is much influenced by this extraordinary geologic structure. Each outflowing stream has trenched a deep canyon in the great white dike, and several of them have developed subsequent branches and a rectangular drainage pattern along the inner or southeastern contact of the dike. It is of course conceivable that this so-called dike map be a peripheral facies of the pitchstone, but it does not appear so in the field. The outflowing streams have transported on their beds much coarse material from the New River Mountains, and practically all of the fragments are of pitchstone. There are some few exceptions to this rule in the shape of small pebbles of a greenstone which appears to be a weathered diorite. Time did not permit extended exploration of the New River Mountains and no determination was made of the intrusive or effusive origin of the dark-colored glassy rocks. The New River Mountains extend some distance beyond the quadrangle and their exploration must be left to future investigators. The structure section shows only the relations which were seen in the field, and here as elsewhere more detailed work on larger-scale maps will undoubtedly reveal greater complexity than is recorded in this folio.

RELATIVE AGES OF INTRUSIVE ROCKS.

The oldest igneous rocks in this region are probably contained within the schist belt in the form of certain uralite-diabases, such as occur at the western end of the Mount Tritle Range. The Bradshaw granite and its diorite contact phase are the oldest plutonic rocks; of these two the diorite commonly crystallized first, because it is found along the contact zone and in breccias occurs as fragments in a granitic matrix. The Crooks complex is of the same age and related to these. The monzonite-porphyry is of doubtful age.

Quartz-diorite is the youngest rock which forms large stocks, and it in turn is cut by some acid dikes and very few basic ones. Exploration has been insufficient to determine the age or structural relations of the rhyolite-porphyry of the New River Mountains. The acid dikes are in general younger than the basic ones. Among the dikes classified as basic there are a few of andesite, notably west of Cedar Canyon and south of Sheep Mountain, which represent conduits for the younger lavas and therefore are younger than the rhyolite-porphyries.

VOLCANIC ROCKS.

RHYOLITE TUFF.

The oldest volcanic ejections known within the Bradshaw Mountains quadrangle are certain light-colored, fine-grained, porous tuffs, consisting of volcanic glass. The siliceous material is further evidence of a period of rhyolite outpourings which are not represented within this quadrangle by any determined flows, unless the obsidians of the New River Mountains prove to be effusive. About the junction of Banty Creek and Castle Creek there is an area of acid tuff lying beneath andesite, with some dacite (quartz-andesite). Near the mouth of Copperopolis Creek diatomaceous earth occurs in the tuffs. Between Banty Creek and Walker Gulch, in a cliff 200 feet high, green tuff with interbedded agglomerate is exposed, showing delta structure built from the southwest, the frontal bedding dipping to the northeast. Here a small overthrust fault is shown in the tuff. At Tollgate east of French Creek a similar green tuff occurs. These are the only areas of tuff indicated on the map, but rhyolitic ash occurs elsewhere within the volcanic agglomerate, notably near the junctions of Ash Creek and Crooks Canyon with Milk Creek, along the extreme western border of the quadrangle. There the volcanic gravels form an upper series and white tuff beds 10 feet thick occur below showing a dip of 10° to the southwest and a strike of N. 40° W. In another outcrop white tuff bands are seen interbedded with sands and gravels. The microscope shows these to be a rhyolitic ash.

The tuff is well lithified, the cement largely quartz or chalcedony. Both fragments and cement are frequently colored green by a diffused ferrous silicate, the color sometimes bright enough to be mistaken for a stain of copper carbonate. Angular fragments of quartz and of andesite and rhyolite lavas could be identified.

VOLCANIC AGGLOMERATE.

All of the coarser fragmental materials containing volcanic ejecta and associated with the lavas are classed as volcanic agglomerate. The greater part of the agglomerate lies under lava, but on the east there are agglomerates interbedded with basalt and spread out on the surface of basalt plateaus. The agglomerate varies with respect to the kind of fragments it contains in different places, and in general it may be subdivided into two areas, western and eastern. In all cases observed the coarser agglomerates contain fragments of the older rocks, granite, schist, diorite, etc., as well as vesicular bombs and angular blocks of lava. In the western area, from Milk Creek to French Creek, the volcanic fragments consist of both andesite and basalt. In the eastern area, extending from the northern to the southern limits of the quadrangle, the lava blocks are basaltic. This difference is shared by the overlying lavas.

The western andesitic agglomerate has a pronounced delta structure, as though built out from mountain wash in basins, and its stratification and cross-bedding show that much of the material has been rearranged by water. It is partially lithified, forming a distinct sandstone near Milk Creek, where it weathers into "badland" sculpturing.

At Cellar basin the wash was from the granite mountains on either side, the delta frontal deposits dipping northeast near Cellar Spring, and in the opposite direction on the east side of the basin. Here, at the foot of the high peak west of Towers Mountain, the delta form is clearly shown. Farther north the agglomerate weathers to form very remarkable pinnate spurs, making long, level-topped, parallel ridges, separated by channels of singular straightness, and each ridge is trenched on either side by innumerable small, straight gulches at right angles to the main channels. This topography is indicated on the map along Slate, Ash, and Blind Indian creeks and Crooks Canyon. That the western agglomerate formerly occupied a larger area than at present is indicated along Cherry Creek, where patches of it are found high up the mountain slope, but all between has been eroded away. The agglomerate was probably once continuous from Cellar basin to Sheep Mountain.

The thickness of the western agglomerate is indicated with some exaggeration in sections D–D and E–E on the structure-section sheet, showing a thinning toward the south, where the greater volume of agglomerate is partly replaced by lava flows. The actual thickness in Cellar basin in places reaches 700 feet, and farther north the thickness is even greater. Beneath the andesites of Sheep Mountain there is a maximum thickness of from 500 to 600 feet of agglomerates, thinning in places to less than 100 feet. The thickness is controlled by a very irregular granite topography beneath, the hollows of which it filled.

The eastern basaltic agglomerates cover wide desert areas east of Stoddard, outcrop under the basalts farther south, are interbedded with the lavas in Black Mesa and Squaw Creek Mesa, and in Squaw Creek Mesa cover their upper surfaces to a considerable depth.

This eastern agglomerate, which also shows delta structure, along Yava Wash consists of angular fragments of diorite, quartz, granite, schist, and basalt; between Bigbug Creek and Agua Fria Creek it has the aspect of a fine-grained conglomerate at the base, is lithoidal, and the rounded pebbles lie in a matrix of calcareous cement. Similar lithified breccias with angular fragments occur under the basalt southeast of Mayer and under the Onyx marble (see fig. 5 on the illustration sheet).

In Squaw Creek Mesa pink and white tuffs as well as coarse agglomerate are interbedded with the basalts; and in sharp contrast with Black Mesa and the mesas east of Agua Fria River, above the upper surface of the highest flow are 300 to 400 feet of subangular washed gravels containing fragments of pitchstone, granite, diorite, and light-colored porphyries—materials derived from the New River Mountains and their foothills.

The thickness of the eastern agglomerates is indicated in sections A–A, C–C, D–D, E–E on the structure-section sheet. These agglomerates rest in the hollows of a very irregular granite topography and vary in thickness in the region south of Richinbar from 0 to 300 feet. In the northeastern region they reach a maximum thickness of 400 feet, and the basalt flows lie among the agglomerates with very irregular surfaces, frequently presenting a chaotic, disordered arrangement, with weird or grotesque topographic forms.

The most common type of agglomerate in the quadrangle has suffered some rearrangement by water. Bedding, delta structure, and heterogeneous pebbles occur in nearly all the agglomerates associated with the vast eastern flows, as in the Cellar basin deltas. The chaotic type is found only in limited areas, and they suggest by their rugged topography proximity to possible conduits, as in the Sheep Mountain district in the southwest and the Ash Creek district of the extreme northeast. No actual craters or cones have been found, but the trachydolerite stock of Little Ash Creek may be the filling of a conduit. The regions of active eruption were probably outside of the quadrangle. All the structures observed can be accounted for as the result of explosive eruption, torrential rains, and occasional lava flows, the last becoming more numerous in the later stages of igneous activity.

ANDESITE.

Augite-, hypersthene-, and hornblende-andesites, with some dacite flows, occur above the agglomerate on Buckhorn and Castle creeks and on Sheep Mountain and the adjacent hilltops. Their topography is rugged and tumultuous, strongly suggesting their volcanic origin. These cappings are outliers of a considerable area of andesite, which extends beyond the quadrangle to the southwest. South of Buckhorn Creek the lavas are horizontal, overlying schist, which near Buckhorn Spring rises about 200 feet above the creek, and is there capped by andesite. The ancient schist topography falls away to the east more steeply than the present topography, lower Buckhorn Creek flowing through a basin filled with andesite and tuff. The summit of Sheep Mountain is capped for 300 feet by massive, columnar, gray andesite, and on the north side of the mountain a 30-foot dike of red andesite trending N. 30° W. cuts the lower lavas. Below are other flows and pink, white, and red tuffs; the bedding is irregular, showing wavy folds, but as a whole it is horizontal, and rests on a very irregular granite topography. An andesite dike cuts the lavas and breccias at White's ranch, and another, remote from any known andesite flows, occurs not far from the Hackberry Creek field of basalt, in a small gulch west of Cedar Canyon. It is probable that the larger conduits through which the andesite flows were erupted lie outside of the quadrangle to the southwest.

The andesitic lavas are dark green, gray, brown, purplish red, and pink, and vary in texture from glassy compact to crystalline, porous, and amygdaloidal. They are generally porphyritic, and contain phenocrysts of feldspar and one or more of the bisilicates hornblende, hypersthene, and augite, and in the dacites quartz as well. The feldspar phenocrysts are sharply idiomorphic and vary in composition from andesine to acid labradorite. The microlites of the groundmass have about the same range of composition. The hornblende is often resorbed and surrounded by magnetite wreaths; the augite is colorless to violet and sometimes serpentinized. Magnetite, zircon, and apatite were noted as accessories, and hematite is a frequent alteration product. The groundmass is glassy in most varieties, containing feldspar and augite microlites, and again it is hyalopilitic or holocrystalline. In a portion of a glassy flow near Tollgate the weathered surface was covered with spheroids and groups of spheroids which readily broke out of the rock and had the appearance of coarse spherulites. In the fresh rock, however, and in thin section no radial structure could be detected in the spheroids, nor could they be differentiated from the matrix by any peculiar structure.

The varieties of andesite observed, as determined by dominant bisilicates, were as follows:

Varieties of andesite in the quadrangle.

Quartz-hornblende-andesite (dacite).
Quartz-biotite-andesite (dacite).
Biotite-andesite.
Biotite-hornblende-andesite.
Biotite-augite-andesite.
Hornblende-biotite-hypersthene-andesite.
Hornblende-augite-andesite.
Hypersthene-augite-andesite.
Augite-andesite.

The variety in mineralogical composition indicated by this list is probably not accompanied by a large range in chemical character. The bisilicates are subordinate to feldspar in amount, and all the rocks are lighter in color and more feldspathic than the normal basalts of the region. The general chemical character is probably fairly well indicated by the following partial analysis of a hornblende-hypersthene-mica-andesite (No. 443), selected as representing the average andesite type of the region.

Partial analysis of hornblende-hypersthene-mica-andesite.

	Per cent.
SiO_2	64.21
CaO	3.29
Na_2O	3.87
K_2O	3.21

The molecular alkali-silica ratio calculated from this analysis is 0.090, which corresponds in general to that found in yellowstonose or andesite.

BASALT.

Basalt occurs as a large dike or conduit north of Groom Creek basin, and, as a capping with vertical columns and horizontal structure, forms Bigbug Mesa, the summit of Malpais Hill, and covers a small area west of Goodwin's ranch, at the western border of the quadrangle. These are scattered remnants where the basalt lies within the high mountain area of granite and schist. The eastern third of the quadrangle is covered by extensive basalt flows, the eroded edge of which produces a marked mesa topography along lower Agua Fria River, and an irregular volcanic topography in the higher and more mountainous volcanic district of the northeast.

The rock is uniform, varying chiefly in its porosity. The upper portions of individual flows are sometimes scoriaceous and amygdaloidal; the lower contacts of the lava are massive, black, and fine grained; exceptionally the basalt is grayish, approaching augite-andesite. It frequently weathers on the surface to lumpy spheres, making fields of black bowlders of very somber and barren aspect, known in the region as "malpais."

The conduit north of Groom Creek is a dike 150 feet thick that trends N. 60° W. and contains inclusions of granite. The fissure filled by the basalt crosses schists charged with granite and basic dikes; apparently its length is not greater than from one-half to three-fourths mile. The basalt is columnar, with nearly horizontal, pentagonal columns pitching slightly to the north.

The basalt on Bigbug Mesa has an average thickness of 500 feet and its mass is inclined toward the east. It consists of a number of flows progressively thinner upward, the lowest having a thickness of 100 feet. On the west side of Black Mesa there is exposed 200 feet of basalt above 300 feet of agglomerate. In Squaw Creek Mesa there are four or five flows of basalt, which have an aggregate thickness of 400 feet on the western face of the cliffs and thin out to less than 100 feet toward the east. The thickness of the wide eastern basalt flows is very variable; the upper surface is relatively horizontal, but the bottom fits the hollows in the underlying granite topography. Thus, near Richinbar the granite reaches the level of the surface of the mesa at several points, while near Bumblebee, 2 miles to the west, the contact of lava and granite lies 800 feet lower. On Malpais Hill, in the midst of the large southern granite stock a flow of partly vesicular basalt 350 feet thick occurs in upright columns. The contact of granite under basalt slopes to the west.

There are a few small basalt flows in the andesitic agglomerate of Ryland Gulch. As the basalt also occurs throughout the western agglomerate, it is clear that basalt began to flow before the andesite period closed.

The basalts are generally holocrystalline, porphyritic, and ophitic. The phenocrysts are chiefly olivine and augite, the latter fresh, the former changed wholly or in part to the mineral called iddingsite. Occasional phenocrysts of lime-soda feldspar (bytownite) were also observed. The groundmass is of feldspar laths (labradorite) with augite, olivine, and magnetite grains, either very finely granular or rarely as microlites in a colorless glass. In amygdaloidal varieties the cavities are often filled with calcite. A specimen from the divide between Ash and Cienagas creeks consisted of fragments of highly vesicular orange-red glass containing minute porphyritic crystals of olivine and augite and black trichites, the whole cemented with calcite.

A partial analysis of a typical basalt from near Richinbar (No. 174) resulted as follows:

Partial analysis of typical basalt from near Richinbar.

	Per cent.
SiO_2	50.62
CaO	9.76
Na_2O	3.17
K_2O	.73

The alkali-silica ratio calculated from this analysis is 0.068—a ratio that defines in general the rock type hessose, an equivalent of basalt.

TRACHYDOLERITE.

A small, irregular, stock-like mass of rock, which may be called trachydolerite, and which is very different in character from the lavas above described, was found in the extreme northeast corner of the quadrangle, on the headwaters of Little Ash Creek, isolated amid the fields of basalt, into which it is clearly intrusive. It is a very coarse-grained granular rock, with pronounced miarolitic texture, and outcrops in a low dome from which irregular arms reach out into the surrounding basalts. It is one of these arms alone which appears on the map, the dome itself and the major portion of the stock lying outside the quadrangle. It seems highly probable, from the absence of similar rocks of effusive character in the neighborhood, that this intrusion did not reach the surface. Furthermore, its border facies present transition forms which approximate the surrounding basalts in composition, and it probably represents a locally differentiated facies of the basalt intruded during the last stages of volcanic activity.

The rock of this intrusive stock varies from a dense, fine-grained, ash-gray type near the contact with the basalt to a very coarse granular, miarolitic rock of reddish-gray color at the center of the mass. The constituents are mainly plagioclase feldspar and augite, both of which minerals appear in well-formed crystals on the miarolitic cavities. The feldspar crystals are white and glassy, and of a perfection and complexity of form very rare in soda-lime feldspars. The crystals are complex twins on the albite, Carlsbad, and Manebach laws and show the common feldspar forms. The faces are somewhat dulled by weathering, but are still sufficiently perfect to give distinct readings on the reflecting goniometer. The augite crystals are of the common prismatic form, terminated by the negative unit pyramid. In some cavities the crystals of both minerals are covered with a coating of a white zeolite determined by chemical tests to be natrolite.

In thin section the rock is found to consist of plagioclase feldspar, orthoclase, nepheline, augite, ægirine, olivine, magnetite, and apatite, with a structure varying from coarse granular to ophitic. The plagioclase constitutes more than half the mass and is oligoclase (Ab_4An_1 to Ab_2An_1), extremely free from alteration. Orthoclase is present in small amounts in all slides examined and a very little nepheline was found in a single section. Augite is the dominant bisilicate, in imperfectly idiomorphic prisms, greenish to pale violet in tint. Many crystals are partially or wholly bordered with bright grass-green ægirine, and occasional complete but small individuals of the latter mineral are also present. Olivine is variable in amount, but never abundant, and is generally largely serpentinized—the only mineral in the rock which has suffered alteration. Magnetite and apatite are both abundant and their sharply bounded crystals are included in all other constituents, most frequently in the feldspar.

The border facies of this rock where it is in contact with basalt differs chiefly in the finer grain and absence of pronounced miarolitic structure, in the more basic character of the plagioclase, which is labradorite (Ab_1An_2), in the absence of orthoclase, nepheline, and ægirine, and the greater abundance of olivine. In short, it is here of distinctly basaltic character. The basic facies is limited to a zone but a few feet in thickness at the one point where its contact with the older basalt was clearly exposed, and the contact was clearly defined by the difference in color and finer grain of the trachydolerite intrusion.

Analyses of these rocks by Mr. George Steiger are as follows:

Analysis of miarolitic trachydolerite from Little Ash Creek (No. 172).

	Per cent.
SiO_2	52.06
Al_2O_3	15.52
Fe_2O_3	5.49
FeO	7.06
MgO	2.23
CaO	5.46
Na_2O	5.24
K_2O	2.24
H_2O-	1.00
H_2O+	.59
TiO_2	2.71
P_2O_5	.32
MnO	.12
Total	99.74

Analysis of basaltic facies of trachydolerite from Little Ash Creek (No. 155).

	Per cent.
SiO_2	46.74
Al_2O_3	16.96
Fe_2O_3	6.44
FeO	4.13
MgO	6.18
CaO	11.90
Na_2O	3.13
K_2O	.50
H_2O-	1.24
H_2O+	.89
TiO_2	1.04
Co_2	.58
P_2O_5	.56
MnO	.23
Total	100.52

If, following the methods of the quantitative classification, the norms of these two rocks be calculated the compositions given in the next table are obtained. From these it is evident that the typical trachydolerite is an akerose, while the basaltic facies is an auvergnose.

The modes of these two rocks have not been calculated. They would differ from the norm chiefly in the absence of hypersthene and the calculation of diopside as titaniferous augite.

Norms of trachydolerite.

	No. 172	No. 155
Orthoclase	12.79	2.78
Albite	44.02	26.20
Anorthite	12.51	31.14
Diopside	10.50	19.65
Hypersthene	4.51	1.56
Olivine	.48	4.11
Magnetite	7.89	9.28
Ilmenite	4.41	1.82
Apatite	.62	.93
	97.73	96.47
Water	1.59	2.13
Total	99.32	98.60

RELATIVE AGES OF VOLCANIC ROCKS.

The rhyolite tuff is apparently the oldest of the volcanic ejecta, as it occurs at the base of the oldest agglomerate. The presence of a rhyolite near Prescott and of rhyolite-porphyry dikes and rhyolitic pitchstones with flow structures on the New River Mountains indicates that siliceous lavas are not wanting, and it is probable that they are the oldest lavas in the region.

Stratigraphically next above the rhyolite tuff is the andesitic agglomerate representing explosive phases of an early eruption period, which was brought to a close by outflows of andesitic lava. The products of andesite eruptions at one time covered the southwest corner of the Bradshaw Mountains quadrangle, but that they did not extend across the area is shown by the fact that such lavas are not preserved under the basalt on the eastern side.

The initiation of the greater basaltic period of volcanic activity followed the outpouring of andesites, but some basalts accompanied the earlier eruptions. The general sequence of lavas was from acid to basic. The later basalts lapped far up the eastern and northern slopes of the Bradshaw Mountains (see structure sections), burying the southern range at least as high as Malpais Hill (5500 feet), and the northern range to heights over 7100 feet (the highest point of Bigbug Mesa). This series of eruptions, as usual, was initiated by explosive discharges, increased erosion, and wash from the mountains, and was accompanied by boiling springs which deposited carbonate of lime and magnesia. There is here no evidence of the site of the original volcanoes except in the case of the basaltic conduit north of Groom Creek basin. The basalts came from the northwest and northeast and the andesites from the southwest, and only the edges of deeply eroded flows are contained in the Bradshaw Mountains quadrangle.

ORIGIN AND RELATIONS OF THE ROCKS.

This area is that of a very ancient land which has been deeply eroded to mature relief, buried under lavas, and then eroded again, with possibly some additional uplift in the mountains. The only evidence of such local uplift is the tilt of Squaw Creek and Bigbug mesas. Such evidence is not conclusive because lavas may be laid down on a slope.

Sections A–A, B–B, C–C on the structure-section sheet show the region of maximum elevation at Spruce Mountain and Mount Tritle, and the relatively gentle slope and slight relief of the land eastward. Section E–E shows the much lower land of the southern border of the quadrangle, with more pronounced relief. Section D–D, from Cellar basin east across the Bradshaw Mountains, shows the maximum relief, with differences of elevation of 4100 feet. The sections indicate the relation of profile to structure in the same way that the map shows the relation of topography to geologic outlines.

ORIGIN OF SCHISTS.

It has been shown that about 7000 feet of schistose sedimentary rocks—conglomerates, sandstone, and slate—occur in the Bradshaw Mountains quadrangle. These beds formerly were flat, but now lie in isoclinal folds as the result of tight compression by a horizontal force which acted from northwest to southeast. This compression has also produced schistosity, which is usually parallel to the color banding, or original bedding, but may lie in planes transverse to that banding in the bends, or axial regions, of folds. The conglomerate contains pebbles of granite, quartz, schist, and quartzite; these pebbles were rounded by water action, either on a sea beach or in a river bed, originally. The sands lie in sequence between conglomerate and slate, in some places suggesting the original off-shore succession of sedimentary deposits.

Such a structure leads to the inquiry, Are any remnants of the old shore still in existence? Can the rocks be found from which the pebbles of the conglomerate were derived? These pebbles resemble the materials of the Bradshaw granite on the one hand and some members of the schist series on the other. On the west slope of Bear Creek, near the junction of Tuscumbia Creek, the conglomerate rests against the granite at a sharp contact between the two formations, and there is here some appearance of an unconformity. At Brady Butte, however, this same granite alternates with schist in bands, and elsewhere the granite is known to be intrusive. It is still more difficult to detect any unconformity within the schists themselves, so uniformly is the whole series crumpled; the beds stand nearly vertical, and original discordances are lost. It has already been pointed out that a considerable thickness of schist lies apparently beneath the conglomerate east and west of Brady Butte (see section C–C). This accords with the appearance of unconformity farther south; and therefore there is a possibility that the granite of Brady Butte and some of the adjacent schists represent an older series of rocks that lie unconformably beneath the conglomerate. Other such unconformities may exist elsewhere within the quadrangle.

RELATION OF SCHISTS TO INTRUSIVE STOCKS.

The theoretical questions of chief importance concerning the igneous stocks are as follows: (1) Were the granites and other rocks intruded into schists? (2) What is the evidence of contact metamorphism? (3) What was the effect of cooling walls (contacts) on the constitution of the magma?

(1) The evidence bearing on the question of the intrusion of granites and other rocks into schists is as follows:

The schists close to and in many places remote from the contacts with the larger intrusive bodies contain dikes and lenses of pegmatite, granite, aplite, and diorite. Bodies of schist, large and small, are inclosed in the large granite and diorite stocks; at the north end of Brady Butte alternations of granite and schist in bands a few feet wide indicate that the granite has there invaded the schist in narrow dikes or lenses. Indirect evidence of intrusion is furnished by the fact that zones of indurated or metamorphic schist follow granite contacts, and in the case of the large southern stock of the Bradshaw Mountains the divergence of the schist banding east and west about the northern end of the stock suggests the splitting apart of the isoclinals by invasion of the granitic magma.

The granite shows indirect evidence of its intrusion into the schist by increased basicity and by the development of quartz-diorite along certain contact zones.

The diorite, as a phase of the granite magma, contains the same strained quartz as the granite, shows other mineralogical evidences of magmatic relationship, occurs chiefly in contact with schists, and is subordinate in quantity to the granite. This is all confirmatory of the hypothesis that the granite contacts are those of an intrusion younger than the schist. The diorite north of Richinbar is an example of a gradual merging of granite into quartz-diorite, and schist is known to be present under the basalt at Richinbar.

The Crooks complex, a banded igneous formation consisting of confused alternations of granite, diorite, gabbro, schist, aplite, and plutonic breccias, is one of the products of the period of granitic intrusion. It is frequently associated with contacts of granite and schist, and is in some places merely a phase of the one or the other or a mixture of the two, the diorite within it being probably produced by local segregation of basic materials within the granite where numerous schist inclusions have induced all the conditions of a contact zone. Thus the transition from normal phyllite through its hornblendic facies to the Crooks complex south of Lehmans Mill, in the southwestern part of the quadrangle, is marked by no definite boundaries in the field. In such places it is highly probable that the banding of the igneous members of the complex was induced by splitting apart schists to form a series of close parallel dikes, originally marked by various compositions in different epochs of the period of intrusion of the magma as a whole. The outcrop of Crooks complex along Squaw Creek and some of those east of Cellar basin show banding parallel to Yavapai schist close at hand; in the Crooks Canyon region, however, this banding is transverse to and discordant with the trend of adjacent schists. The Crooks complex as a whole is an intricate manifestation of the intrusive nature of the granite magma in its relation to the schists, and the areas mapped as this formation may be considered examples on a scale too small to map of all the contact features of granite, diorite, and schist shown elsewhere on a larger scale.

(2) The evidence bearing upon the problem of contact metamorphism is as follows: The schists are shown on the map to develop a metamorphic zone, bearing distinctive contact minerals, along the borders of the great Bradshaw stock and along portions of the contact of the elongate group of igneous formations from Briggs to Mount Union, including granite, Crooks complex, and diorite, all three of which are believed to be manifestations of the same magma. Included strips or belts of schist within these igneous masses usually show the same metamorphic character. Exceptionally the schist is normal at the contact, and there are many local occurrences of amphibolite and other forms of highly metamorphic schist in places where no plutonic masses are visible. The greater part of the evidence, however, shows a connection between induration or amphibolitization of the schists and the proximity of the plutonic contacts. Hornblende is not always the dominant contact mineral; in a case cited, in the Crazy basin (see p. 3), at the northern contact of the Bradshaw stock, the mica-schist at the contact is charged with quartz and pegmatite veins carrying andalusite and tourmaline; on receding from the contact coarse mica-schist is found, and schists containing staurolite, garnet, and tourmaline. The coarseness of crystallization decreases on going farther, until the fine-grained phyllites are reached. This transition takes place in distances varying from three-quarters of a mile to 1½ miles. The change is along the strike of the schists. In other places, as between Mount Tritle and Spruce Mountain, for instance, the schists are altered to great masses of dense black or greenish hornfels or hornblende-schists; possibly the original schist was here richer in iron, lime, and magnesium than in the Crazy basin section above cited. In both cases large stocks of plutonic rock are close at hand. It is worthy of note that four small stocks of diorite occur within the hornblendic schists of the Mount Tritle district, while only massive quartzose granite occurs in the Crazy basin district. This difference suggests that possibly the relative basicity of the adjacent plutonic eruptive affects the product of metamorphism, if this metamorphism along contact zones is to be considered the effect of contact action of the intrusive rock on the schist invaded.

The above statement of the facts and of the suggested explanations shows that there is here illustrated one of the most profound and least understood problems in metamorphic geology—namely, the meaning of metamorphism and of granitization. (See Termier, Les schistes cristallins des Alpes occidentales: Compte Rendu IX Congrès Géologique International, Vienna, 1903.) It is probable that metamorphism and the intrusion of granitic magmas are parts of a single process and are mutually interdependent. That they are *related* in the Bradshaw Mountains can not be questioned. What was the process of cause and effect whereby the observed relation of contact zone to granite stock came about is unknown at present. The contact minerals may have been produced by recrystallization, by crystallization from heated vapors (pneumatolytic action), by direct importation of new material from the intrusive magma, by an exchange of material, or by fluids which followed the contact after the intrusion of the granite had ceased. Geologists know little of the physicial conditions which govern the movements and mechanism of crystallization of granite prior to its solidification. Lastly, it is not impossible that the granite itself developed in situ from preexistent rocks by a process of solution and digestion not at present understood. In any case, the so-called intrusion of the granite magma took place under conditions of temperature and pressure unknown to the modern laboratory, and probably saturation with water and other vapors at profound depths in the earth's crust. It is to be hoped that future studies in detail of the contact zones of the Bradshaw Mountains will throw new light on these vexed questions.

(3) The cooling walls (contacts) may affect the constitution of the magma by endomorphism. It has been suggested above that diorites were especially abundant in the hornblende-schist of the Mount Tritle district, and might frequently have originated in the Crooks complex by differentiation of the granite magma in those places where inclosed belts of schist were numerous. It has been shown that near Bland Hill a long belt of diorite appears to be a contact facies of the granite, contains similar minerals, and grades into the more acid rock. It has also been shown that this gradation is not general; there are exceptions quite as conspicuous as the case cited. Even at Bland Hill the diorite has exerted no strong metamorphosing action on the adjacent schist; at Cordes it penetrates unmetamorphosed phyllite, and to the south extends beyond the quadrangle as a contact phase of the Crooks complex. The evidence, therefore, for an endomorphic zone in the granite is not as complete as that for the exomorphic zone in the schist. It is quite certain, however, as stated above (1) that the diorite, wherever found, is almost invariably in contact with schist, and in these cases, if the diorite is considered a phase of the granite, the question arises, Why is the magma more basic along certain contacts or within certain schists?

As no diorite zone has been continuously traced around the Bradshaw stock or the western stocks, it can not be supposed that internal differentiation of the granite magma, due to its physical condition on the cooling walls of the fissure which it filled, was the cause of its variation to diorite, unless it is supposed that the segregated diorite, wherever it is absent, was all absorbed in the process of making a metamorphic aureole in the schists. This seems improbable, as the metamorphic zone about the northern border of the Bradshaw stock is, as shown above, not basic, but highly siliceous; and in the Mount Tritle region, where it is basic, diorites are abundant. If the change in the magma was not due to internal differentiation, what could the schists have added to the magma to produce diorite? There may have been some actual absorption of basic material in those places where the schists were already basic; in such a case the location of the diorite would be due to the original composition of the schists at those points. There is no evidence to show that the schists were especially basic, or that they contained more ancient metamorphic eruptives at the places where diorite is now found. Therefore, we must consider that the physical cause for the sporadic endomorphism shown by the granites of the Bradshaw Mountains is not satisfactorily explained.

AREAL GEOLOGY.

MOUNT UNION DISTRICT.

The Mount Union district comprises the highest mountains in the quadrangle, and includes the area from Lynx Creek, in the northwest quarter of the quadrangle, to Cellar basin, on the western side, where the mountains fall away toward the Hassayampa Valley. A belt of Bradshaw granite extends north-northeast and south-southwest through Mount Elliott, Mount Davis, and Mount Union. At Crooks Canyon the granite changes gradually southward to alternations of granite, diorite, gabbro, gneiss, schist, breccias of diorite in a granite matrix, aplite, tourmaline-epidote-gneiss, and other rocks. All of these, occurring in irregular bands, are classed together as the Crooks complex, the igneous rocks in some places appearing as dikes or lenses, elsewhere as irregular bands and minor stocks. The predominant rocks in the complex are the granite and its diorite phases. The belt of granite and Crooks complex, extended farther south under the volcanic agglomerate of Cellar basin, is succeeded at Cherry Creek by more uniform granite-gneiss, which extends beyond the quadrangle on the west. East of Cherry Creek the Crooks complex continues southward under the andesitic lavas.

The northwest corner of the quadrangle is occupied by a belt of Yavapai schist and its hornblendic phase, invaded by stocks of quartz-diorite and diorite, and bounded on both sides by Bradshaw granite. At least one-half of the schist is fine-grained green-black hornfels and amphibolite, and this portion of the formation is most invaded by eruptives. A belt of conglomerate on the east slope of Mount Tritle, associated with sandstones and phyllites toward the south and west, suggests that the body of schist was originally sedimentary. The diorite which invades them probably represents outlying intrusions of the Bradshaw granite magma. Between Groom and Granite creeks a small basaltic conduit occurs as a dike; this is unique, basalt elsewhere occurring only as flows. Strikingly accordant with the open contours of the basin between Hassayampa and Groom creeks is the large stock of quartz-diorite which erosion has carved into a lowland, in contrast to the indurated schists of Spruce Mountain and the Tritle Range. Along the contacts of the quartz-diorite are many mines and prospects. In the field the contrast between this formation and the rocks in contact with it is striking. At Walker there is a smaller stock of quartz-diorite, and some ore bodies occur along its border.

In the Mount Union district acid porphyry dikes are more abundant in an eastern belt from Walker to Mount Tritle, and basic ones in the extreme northwest corner of the quadrangle.

Summarizing, the Mount Union district consists of a belt of schists, which shows metamorphic phases along the contact with Bradshaw granite and diorite, and is further metamorphosed by the intrusion of quartz-diorite. Ore-bearing quartz veins are found most abundantly along the contacts of the quartz-diorite.

BIGBUG DISTRICT.

The Bigbug district includes the middle part of the northern half of the quadrangle, from Bigbug Mesa to Copper Mountain, inclusive, and extends south to Crazy basin. This region contains the widest belt of Yavapai schist, and many quartzite ledges; conglomerate occurs within the schist east and west of Brady Butte, at Bueno, and at Ticonderoga Gulch. East and west the schist belt is bounded by Bradshaw granite, in great part concealed by basalt on the eastern side, but clearly continuous from Yava Wash to the hills east of Cordes. At Brady Butte a long stock of granite splits the schists. As in the Mount Union district, all the gold mines and prospects of the Bigbug district center about a region of younger eruptive stocks of quartz-diorite near Bigbug post-office and McCabe. Here again the schists are partly altered to amphibolite. Diorite occurs near the head of Bigbug Creek, apparently as a contact phase of the granite. Copper prospects occur, in association with silicified schist and porphyry dikes, at Stoddard and in the Crazy basin. There is evidence that the basalt formerly extended across the Bigbug district, a thick remnant of it existing high up the mountain slopes in Bigbug Mesa, and outliers occur in Hackberry Creek basin, east of Bigbug Mesa, at Valverde, and at Stoddard. At Mayer a deposit of onyx marble, with its associated breccias of schist in a calcite matrix, so resembles calcareous breccias which occur under the basalt of Hackberry basin and elsewhere that there is good reason to suppose this deposit also lay under a thick basalt sheet. Schist, diorite, and quartzite recur east of Brushy Wash.

CROWN KING DISTRICT.

The Crown King district includes the belt of schist and eruptives from Silver Mountain to the Crazy basin and from Bueno to Blanco Springs. This belt includes the schists on the west side of the Bradshaw Mountains, where a large granite stock splits apart the southern extension of the schists of the Bigbug district. An elongate granite body at Minnehaha on the one side and the Bradshaw Mountains stock on the other have inclosed this schist and are in some sense associated with its metamorphism, so that the greater part of it is included in the hornblende-schist phase. But on Buckhorn Creek south of Silver Mountain mica-schists and phyllites of the character of those in the Bigbug district occur, and north of Crown King, at a distance from the granite, phyllite and mica-schists replace the more metamorphic varieties of the granite contact. A stock of quartz-diorite forms an open basin in the mountains west of Crown King and determines, as in the northern districts, the occurrence of ores about its periphery. The Minnehaha granite area appears to have been rent apart by this invasion of quartz-diorite, its northern continuation extending from Towers Mountain to Brady Butte. A belt of the hornblende-schist phase of the Yavapai formation extends along the eastern border of the Crooks complex from Bigbug Mesa to Towers Mountain, merging into normal schists on the east. Toward the south also this belt merges into Yavapai schists, in the valley north of Minnehaha, where mica-schists occur with remarkably flat dip; at one point there is some appearance of a northerly pitching anticline and a dip of only 20°. (See section D–D.) An elongate stock of Bradshaw granite extends from Crown King northeast and is separated by a belt of amphibolite from the Bradshaw Mountains stock. This narrow schist zone, like the one west of Towers Mountain, has been worn down to form a valley, with mountains of eruptive rock on either side. At Battle Flat occurs a stock of monzonite-porphyry which has produced a shallow basin somewhat similar to those occasioned by the quartz-diorite. A number of rhyolite-porphyry dikes trending parallel to the schistosity traverse the Crown King district, and one of these is remarkably continuous for 13 miles.

SOUTHERN BRADSHAW RANGE.

The southern Bradshaw Range includes the Bradshaw Mountains from Crazy basin southward and the Black Canyon schist belt to the east. The Bradshaw Mountains are formed of granite and inclosed bodies of schist in strips and blocks sometimes several miles long. The granite retains a gneissic structure, which is especially conspicuous parallel to the eastern contact. Wherever the contact is seen the schist is charged with granite lenses, and the presence of much schist in the granite indicates a process of intrusion whereby the schists were gradually absorbed rather than violently disrupted. Some copper prospects occur along Black Canyon. The only gold mines in this district are near Columbia, where there is much included schist and large porphyry dikes occur. The Black Canyon schist belt is essentially vertical, with some inclination to the west; this tends to give erosion an undermining effect on the granite and accounts in part for the steeper eastward face of the mountain spurs. Ferruginous quartzites and amphibolite occur next to the granite; farther away on the east is a sericite-schist belt which is in places siliceous and salient. Within the deep canyons of the east-flowing streams and at their junction with Black Canyon the gulch slopes are steep and the creep of surficial soil frequently produces in the schists a false dip by bending the laminæ from 15° to 40°, so that the apparent dip is into the hill. Thus, western slopes show easterly dip and eastern slopes westerly dip. On the eastern side of this schist belt diorite occurs and merges by gradations into Bradshaw granite farther east. This granite underlies the basalt and has its greatest exposure in the region east of Cordes. An outlier of basalt occurs on one of the summits of the Bradshaw Range, Malpais Hill.

Summarizing, the distinctive features of the southern Bradshaw Range are a great stock of gneissic granite with included schists, a belt of amphibolite, quartzite, and sericite-schist to the east, and beyond that granite with a diorite contact phase. Ores of the precious metals occur only where the included schists are abundant in the granite.

SHEEP MOUNTAIN DISTRICT.

The Sheep Mountain district includes an area of andesitic volcanic rocks in the southwest corner of the quadrangle. Rhyolitic tuff and agglomerate are the lower members in a series of unevenly bedded lavas, with andesite flows capping them (see section E–E), which extend beyond the limits of the quadrangle to the southwest. The agglomerate occurs in outlying patches to the north near Donnelly ranch and Fenton's ranch, and these patches serve to connect the wide agglomerate area of Cellar basin with the southern exposures, showing that the volcanic gravels were once continuous through the intermediate space. Some basalt flows occur. The series of ancient crystalline rocks which form the old land under the lavas, from west to east, is as follows: Granite, Crooks complex, hornblende-schist, Yavapai schist, granite. The western granite is gneissic, with small schist bands which are often stained with chrysocolla; this has given rise to copper prospecting in this vicinity. The metamorphic phase of the Yavapai formation has here the aspect of heavy beds of hornblende- and mica-schist with granite veins. A considerable area mapped Yavapai schist occurs between Buckhorn Creek and Briggs, which consists in detail of mica-schist, a breccia of blue quartz in the schist, some gneiss bands, and hornblende-schist with dikes of tourmaline-granite. The eastern granite is coarse, micaceous and pegmatitic, and represents the extension southward of the great stock, which here emerges from beneath the lavas and extends farther south to the mountains east of Castle Creek Hot Springs, beyond the quadrangle.

Summarizing, the Sheep Mountain district is characterized by agglomerates and andesitic lava flows, the latter overlying the former, and both resting on a topography of granite and schist. The schist has a northeast trend and represents the southern extension of the Crown King belt.

AGUA FRIA VALLEY.

Agua Fria Creek enters the quadrangle at Valverde Smelter, flows southeast to Mitchell ranch, then, as Agua Fria River, its course is southwest and south through the Richinbar basalt canyon to Goddard's, where it enters a canyon of schist and follows a sinuous course southward beyond the quadrangle. The northern part of its valley in the Yavapai schist is a moderately deep gorge, with fertile alluvial bottoms. The loam and gravel are from 15 to 30 feet deep, and at the bend in the gorge 2 miles south of Valverde the Agua Fria has trenched the alluvium to a depth of 15 feet, showing horizontal bedding, but the side streams have only very slightly incised their beds into the deposit; the result is to give the tributaries the aspect of miniature hanging valleys. The schists are like those of the Bigbug district and consist of phyllites, gneiss, and amphibolite, with quartzite ledges in prominent relief on the spurs of the northeastern granite mountains.

Two miles below Stoddard Agua Fria Creek enters agglomerate and basalt in an open, dry desert country. The agglomerate covers many square miles of flat land and consists of angular gravel made up of slate and quartz fragments, appearing loose on the surface, but in stream trenches seen to be lithified with a calcareous cement. This agglomerate underlies the basalt flows on the northeast and overlies those basalts which form the walls of Agua Fria Canyon to the south. The first basaltic canyon is entered by the creek at about the mouth of Yava Wash, and is trenched to a depth of 200 feet, the basalt on the upland weathering to fields of black rubble. At the mouth of Sycamore Creek the stream flows through a fertile bottom land. Under the basalts are agglomerates composed of heavy basaltic bombs in a dolomitic matrix, and fields of white dolomitic travertine containing chert appear on both banks of the stream. These replace the agglomerate under the basalt over a considerable area. The basaltic fields of the northeast are interrupted by dikes and probably by remnants of old craters, for their sky line is rugged and differs from the flat plateau farther south. A small stock of trachydolerite intrusive in the basalt occurs on the headwaters of Little Ash Creek in the northeast corner of the quadrangle. South of Sycamore Creek the Agua Fria flows through granite, passing along the foot of conspicuous hills of this rock. The granite rises from beneath basalts on the east and presents a very varied topography under the basalt. A section of the volcanic series at the junction of Indian and Agua Fria creeks shows above the granite 75 feet of cemented arkose and agglomerate, 30 feet of amygdaloidal lava, 20 feet of buff volcanic sandstone, and 150 feet of columnar basalt. Dikes of granite-porphyry cut the granite, which varies by magmatic gradations to diorite and contains schist toward the west. At Richinbar the river has trenched deeply through the basalts and granite, forming a canyon over 1000 feet deep, bounded on either side by wide basaltic mesas which slope gently toward the southeast and vary in height from 3200 to 4000 feet above sea level. At Richinbar a narrow belt of schist in granite occurs under the basalt, and ore-bearing veins have been found there.

North of Richinbar quartz-diorite occurs, apparently as a facies of the Bradshaw granite, and the same change in the granite is observed all along its contact with the Black Canyon schist belt from Cordes southward. On going south from Richinbar the granite becomes more dioritic and more charged with schist inclusions, and this change corresponds to a similar change observed at the southern end of both the Brady Butte and Mount Union granite belts. Thus the transition to Crooks complex is gradual, though it is indicated on the map as a definite line, south of Bumblebee, east of Black mesa, and on Squaw Creek. At Goddard's the river emerges from the lavas, traverses a wide alluvial tract, and then at its junction with Black Canyon plunges again into a deep sinuous gorge in the Yavapai formation, which it follows beyond the quadrangle.

Summarizing, the Agua Fria Valley follows the western boundary of agglomeratic and basaltic lavas, sometimes trenching them and revealing the eastern contact of Yavapai schist with a wide granite tract which underlies the lavas. Along this contact the granite has given place to diorite, and toward the south it changes to the Crooks complex. The lavas from north to south change from disorderly to horizontal. Their thickness varies greatly, as they fill hollows in an uneven granite topography beneath.

NEW RIVER MOUNTAINS.

The New River Mountains, in the extreme southeast corner of the Bradshaw Mountains quadrangle, consist largely of rhyolite-porphyry. A very large dike of white porphyry, over 1000 feet thick, marks the boundary between this formation and the Crooks complex. The latter, here consisting of alternate diorite, white quartz, granite, aplite, gabbro, and diorite breccia in bands trending northeast, forms low foothills that are separated from the mountains by the gorge of Moore Gulch. This gorge is remarkably straight, following the west wall of the dike, and all of the northwest-flowing streams from the mountains cut deep canyons through the dike, the resistant rock causing waterfalls. Squaw Creek Mesa differs in structure from the lavas farther north in that the basalts are covered with a deep agglomerate deposit, consisting of subangular washed gravels from the New River Mountains. North of the New River Mountains, along Squaw Creek, the Bradshaw granite rises to within 300 feet of the surface of the basalt plateau. The New River Mountains extend beyond the quadrangle, and have not been thoroughly explored.

GEOLOGIC HISTORY.

The oldest rocks known in the Bradshaw Mountains are the schists. The conglomerates and sandstone within the schist series were originally deposited against preexistent land composed also of schist, quartzite, and granite, but no part of such basement is positively known. The schists were in small part ancient volcanic flows or intrusive sheets, now metamorphosed to uralite-diabase.

The whole series in pre-Cambrian time was involved in several periods of deformation and erosion, whereby the original sedimentary structures were largely destroyed and a structure of closely appressed folds was produced. The folding brought the bedding planes to a vertical or nearly vertical position, with dips at high angles east and west, and strikes northerly.

During this deformation, while the strata were deeply buried in the earth's crust, intrusive plutonic magmas invaded them. These crystallized as large stocks of granite, and smaller stocks and zones of diorite, which are now found wedged among the schists. The boundaries of the stocks and their lenticular habit show that the schistose parting planes were in an upright position at the time of intrusion—i. e., that intrusion was guided by isoclinal structure already developed. There were some aplite, camptonite, and other dikes which represent the last acid or basic segregations of these magmas that filled shrinkage cracks in stocks and schists alike. Portions of the plutonic magma crystallized with a very irregular banding of alternations of diorite-granite and intermediate or extreme basic or acid rock types, and these form the Crooks formation, which in different places merges into granite or diorite. The origin of the banded structure in this igneous complex is obscure.

The schists in contact with granite or diorite became more highly crystalline than elsewhere, and developed an abundance of hornblende, epidote, tourmaline, staurolite, mica, zoisite, and garnet. Locally some change occurred within the intrusive magma also, the more basic or dioritic forms of the granite being segregated along the contact zone, or forming small stocks wholly within the schist.

Later stocks of quartz-diorite, marking apparently a different period of eruptivity, filled fissures in schists, diorite, and granite. These stocks are smaller than the earlier ones of granite, and have been less subject to strain or deformation since their intrusion. Ores of the precious metals were developed in abundance as veins in the rocks adjacent to the contacts of this quartz-diorite.

The age of the plutonic intrusive rocks may be inferred by analogy with the evidence for the age of the schists. There are stocks and lenses in the Jerome and Grand Canyon sections similar in all respects to the granites and diorites of the Bradshaw Mountains, and intrusive into partly sedimentary schists which are considered identical with the Yavapai formation. These northern stocks are definitely pre-Cambrian, the Tonto sandstone (Cambrian) lying unconformably across their eroded surface. They are also older than a still lower series of rocks carrying a meager brachiopod, pteropod, and trilobite fauna (Grand Canyon series), which on geographic and stratigraphic grounds Walcott considers upper Algonkian in age. The lower schist series (Vishnu-Yavapai) then becomes lower Algonkian, and the intrusives represent an epoch or group of epochs after or during the deformation of the lower Algonkian strata and before their uplift and erosion to receive the deposits of the upper Algonkian on their surface.

Periods of uplift, erosion, and depression followed and the beveled surface was formed on which Paleozoic, Mesozoic, and Tertiary sediments were deposited. Probably the rhyolite-porphyry dikes rose through the schist and granite in early Tertiary times and formed intrusive bodies in the overlying sediments.

Erosion has removed all the flat-lying Paleozoic sedimentary rocks from the Bradshaw Mountains (if they at one time overlapped this range) and has worn back the escarpment that marks their edge to Verde River and to Tonto basin. The underlying schists and crystalline rocks were also deeply eroded, probably within Tertiary time, when great continental movements took place that elevated the whole Cordilleran district of North America.

These movements were accompanied by volcanic eruption. The volcanoes ejected fragmental material by explosive action and poured out rhyolites, andesites, and basalts in turn; evidences of these processes are found in the rhyolitic tuffs, agglomerates, andesites, and basalts.

All the rocks have been further elevated and subjected to the erosion of Quaternary times, and this process is still going on.

ECONOMIC GEOLOGY.

MINERAL RESOURCES.

The mineral resources of this quadrangle include gold, silver, copper, and iron-ore deposits, building and ornamental stones, and undeveloped bodies of volcanic ash.

Gold, Silver, and Copper Deposits.

INTRODUCTION.

Historical sketch. — Precious metals were discovered in the Bradshaw Mountains quadrangle in 1863, when the placer gold deposits of Hassayampa and Lynx creeks were first worked by a party of pioneers under the leadership of Joseph Walker. In the "rush" following this discovery productive placers were found along most of the larger streams of the area, and numerous gold- and silver-bearing veins were located, especially in the northern part, on Bigbug, Lynx, and Hassayampa creeks. The remoteness of the district from lines of transportation and the fact that it was a stronghold of the hostile Apache Indians caused mining developments to proceed slowly until a new impetus was given to the industry by the discovery of rich silver deposits.

The Tiger mine, located in 1871, and the Tiptop and Peck mines, opened in 1875, each produced a million dollars or more during the first five years of their working. A period of active prospecting, mill building, and development followed, during which some old and many new productive veins were exploited. The rapid exhaustion of the silver mines and the fall in the price of silver brought this period to a close by 1885, but the gold deposits were by no means exhausted and with the completion of the transcontinental railroads to the south and north, and of the connecting branch to Prescott in 1888, came a new era of moderate productiveness, which continues to the present time.

Production.—No definite statement of the output of precious metals from this region is possible, but an estimate based on scattered contemporary statistics and on the Mint reports gives an approximate value of $9,500,000, about equally divided between gold and silver.

At the time of survey (1901) but two or three large mines were actually producing, and the output of the district, chiefly gold, was probably less than $200,000. A number of other mines recently active and of demonstrated value were closed down by reason of litigation or other adverse circumstances. The activity was limited to prospecting and to the development of small properties to the producing stage.

VEIN DEPOSITS.

CHARACTER OF ORE BODIES.

The fissures are generally well defined, the vein filling being separated from the walls by clay "gouge." The vein material is chiefly white quartz, with banded structure, which is often very prominent, the center of the vein not rarely showing open vugs. In most of the mines where development allowed a satisfactory study of the ore bodies the vein filling was found to consist of lens-like bodies of irregular form, which on the edges are composed wholly of quartz and increase in metallic sulphides toward the thicker central parts. These lenses sometimes overlap slightly, or are separated by barren stretches, which may be as long as the diameter of the lens, where the vein is represented by a mere stringer of quartz or by the line of "gouge" alone.

MINERALS OF THE VEINS.

The minerals composing the veins may be classified into ore and gangue minerals. Oxidized minerals of secondary nature produced by alteration of the original vein contents form a third class. The ores comprise native gold and silver, galena, argentite, pyrargyrite, chalcocite, chalcopyrite, and tetrahedrite. The metallic minerals that are not of themselves valuable but often mechanically inclose free gold are pyrite, sphalerite, arsenopyrite, bournonite, bornite, jamesonite, stibnite, magnetite, and pyrrhotite. The nonmetallic gangue minerals are quartz, chalcedony, siderite, dolomite, calcite, barite, fluorite, epidote, and hornblende; the two latter uncommon gangue minerals are found in several quartz veins of the region in considerable amount.

Of secondary minerals formed in the surface zone of weathering the more important are cerargyrite, anglesite, cerussite, limonite, hematite, pyrolusite, gypsum, native copper, cuprite, chrysocolla, malachite, azurite, brochantite, scorodite and wulfenite, chlorite and kaolinite.

COUNTRY ROCKS.

The ore deposits of the quadrangle are, with few exceptions, fissure veins of simple structure. The veins are not confined to any one rock formation, but occur most abundantly in the schistose rocks (Yavapai schists, amphibolites), particularly in portions of these near the borders of the latest intrusive stocks of quartz-diorite; the Bradshaw granite and its diorite facies contain some veins also, while in the Minnehaha complex they are almost entirely wanting. The veins were formed before the volcanic period represented in the quadrangle, and hence are wholly absent in the volcanic agglomerates, andesites, and basalts, which cover so large a portion of the quadrangle.

AGE OF VEINS.

Little can be said definitely of the geologic age of the period of vein formation; it was probably post-Carboniferous, for in the region about Jerome, immediately north of the quadrangle, similar veins pass upward from the Algonkian crystalline complex into the horizontal Carboniferous rocks. The veins are certainly older than the lavas, which are supposed to be Tertiary. A close association is observable between the distribution of acid dike rocks and of veins, which suggests that the formation of the fissures which both occupy was due to similar forces acting at about the same period.

TRENDS AND OUTCROPS OF VEINS.

The trend of the fissures follows in general the trend of the containing schists, which is predominantly from north-south to northeast-southwest. A second system of fissures cutting across the schistose structure with trends about at right angles to the first, east-west or northwest-southeast, is also slightly developed, but is nowhere dominant. The dip of the veins, like that of the schist, is high, often vertical, and rarely less than 70°; the direction of dip in the dominant fissure system is variable, but oftener westward in the southern part of the quadrangle and eastward in the northern part.

The veins are generally narrow, from 6 feet down to a foot or less, and are not marked in general by prominent outcrops. In this respect they present a marked contrast to the great quartzite ledges which are widely distributed throughout the schist series and in position, form, and character suggest quartz veins. So far as known, no ore deposits have ever been found in the quartzite, although the rich Peck vein was in immediate contact with one of these ledges.

CLASSIFICATION OF THE VEINS.

The veins may be classified, according to the dominant values of their contents, into gold, silver, and copper deposits, and have been so indicated on the map in most cases, but the distinction is not a sharp one, since all of these metals commonly occur together, and their relative amounts may vary widely in different portions of a single deposit.

Gold deposits.—Free gold is not common in the veins of this region, the gold values being largely contained in the associated sulphides, chiefly pyrites, chalcopyrite, arsenopyrite, sphalerite, and galena. Nevertheless, in several of the largest gold mines considerable bodies of ore very rich in free gold have been discovered at depths far beyond the limit of surface weathering, and in a few gold veins upward to half the value of gold is free. The gangue of these veins is generally quartz with very little carbonate.

Silver deposits.—The typical silver veins of the district are narrow veins carrying argentiferous galena, argentite, pyrargyrite, and probably other antimonial silver minerals in their deeper portions, and cerargyrite and sulphate and carbonate of lead at the surface. The gangue is largely siderite, with more or less quartz and calcite. Several very rich veins of this character were found in the quadrangle, but they have long been exhausted and abandoned, so that in the field at present little can be seen of their character. Silver is also present in varying amounts in the veins classed as gold veins, and in ores rich in galena frequently exceeds the gold in value.

Copper deposits.—No copper deposits of proved extent and value are yet known in this district, but several promising prospects were seen, and as some of them are quite different in character from the gold and silver veins they have been separately indicated on the map. Two types of copper deposits were recognized. One consists of distinct veins, carrying chalcocite, chalcopyrite, tetrahedrite, and in some instances bournonite, with a gangue of quartz, fluorite, and barite. The sulphide minerals are largely altered at the surface to chrysocolla and malachite. These veins carry silver values as well as copper.

The second type consists of impregnation zones in schist; chalcopyrite, pyrite, and bornite, with more or less quartz, replace chlorite-schist or amphibolite, forming bodies of irregular and indefinite outline. Small stringer veins carrying the same minerals are also present in places, but the formation as a whole appears to be a direct replacement. The surface zones of such deposits are siliceous schists pitted and copper-stained with films of native copper and sometimes of cuprite. Small gold values are also found in these deposits.

DISTRIBUTION OF THE VEINS.

The important mines in the quadrangle are in its northern and western portions, and occur in groups associated in a striking manner with the four intrusive stocks of quartz-diorite which occupy the basins of Groom and Hassayampa creeks, of Lynx Creek, of Bigbug Creek and its branches near McCabe, and of Poland Creek near Crown King. Brief descriptions of the veins in these four areas will first be given and then the less important outlying veins will be considered.

Groom Creek district.—The mines of this district are prospects developing veins which carry both gold and silver. The veins occur in the amphibolite and schist on either side of the northern portion of the Groom Creek quartz-diorite stock. They are narrow and highly mineralized, with native silver, galena, pyrite, and sphalerite in a gangue of coarse white quartz and calcite. Many of these veins are said to be very rich in their upper portions, but they have not been sufficiently developed to prove their permanence in depth.

Hassayampa Creek district.—The southern part of the same stock of quartz-diorite is drained by Hassayampa Creek. It is bordered to the south and east by the amphibolites and basic diorite of the Mount Tritle Range, and here are found several important gold mines, of which the Senator and Cash are the best developed. Beyond this belt to the east, on the slopes of Mount Union, is an area of granite-gneiss, in which are found similar deposits, such as the Crook. These mines are all on veins trending northeast to southwest and their chief value is in gold. In the Senator a fairly continuous vein of banded quartz, 3 to 6 feet wide, occurs parallel to and near the contact of hard, black, banded amphibolite and metamorphic conglomerate, some distance from the edge of the quartz-diorite stock. The ore is chiefly pyrite, galena, and sphalerite in coarse, white, banded quartz. A large body of free gold with pyrite was opened on the 500-foot level next to the conglomerate wall rock. This is the oldest gold mine in the area, having been worked with many intermissions since 1870–1875. The Cash mine is somewhat farther from the quartz-diorite. The ore body in this mine is in the form of a series of well-defined lenses that have a maximum thickness of 2½ feet and occur in sericite-schist which is at places black and graphitic. The ore is rich in sulphides, chiefly galena, sphalerite, pyrite, and chalcopyrite, contains some tetrahedrite in quartz, and is characterized by comb and banded structure, the center of the vein being generally open and lined with beautiful crystals of all the vein minerals. A rich body of free gold ore was found in this mine at a depth of 200 feet from the surface.

The Crook mine is very similar in character of ore. The vein follows for some distance a black dike of decomposed camptonite, and it is paralleled on the west by a striking zone of brecciation with sulphide cement, which has been opened by several prospects.

In the diorite southwest of Mount Tritle is the Blue Dick mine, which is on an east-west vein and carries high silver values in an ore consisting of arsenopyrite, tetrahedrite, galena, and pyrite. The croppings are rich in horn silver.

Lynx Creek, near Walker.—The veins of the Lynx Creek basin occur near the contact of quartz-diorite with schist and granite-gneiss. The only active mine is the Mudhole mine, which is working two nearly parallel 6- to 8-foot veins in granite-gneiss, inclosing between them a white rhyolite-porphyry dike reduced in places to a friction breccia that is cemented by a siliceous matrix.

The quartzose vein matter is banded with a granular admixture of galena, sphalerite, pyrite, chalcopyrite, and arsenopyrite. The values are about equally gold and silver.

In the Amulet mine rich silver values were obtained from a contact-breccia zone that occurs between slate and granite and is cemented by quartz and sulphides.

Much mining of a surface character has been done in this basin on small veins carrying free gold in the oxidized zone.

McCabe district.—Near the town of McCabe and along Bigbug Creek to the south are a large number of veins, most of which are in schist and amphibolite near the periphery of a small stock of quartz-diorite; veins also occur in the quartz-diorite and in the granite-gneiss of Mount Elliott, to the west. With few exceptions the veins trend with the schists, northeasterly. The McCabe mine shows the most development in this group. The vein is a series of lenses which have a width up to 4 feet and are characterized by band and ribbon structure, the metallic contents being largely confined to the center of the vein. Open vugs lined with large crystals of quartz and arsenopyrite are common. Arsenopyrite with pyrite and chalcopyrite carry the values, which are largely gold with some silver. Galena is sparingly present.

The Rebel vein is in quartz-diorite, which at this point should be called rather an alkali granite. It appears to be a zone of brecciation, the ore, which is largely sphalerite, galena, and pyrite, occurring with quartz and dolomite as the cementing matrix. A similar zone of brecciation with quartz and ore cement is found in the Great Belcher vein on Bigbug Creek. Gold values largely predominate in all of these veins.

Farther to the east and well within the main body of the schists which occupy the central part of the quadrangle is a zone in which veins rich in silver and copper with subordinate gold values have been slightly developed. The Boggs and Silver Belt mines are of this type, the former containing a number of minerals, such as bournonite and jamesonite, not found elsewhere in the region. These mines are no longer active.

Crown King district.—The Crown King stock of quartz-diorite is in contact west, south, and east with granite and amphibolite and north with the diorite of Towers Mountain. At and near the southern and northern contacts are a number of mines, of which the Tiger and Crown King are the most important.

The Tiger mine was the first of the rich silver mines to be developed and is the only one of them that is still open, but it is no longer productive. The vein, which passes from the quartz-diorite into amphibolite with the northerly trend of the latter, is from 7 to 10 feet wide, and in the upper portions, where it was productive, consists of quartz with argentiferous galena, argentite, free silver, and horn silver. With depth the ore becomes low grade and unprofitable under local conditions. It consists of pyrite and galena with small values about equally gold and silver. The ore bodies are said to be larger than is commonly the case in the district.

South of the Tiger mine, in the amphibolite, are a number of prospects on gold-bearing veins similar in character to the Crown King vein to the north.

The Crown King mine, the most important gold mine in the quadrangle, is situated on a well-defined quartz vein in amphibolite with northerly trend and a westerly dip of 60° to 70°. The vein is continuous; its width varies from a mere stringer up to 8 feet and averages about 2 feet. The productive part of the vein is an ore shoot several hundred feet wide, with flat pitch to the north. The ore is characterized by the usual sulphides; pyrite and sphalerite are the most abundant, and native gold is uniformly present, so that at least half the gold value is free. At two points along the ore shoot, at the surface and again about 500 feet down, ore very rich in free gold was found.

The Gladiator vein is probably a northerly extension of the Crown King vein and is of similar character. A number of prospects on Towers Mountain are of somewhat similar nature.

Southern Bradshaw Mountains.—The mines of this region are found in the southern extension of the great stock of Bradshaw granite, which is here coarsely gneissic and contains many schist bands or inclusions. At and near Tiptop the veins were rich in silver. The Tiptop mine produced nearly $2,000,000 in silver between 1875 and 1883. It was on a vein from 1 foot to 1½ feet wide in granite-gneiss, and carried antimonial silver ores, with native silver and horn silver at the surface. It was worked to a depth of about 800 feet. Little or no work is now being done in this vicinity.

Near Columbia are many narrow gold veins which are worked in a small way for free gold ores, no mines, so far as known, having been carried beyond the oxidized zone.

Castle Creek district.—Copper-bearing veins are rather numerous in the belt of schistose rocks near Briggs, and several of them have been prospected. The veins are well defined and narrow and at the surface brilliant with chrysocolla. Chalcocite appears to be the principal sulphide mineral in these veins.

Minnehaha district.—Near Minnehaha, along the contact of the granite with the belt of Crooks complex to the west, are several gold deposits, of which the Fortune is said to have been a large producer. The Boaz mine is working a large vein of pyritiferous quartz with low gold values.

Peck Canyon.—A group of rich silver veins, of which the Peck vein may be considered the type, was at one time actively worked in Peck Canyon. The vein was hardly more than a stringer a few inches wide, consisting at the surface of native silver, horn silver, and antimonial silver and copper minerals in a gangue of quartz and siderite. In depth argentiferous galena became the principal mineral, and the values rapidly decreased so that work ceased at a depth of about 500 feet. The vein lay next to a huge quartzite ledge with a foot wall of slate. About one million dollars in silver seems to have been taken from this mine between 1875 and 1885. This and the numerous similar mines near it which were more or less productive for short periods are now wholly abandoned.

Western copper belt.—From a point about a mile north of Alexandra through the Blue Bell mine to Copper Mountain, 12 miles to the northeast, the schists of the Yavapai formation have a remarkably uniform trend of N. 20° to 30° E. The schists comprise phyllites, silvery sericite-schists, quartz-schists, and chlorite-schists, with boldly cropping quartzite ledges. At the three points mentioned the schists are impregnated with copper ores and have been more or less prospected, although no mines have been as yet developed. The continuity and linear character of this belt of schists, and the similarity of the copper deposits at intervals along it, indicate a widespread uniformity of conditions as existing here and point to the probable existence of a more or less continuous copper-bearing zone. The nature of these deposits has been already described in general terms. The ore bodies of the Stoddard mine at Copper Mountain, of the Blue Bell mine, and in the Copper Buster and other claims near Alexandra are impregnations of chalcopyrite and pyrite in the schists, accompanied by more or less silicification. The Blue Bell mine is the best developed of these prospects, and shows a zone of impregnation up to 30 feet wide, which has been followed down to a depth of 300 feet, the width increasing with depth. Besides copper the ore carries small gold values.

The Blue Bell mine was the only property in the quadrangle which the geologists of the Survey did not examine. The information concerning it is, therefore, based on what could be seen at the surface and on statements as to relations underground which were not verified.

Eastern copper belt.—A similar but even less defined and less explored series of copper deposits appears in the narrow belt of schist which follows the eastern border of the main Bradshaw Mountains granitic stock. Near the northern end at Theising's claim and toward its southern end at Soap Creek are prospects similar in character to those just described. The evidence is, however, far too meager to permit of the assertion that the zone will be found in any sense continuous, but the repetition of similar conditions is suggestive.

Eastern gold belt.—A number of widely scattered veins carrying gold values occur in the granite-gneiss of the eastern portion of the quadrangle. The Valencienne mine has produced some gold in the past, and the Richinbar mine is a developed property on a vein in gneissic granite on the edge of Agua Fria Canyon. The vein is well defined and narrow, and composed of coarse quartz containing pyrite, galena, and sphalerite; the values are found chiefly in irregular vertical shoots. The ore is free milling.

VALUE OF THE ORES.

It is difficult to give average values for the ores produced in this region, both because of the lack of reliable data and because of the extreme variability of the tenor and character of the ores. The free-milling gold ores now being worked probably average about twenty dollars gold and from 1 to 12 ounces silver to the ton; values of less than twelve dollars per ton will rarely pay under present conditions of working. An idea of the character of some of the smelting ores produced is given by the average value of five shipments of selected ore from a mine now active, which yielded 3½ ounces of gold, 16½ ounces of silver, and 4 per cent of copper to the ton. Reliable data for the value of the rich silver ores formerly worked are not at hand. The ores appear to have run as high as 200 ounces, and probably much more, to the ton.

PLACERS.

Rich placer deposits formerly existed along most of the streams of the quadrangle, and it is estimated that not less than a million dollars was obtained by placer mining up to 1881. Most of this value was won from Lynx, Bigbug, and Hassayampa creeks in the north and from Turkey Creek, Black Canyon, and Castle Creek in the south of the quadrangle. At the present time the river placers are almost exhausted, but a little work is still being done on Lynx Creek and along Oak and Cherry creeks in the western part of the quadrangle.

It has been found that some of the gravelly beds in the western belt of volcanic agglomerate are auriferous, and just beyond the western boundary of the quadrangle, on Slate and Milk creeks, some hydraulic washing is being done on deposits belonging to this formation. To what extent this auriferous character prevails in the large deposits of the formation within the quadrangle is not yet determined. At the time of survey a dredging plant was about to begin operations upon an alluvial deposit which caps a flat ridge near Mayer and in which a small gold content has been proved. The success of the experiment is not known, but even if profitable the amount of auriferous alluvium available for such operations appears to be very limited.

Iron Ores.

No iron ores of proved value are known in the quadrangle. Iron ores of possible value were, however, noted at one point. On the ridge at the head of Blind Indian Creek, about 2 miles southwest of Bueno, is a body of schist rich in magnetite. This schist is mapped as part of the hornblendic phase of the Yavapai schist; here the schist is largely quartzitic, various bands containing more or less hornblende, epidote, tourmaline, and magnetite. The last-named mineral is in some layers so abundant that it makes from 50 to 60 per cent of the rock and, judging by the hand specimens, might well be considered an iron ore. The schist is sharply banded and highly contorted. Microscopical study shows it to have a small amount of epidote and garnet in addition to the predominant magnetite and quartz. The quartz is in a fine mosaic of very uniform grain, and the banded appearance is due to the crowding of certain layers with magnetite crystals.

Time did not permit of the study of this deposit in such detail as to determine its limits or extent. It may be of very local development, but examination of the whole ridge indicates more or less ferruginous schist for upward of 2 miles north and south of the locality in which the richest specimens were found.

Rocks similar to those above described were found along the road about 1½ miles north of White's ranch, near Minnehaha. Here is an outcrop of mica-schist that is rich in sharply crystallized garnet and contains magnetite in considerable quantity. At the point seen, however, the iron oxide was not sufficiently abundant to warrant calling the rock an ore of iron.

Building and Ornamental Stone.

Rhyolite tuff.—Owing to the sparseness of the population, little or no call has been made upon the building-stone resources of the region and little is known as to the character of the various rocks as building stone. So far as known the only stone quarried in the quadrangle for building purposes is the green rhyolite tuff found abundantly in the valley of Castle Creek, which has been used in the construction of the hotel at Castle Creek Hot Springs, situated about 2 miles to the south of the quadrangle. The quarry from which most of this stone was taken was near the hotel, but a small opening in similar rock was made farther up the creek, within this quadrangle. The stone was said to be soft and easily worked when quarried; it hardens on exposure and gives a handsome appearance. Nothing is known of its durability. Reference has already been made to the onyx marble at Mayer, which is, however, a decorative rather than a building stone.

Limestone.—No deposits of limestone of economic importance occur in the quadrangle with the exception of the onyx marble, described below. Thin beds of impure gray limestone of lens-like character and but a few inches thick were noted in the Yavapai schist in Peck Canyon; and at the junction of Agua Fria River and Squaw Creek is a bed of magnesian travertine of considerable extent. Both of these deposits are believed to be too impure to be available as sources of limestone for building.

There are no limestones other than this, nor sandstones suitable for building stone. The younger quartz-diorite, which is available in inexhaustible quantities, would probably make a handsome building stone, but has not been so used.

Onyx marble.—Near Mayer, on the left bank of Bigbug Creek, is a considerable deposit of onyx marble, small portions of which are of a quality that renders it suitable for a decorative stone.

The deposit, which covers an oval area about three-quarters of a mile long by less than half a mile broad, is superficial and varies in thickness from a thin layer on the crown of the hill to a maximum of about 25 feet on the bank of the creek. The geologic nature of this deposit has been described above. Many prospecting pits have been sunk on it in all parts of the area, and a quarry was opened in one of the thicker portions, but very little has been shipped and no work was being done when it was visited.

The onyx is extremely variable in color and texture. Most of it is white or pale green when fresh, but weathering has produced variations of color which give it most of its decorative value. The structure is distinctly banded, the individual bands varying in thickness from 8 inches to a fraction of an inch. The broadest bands are coarsely fibrous, are transverse to the bedding, and consist of aragonite. Many large blocks cut in the quarry are almost wholly of material of this character. The greater part of the onyx is in thin bands of wavy cross section, not distinctly fibrous, and composed of calcite. The calcite has been shown by analysis to contain a small amount of ferrous carbonate, and this tends to give the onyx a pale sea-green color when fresh. Oxidation of the iron, however, sets free either brown limonite or deep-red hematite, and this powder remains suspended as a coloring matter in the calcite, giving brilliant color contrasts against the white or green original material. Pale-pink and salmon tones are also occasionally developed, and rarely the whole mass of the onyx is in alternating layers of black and white.

The more massive portions of the deposit are chiefly white, and while large blocks may be obtained, the lack of color variety makes it less decorative. The most valued variety is the green with red and yellow banding, and large blocks of this color are difficult to obtain.

The chemical change by which the iron contained in the carbonate has been set free without breaking down the texture of the calcite as a whole has been studied particularly by Merrill (Report U. S. Nat. Mus., 1893, pp. 539–585), whose analyses of the unoxidized, green onyx and of the oxidized, brown material are here reproduced.

Analyses of onyx marble from Mayer.

	I.	II.	III.
$CaCO_3$	93.93	93.50	93.82
$MgCO_3$	.56	....	.53
$FeCO_3$	5.50	5.51	4.06
Fe_2O_3	....	....	1.73
SiO_2	.05	....	.05
H_2O	not det.	.40	not det.
Total	100.04	99.41	100.19

I and II. Onyx marble, green, Mayer, Ariz.
III. Onyx marble, brown, Mayer, Ariz.

The oxidation process, as shown by these analyses, has been accompanied by little or no accession of iron oxide, and the calcite is still present in the original form. The process takes place from the surface, along flaws, which permit freer movement of the oxidizing solutions, and along individual bands which may be slightly less dense than others. The illustrations in Merrill's description cited above show this process admirably. Where complete oxidation of the iron has taken place and the whole mass has been changed to red or brown calcite it becomes quite opaque, and while the stone then has a new and very unusual color effect, it is not in demand by workers of this material. Probably it is the prevalence of these limonitic bands, which make it difficult to obtain large pieces of light-colored material, that has led to the practical abandonment of this property.

Slate.—A large portion of the Yavapai schist consists of phyllites with a more or less well-developed slaty cleavage; but so far as now known, the phyllites are nowhere of such fine and even grain nor possessed of sufficiently perfect cleavage to be properly designated slates, nor have they been utilized as such anywhere in this or neighboring areas.

Volcanic Ash.

No deposits of volcanic ash of proved value for any of the various uses to which this material may be put are yet known in this region. Two localities may, however, be mentioned which might afford suitable material for working. Near the point on the western border of the quadrangle at which Ash Creek, Milk Creek, and Crooks Canyon come together there is found, interbedded in the volcanic agglomerates and gravels, a bed of pure white ash up to 10 feet in thickness. Some layers of this bed are fine grained, almost impalpable, and are found, when examined with the microscope, to consist almost wholly of sharp angular fragments of glass, the few impurities consisting of fragments of feldspar and iron oxides. The extent of these beds of fine material is considerable, their outcrop extending for several hundred yards along the bank of Milk Creek. A second point where exploration for this class of material might be rewarded is on Castle Creek at the point where Copperopolis Creek enters it. Here a bed of white ash about a foot thick is interbedded with the coarse rhyolitic tuff which covers a large area in this vicinity. The ash is largely composed, like the previously described deposit, of volcanic glass, but contains also diatom remains and some coarse material, rock fragments and mica crystals among others. It is, except for these latter, exceedingly fine grained and is porous, adhering to the tongue like some clays. If a portion of the bed could be found free from coarse inclusions the material would be adapted for use as an abrasive or otherwise.

Clays.

No clays sufficiently uniform and pure for economic purposes were discovered in this survey of the quadrangle.

WATER SUPPLIES.

The only permanent stream in the quadrangle is Agua Fria River, which throughout the year contains a moderate amount of water. This water is utilized at one point, in the deep canyon below Richinbar, for generating electricity as power for the mines and mills on the brink of the canyon. All the other streams are dry except during and immediately after the heavy thunder showers of the fall and winter. At most of the mines water for running the mine and mill is obtained from the mine itself or from springs, which are sparsely present in the higher, forest-clad portions of the region. In the southern half of the quadrangle desert conditions prevail and water is to be had only at widely scattered points, chiefly from wells.

SOILS.

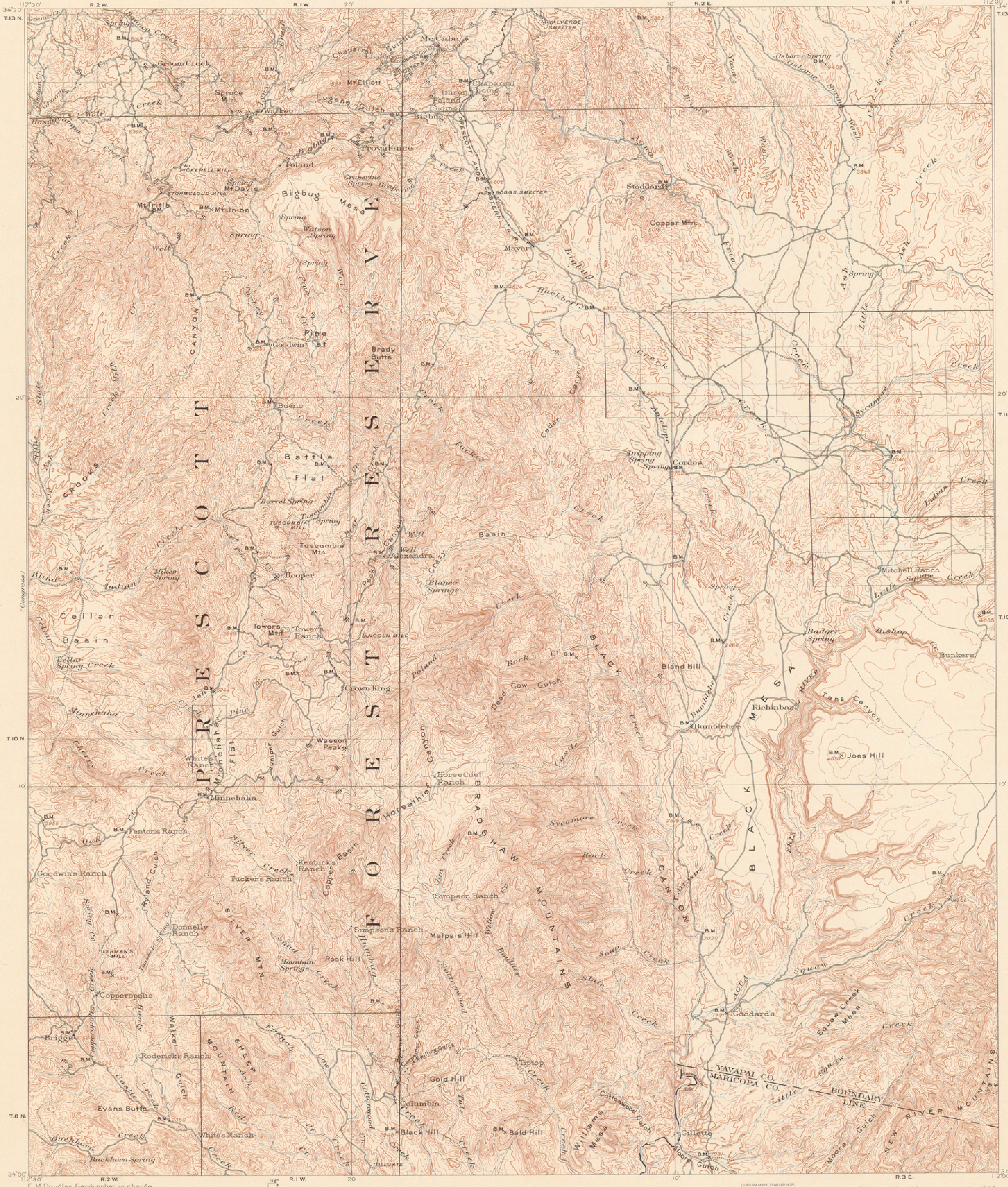
Beyond the small areas of alluvium along the streams, the soils of the quadrangle are sparse and poor. Areas underlain by the various members of volcanic agglomerate are apt to develop fairly heavy soils which in seasons of good rainfall maintain a growth of grass. The most notable area of this sort is the northeast corner of the quadrangle, which is a good grazing ground. The schists are for the most part very thinly soil covered, and generally the outcrops of the vertical strata are seen for miles almost wholly devoid of soil. The broad areas covered by basalt are also nearly devoid of soil. The basalt weathers into spheroidal forms, large and small, which cover the surface like a bed of coarse conglomerate; this is the so-called "malpais" of the local inhabitants. A little soil accumulates in the interstices of these bowlders, and a sparse growth of grass springs up in the rainy season, but soon withers. The quartz-diorite and the granite weather to a sandy soil which supports a good forest growth in the higher northern mountains of the quadrangle; the former has been mentioned as conspicuous for its easy weathering and the consequent basin or park-like form of its outcrops.

February, 1905.

U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT
DIRECTOR

TOPOGRAPHY

ARIZONA
BRADSHAW MOUNTAINS
QUADRANGLE



LEGEND

RELIEF
(printed in brown)

Figures
(showing heights above mean sea level instrumentally determined)

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

DRAINAGE
(printed in blue)

Streams

Intermittent streams

Springs

CULTURE
(printed in black)

Roads and buildings

Private and secondary roads

Trails

Railroads

U.S. township and section lines

Triangulation stations

Bench marks

Mines and prospects

E. M. Douglas, Geographer in charge.
Triangulation by H. L. Baldwin Jr.
Topography by T. M. Bannon, F. E. Matthes, and A. Stiles.
Surveyed in 1900-01.

APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{125000}$

Contour interval 100 feet.
Datum is mean sea level.

Edition of Feb. 1903, reprinted Mar. 1905.

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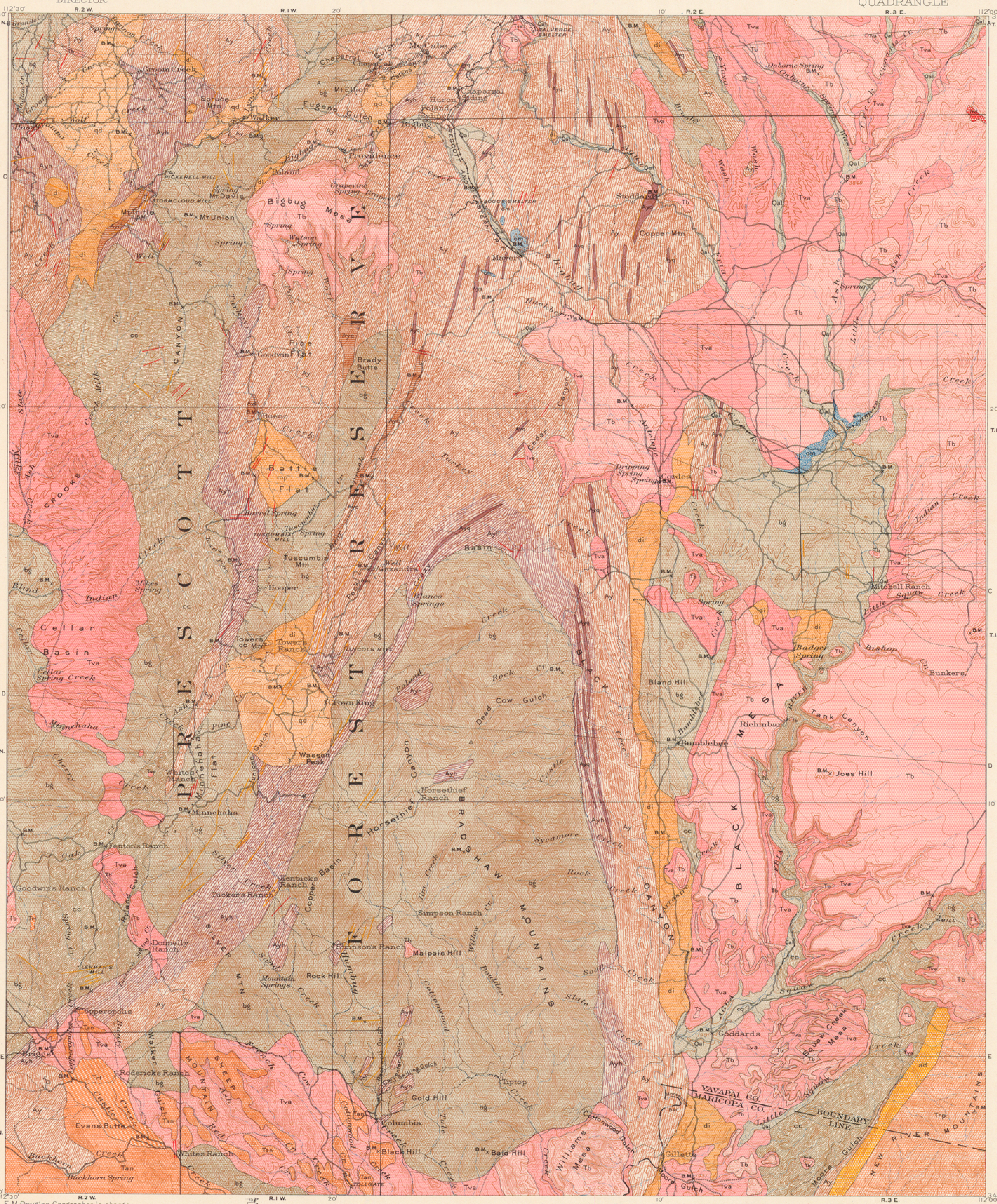
DIRECTOR

AREAL GEOLOGY

ARIZONA
BRADSHAW MOUNTAINS
QUADRANGLE



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APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{125000}$

Contour interval 100 feet.
Datum is mean sea level.
Edition of April 1905

DIAGRAM OF TOWNSHIP

Geology by T. A. Jaggar Jr. and C. Palache.
Surveyed in 1901.

LEGEND

om — Onyx marble (*hot-spring travertine, partly dolomitic, probably of Tertiary age*)

SEDIMENTARY ROCKS

(Areas of subaqueous deposits are shown by patterns of parallel lines, subaerial deposits by patterns of dots and circles; metamorphism is shown by parallel wavy lines which indicate the direction of banding or strike)

QUATERNARY

Qal — Alluvium (*loam and gravel of streams*)

ALGONKIAN — Metamorphic

Ay — Yavapai schist (*chiefly phyllite, mica-schist, and hornblende schist, with limestone lenses, quartzite and siliceous schist lenses, Ayq, schistose conglomerate lenses, Ayc*)

Ayh — Hornblende-schist phase of Yavapai formation (*chiefly hornblende-epidote, and staurolite-schists and hornfels*)

IGNEOUS ROCKS

(Areas of igneous rocks are shown by patterns of triangles and rhombs; metamorphism is shown by parallel wavy lines which indicate the direction of banding)

TERTIARY?

Ttd — Trachydolerite (*plagioclase-augite rock with crystal-lined cavities*)

Tb — Basalt (*black basalt, amygdaloidal and massive*)

Tan — Andesite (*augite-hypersthene-and hornblende-andesites; rarely dacite*)

Tva — Volcanic agglomerate (*gravels, sands, and tuffs*)

Trt — Rhyolite tuff (*white or greenish vitreous ash*)

Trp — Rhyolite-porphyry (*dark-colored pitchstone, probably in part volcanic*)

PROBABLY ALGONKIAN

ad — Acid dikes (*light-colored rhyolite-porphyry, granite-porphyry, and syenite-porphyry*)

Basic dikes (*chiefly dark-colored diorite-porphyry, diabase, and gabbro*)

qd — Quartz-diorite (*a granitic quartz-mica-hornblende rock*)

mp — Monzonite porphyry (*gneissic rock containing quartz, hornblende, and plagioclase*)

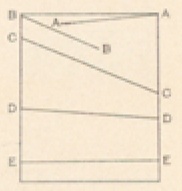
di — Diorite (*hornblende-plagioclase rock varying to gabbroid forms*)

Metamorphic:

cc — Crooks complex (*irregular bands of diorite, granite, aplite, and schist, some breccia*)

bg — Bradshaw granite (*gneissic granite, sometimes very coarse, many schist inclusions*)

Sections



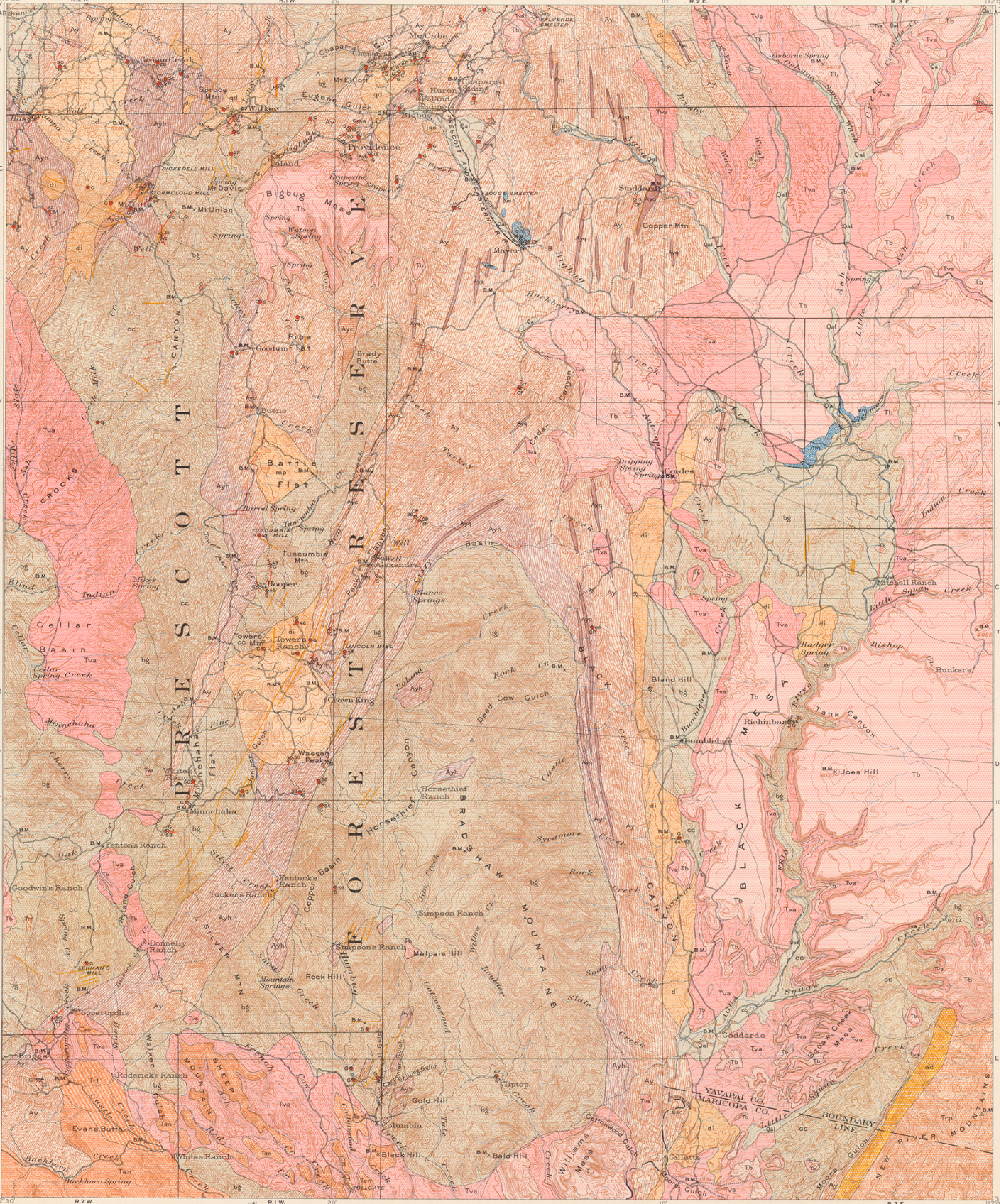
U. S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT
DIRECTOR

ECONOMIC GEOLOGY

ARIZONA
BRADSHAW MOUNTAINS
QUADRANGLE

NAMES OF MINES.
(Indicated on the map by numbers)

1. Iron King.
2. Silver Belt.
3. McCabe.
4. Gladstone.
5. Little Kicker.
6. Rebel.
7. Little Jessie.
8. Dividend.
9. Gopher.
10. Henrietta.
11. Cyprus.
12. Boggs.
13. Stoddard.
14. Hackberry.
15. Sterling.
16. Lottie.
17. Annie.
18. Mammoth.
19. Great Belcher.
20. Red Rock.
21. Poland.
22. President.
23. Mudhole.
24. Amulet.
25. Homerun.
26. Little Giant.
27. Empire.
28. Monte Cristo.
29. Silver King.
30. Silver Flake.
31. Jersey Lily.
32. Blue Dick.
33. Senator.
34. Cash.
35. Crook.
36. Mayflower.
37. Blue Bell.
38. Whale.
39. Copper Buster.
40. Peck.
41. Black Warrior and Silver Prince.
42. Tuscumbia.
43. Mohawk.
44. Buster.
45. Hoosier.
46. Del Pasco.
47. Gladiator.
48. Lincoln.
49. Crown King.
50. Tiger.
51. Luke.
52. Gray Eagle.
53. Ora Bell.
54. Big Belle.
55. Legal Tender.
56. Fortuna.
57. Button.
58. Boaz.
59. Lane.
60. Jones.
61. Whipsaw.
62. Tiptop.
63. Red and Blue.
64. Valencienne.
65. Richinbar.
66. Theising.



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LEGEND

Onyx marble (hot-spring travertine, partly dolomitic, probably of Tertiary age) — om

SEDIMENTARY ROCKS
(Areas of subaqueous deposits are shown by patterns of parallel lines, subaerial deposits by patterns of dots and circles; metamorphism is shown by parallel wavy lines which indicate the direction of banding or strike)

QUATERNARY
- Qal — Alluvium (loam and gravel of streams)

ALGONKIAN — Metamorphic
- Ay (Ayc, Ayq) — Yavapai schist (chiefly phyllite, mica-schist, and hornblende schist, with limestone lenses, quartzite and siliceous schist lenses, Ayq, schistose conglomerate lenses, Ayc)
- Ayh — Hornblende-schist phase of Yavapai formation (chiefly hornblende-, epidote, and staurolite-schists and hornfels)

IGNEOUS ROCKS
(Areas of igneous rocks are shown by patterns of triangles and rhombs; metamorphism is shown by parallel wavy lines which indicate the direction of banding)

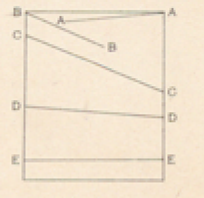
TERTIARY ?
- Ttd — Trachydolerite (plagioclase-augite rock with crystal-lined cavities)
- Tb — Basalt (black basalt, amygdaloidal and massive)
- Tan — Andesite (augite-hypersthene- and hornblende-andesites; rarely dacite)
- Tva — Volcanic agglomerate (gravels, sands, and tuffs)
- Trt — Rhyolite tuff (white or greenish vitreous ash)
- Trp — Rhyolite-porphyry (dark-colored pitchstone, probably in part volcanic)

PROBABLY ALGONKIAN
- ad — Acid dikes (light-colored rhyolite-porphyry, granite-porphyry, and syenite-porphyry)
- Basic dikes (chiefly dark-colored diorite-porphyry, diabase, and gabbro)
- qd — Quartz-diorite (a granitic quartz-mica-hornblende rock)
- mp — Monzonite porphyry (gneissic rock containing quartz, hornblende, and plagioclase)
- di — Diorite (hornblende-plagioclase rock varying to gabbroid forms)
- Metamorphic: cc — Crooks complex (irregular bands of diorite, granite, aplite, and schist, some breccia)
- Metamorphic: bg — Bradshaw granite (gneissic granite, sometimes very coarse, many schist inclusions)

Probably productive formations
- om — Onyx marble (ornamental stone)

Gold, silver, and copper veins showing strike and dip
Gold, silver, and copper mines and prospects
G. Gold
S. Silver
CP Copper
Mines, character unknown
ONYX Onyx marble quarry

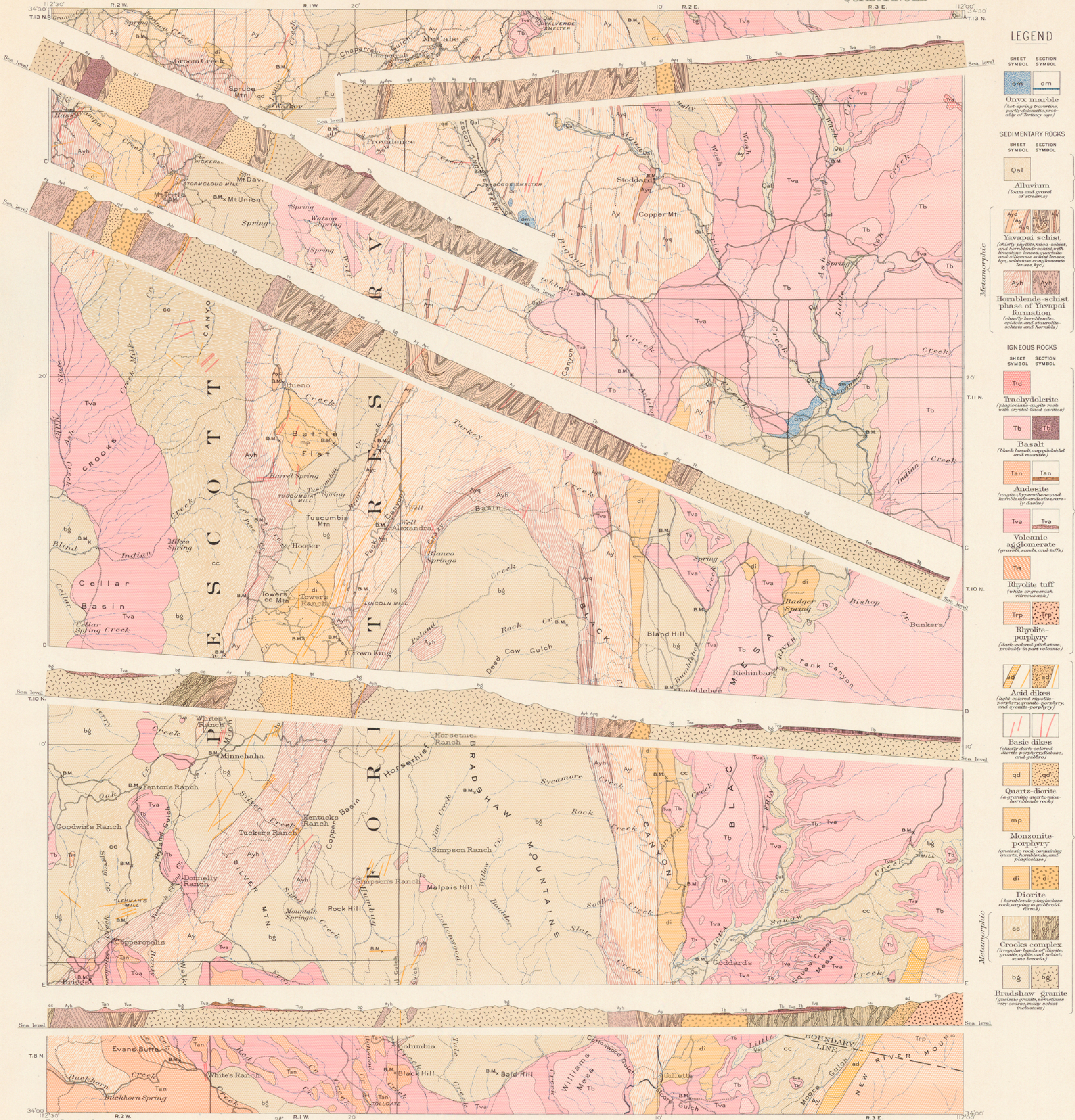
Sections



U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT
DIRECTOR

STRUCTURE SECTIONS

ARIZONA
BRADSHAW MOUNTAINS
QUADRANGLE



E.M. Douglas, Geographer in charge.
Triangulation by H.L. Baldwin Jr.
Topography by T.M. Bannon, F.E. Matthes, and A. Stiles.
Surveyed in 1900-01.

Scale 1/125000

Edition of Aug. 1905

Geology by T.A. Jaggar Jr. and C. Palache.
Surveyed in 1901.

ILLUSTRATIONS

Fig. 1.—SILVER MOUNTAIN LOOKING EAST FROM HILL AT COPPEROPOLIS.

Characteristic schist topography. At the left is horizontally bedded agglomerate and basalt flow.

Fig. 2.—SHEEP MOUNTAIN, LOOKING SOUTHEAST FROM HILL AT COPPEROPOLIS.

The mountain consists of andesitic lavas and tuffs. In the distance at the left are basalt mesas, and on the extreme left is a mountain spur of granite.

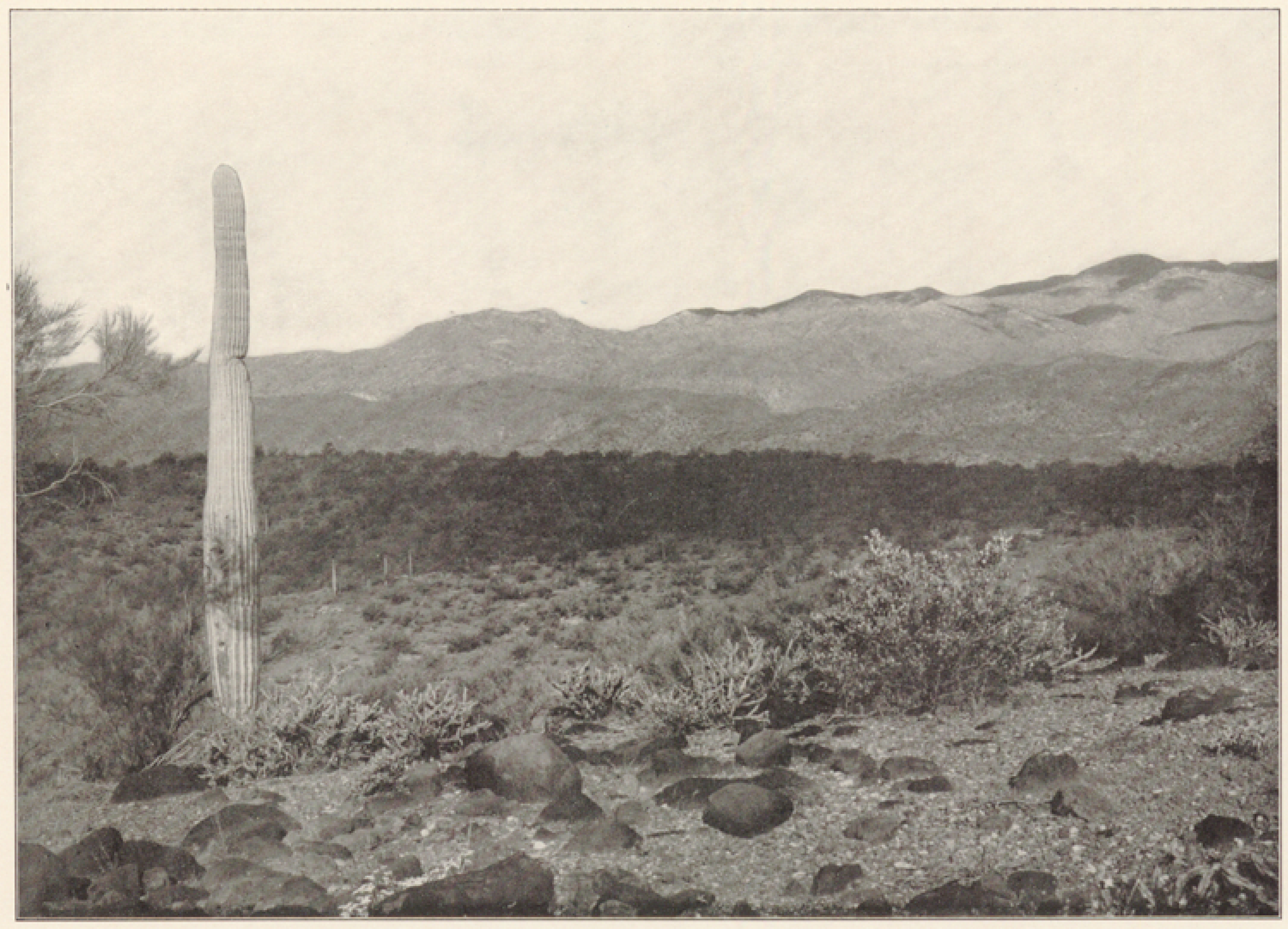


Fig. 3.—BRADSHAW MOUNTAINS, LOOKING NORTHWEST FROM HILL SOUTH OF GODDARDS.

Mountains composed of Bradshaw granite; in the foreground, basaltic agglomerate with loose bowlders weathered out.

Fig. 4.—AGUA FRIA CREEK NEAR JUNCTION OF ASH CREEK.

Volcanic agglomerate at the left, and overlying basalt flow forming cliff in the center.

Fig. 5.—DETAIL OF ONYX MARBLE AND TRAVERTINE BRECCIA WITH SLATE FRAGMENTS, AT MAYER.

In outcrop the marble overlies the breccia.

Fig. 6.—DETAIL OF QUARTZ-DIORITE CONTACT BRECCIA, SOUTH SIDE OF TOWER MOUNTAIN.

Fragments of quartz-diorite, diorite, and monzonite-porphyry in dark matrix.

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

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

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

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

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

Symbols and colors assigned to the rock systems.

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

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

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

SURFACE FORMS.

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

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

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

THE VARIOUS GEOLOGIC SHEETS.

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

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

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

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

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

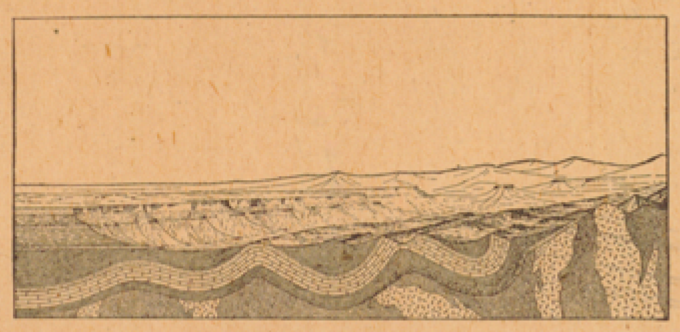


Fig. 2.—Sketch showing a vertical section at the front and a landscape beyond.

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

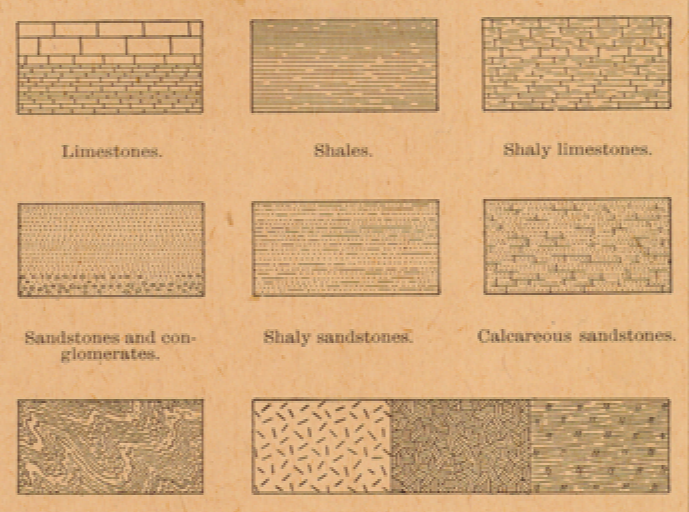


Fig. 3.—Symbols used in sections to represent different kinds of rocks.

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

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

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

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

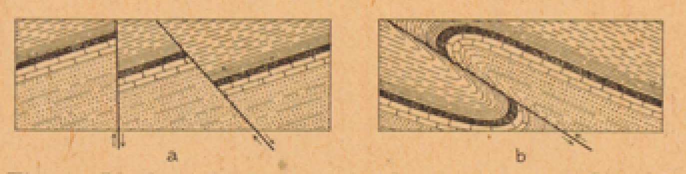


Fig. 4.—Ideal sections of strata, showing (a) *normal* faults and (b) a *thrust* fault.

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

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

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

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

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

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

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

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

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

CHARLES D. WALCOTT,

Director.

Revised January, 1904.

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