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# GEOLOGY OF THE LOWER GILA REGION, ARIZONA.

By Clyde P. Ross.

## INTRODUCTION.

In 1917 and the early part of 1918 the writer made an investigation of desert watering places and routes of travel in a part of southwestern Arizona. The results of this work are to be published in two water-supply papers of the United States Geological Survey—a preliminary report giving information in regard to roads and watering places and a final report which is to include also much miscellaneous information on the geology, geography, and hydrology of the region. In the present report the geologic information obtained in the course of the work is summarized. As the geologic investigation was necessarily of a reconnaissance character, the information obtained is incomplete, but much of it is new and it is hoped will prove of value.

The area covered lies in the central part of Yuma County and the western part of Maricopa County, Ariz. In Maricopa County it includes an irregularly triangular region with Phoenix at its eastern vertex, bounded on the north and northeast by the road from Phoenix through Wickenburg to Wenden and on the south by the valleys of Salt and Gila rivers and extending westward to the county boundary. In Yuma County the area is bounded on the north by the road between Wenden and Parker through Cunningham Pass and on the south by the valley of Gila River and extends entirely across the county to the western boundary, Colorado River.

The commercial development of such a region as the one here described is intimately related to the geology. The hope of finding mineral deposits usually furnishes one of the initial incentives for pioneering in such regions. When promising deposits are found, as they have been here, towns spring into existence and the settlement of the country commences. In the early days in southwestern Arizona fur trapping vied with prospecting as an occupation for the adventurous frontiersmen. When the country became a little better known and more settled, cattle raising and farming were introduced. Both of these industries, particularly farming, depend for their success on a supply of water. The available surface water here soon proved insufficient, and the settlers began to utilize the ground water by means of wells. The distribution, quantity, and quality of the ground water in a region are directly dependent on the geology and physiography of the region.

## ROCK FORMATIONS.

At first glance most of the mountains in this section of the country present a very similar appearance. Examination soon shows, however, that they are composed of rocks of a number of very diverse types. There are great masses of ancient metamorphic rocks, of granites and granitic gneisses, and of lavas and tuffs belonging to at least two distinct periods, together with subordinate amounts of sediments associated with the older lavas and tuffs, and sand and gravel filling the valleys between the ranges. More detailed work will undoubtedly result in still further subdivision of the rocks. The metamorphic rocks certainly represent two and probably more than two periods. The granitic rocks belong to at least two periods of intrusion.

### BASAL COMPLEX.

*Definition.*—Highly metamorphosed sedimentary rocks with associated granitoid gneisses and other rocks of igneous origin make up the whole or a large part of many of the mountain ranges in this region. These rocks will be referred to collectively as the basal complex. They may be divided into four general groups—(1) igneous rocks, (2) highly metamorphosed schistose rocks, probably in the main of sedimentary origin, (3) thoroughly metamorphosed but much less schistose sedimentary rocks separated from those of the second group by an unconformity, and (4) metamorphosed but not schistose limestone and quartzite, the youngest sedimentary rocks in the basal complex. The igneous rocks may be further subdivided into batholithic masses with associated dikes and a group of somewhat younger dikes which cut the less metamorphosed portions of the basal complex.

*Distribution and character.*—This ancient complex is present in every mountain range and almost every range of hills in the region under consideration. Even in those mountainous areas where it is not shown on the geologic map (Pl. XLV, in pocket) outcrops can be found in stream beds that have been cut through the younger formations which elsewhere cover it. In some of the hills, especially those which are composed of basaltic lavas, such as the Bouse Hills and Palo Verde Hills, metamorphic rocks do not occur.

Many of the exposures of the basal complex consist of granitoid rocks. The bulk of these rocks are gray and pinkish gneisses which before their metamorphism were normal granites and intrusive rocks of similar types. These rocks are older than nearly all the other formations in the region, and they crop out in most of the mountain ranges. Plate XLI, *B*, shows their typical appearance. There are also in the region certain younger granites, not gneissoid, which Bancroft [1] considers to be Mesozoic. These are very similar in superficial appearance to the ancient granites in the several areas of such rocks mapped by previous workers. (See geologic map, Pl. XLV.) In the Buckskin Mountains near Osborne's Well there are outcrops of a fresh gray granite with no suggestion of gneissic structure. This rock contains specularite in places and perhaps has been otherwise mineralized, as several shallow prospect holes have been sunk in it. Probably it belongs to the group of Mesozoic intrusive rocks. The boundaries of this mass were not mapped. Jones [2] reports the presence of Mesozoic intrusive rocks near Kofa, in the S. H. Mountains and in the Dome Rock Mountains. Bancroft [3] found dikes probably of Mesozoic age in the Harcuvar Mountains and Granite Wash Hills. It is probable that there are other areas of igneous rock of this age in the region.

The basal complex also includes small dikes composed for the most part of diabase and pegmatite. They are of general occurrence but have nowhere been found in large quantity. Bancroft [4] describes these rocks and also mentions certain exposures in the region north of that covered by the present report which he considers to be metamorphosed lava flows genetically related to the diabasic intrusive rocks.

In the Buckskin Mountains between Butler Well and Midway there are some good exposures of the ancient rocks. At one place in particular the unconformity between the major series of metamorphosed sediments, described below, and the gneiss can be clearly seen. Associated with the gneiss and clearly below the surface of unconformity are intensely metamorphosed schists, mostly somewhat chloritic. In the Gila Bend Mountains also there are small masses of fine-grained mica schists and quartzose schists included in the gneiss. At the southern extremity of the Big Horn Mountains, just north of the Palo Verde mine, is a hill composed entirely of dark-green foliated chloritic schist. (See Pl. XLI, *A*.) This rock is different from any observed elsewhere in the area, but presumably it is related in age to the rest of the metamorphic rocks. As it is very highly schistose, it is probably related to the most ancient of the schistose rocks. Blanchard [5] reports inclusions of metamorphosed limestone and dolomite in a few places in the gneiss of the Buckskin Mountains. In one outcrop of dolomite he found what he considers may be indistinct traces of organic remains.

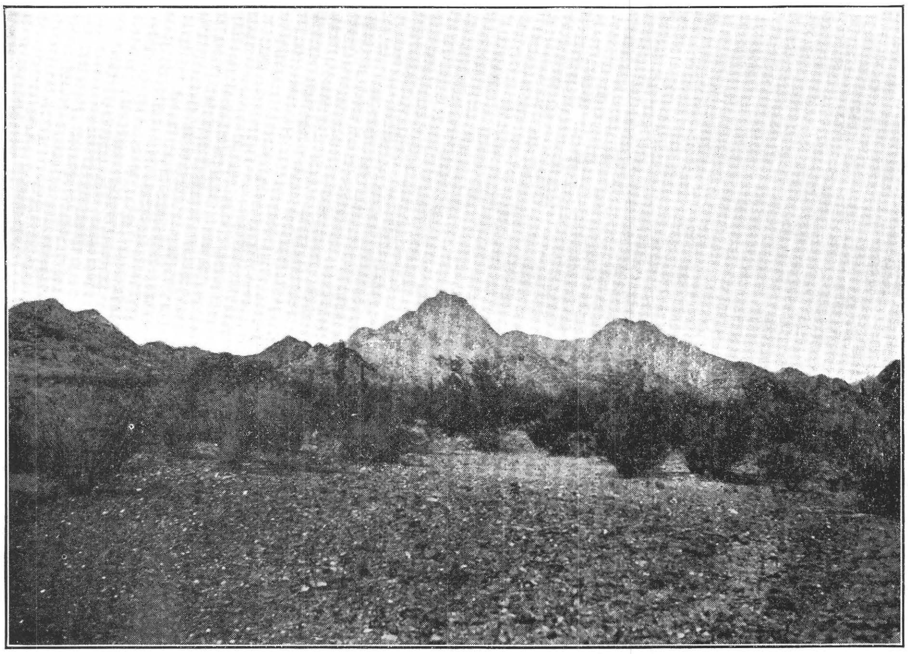
[1] Bancroft, Howland, A reconnaissance of the ore deposits in northern Yuma County, Ariz.: U. S. Geol. Survey Bull. 451, p. 29, 1911.

[2] Jones, E. L., jr., A reconnaissance in the Kofa Mountains, Ariz.: U. S. Geol. Survey Bull. 620, pp. 151-164, 1916; Gold deposits near Quartzsite, Ariz.: Idem, p. 47.

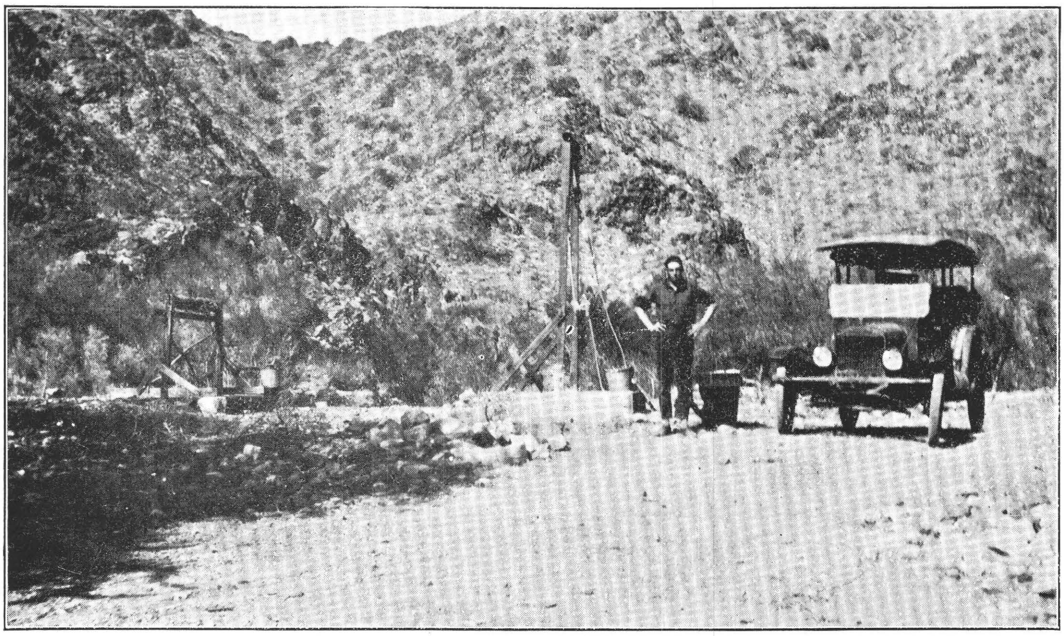
[3] Bancroft, Howland, op. cit., p. 30.

[4] Idem, p. 28.

[5] Blanchard, R. C., The geology of the western Buckskin Mountains, Yuma County, Ariz.: Columbia Univ. Contr. Geol. Dept., vol. 26, No. 1, pp. 33-34, 1913.

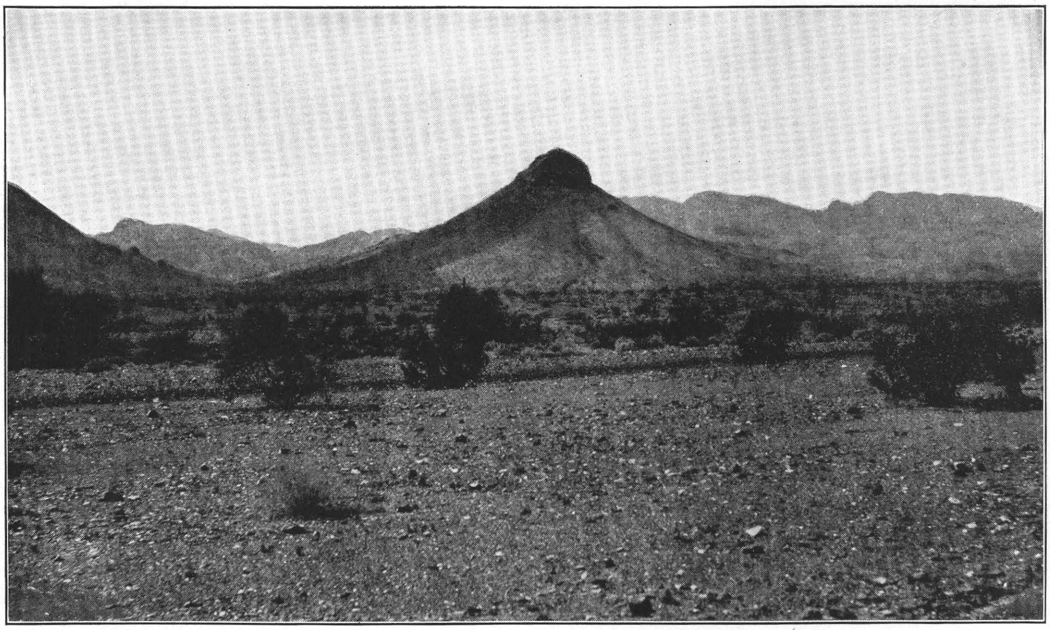


*A*. HILLS OF CHLORITIC SCHIST AT THE NORTH END OF THE BIG HORN MOUNTAINS, NEAR THE PALO VERDE MINE, MARICOPA COUNTY, ARIZ.

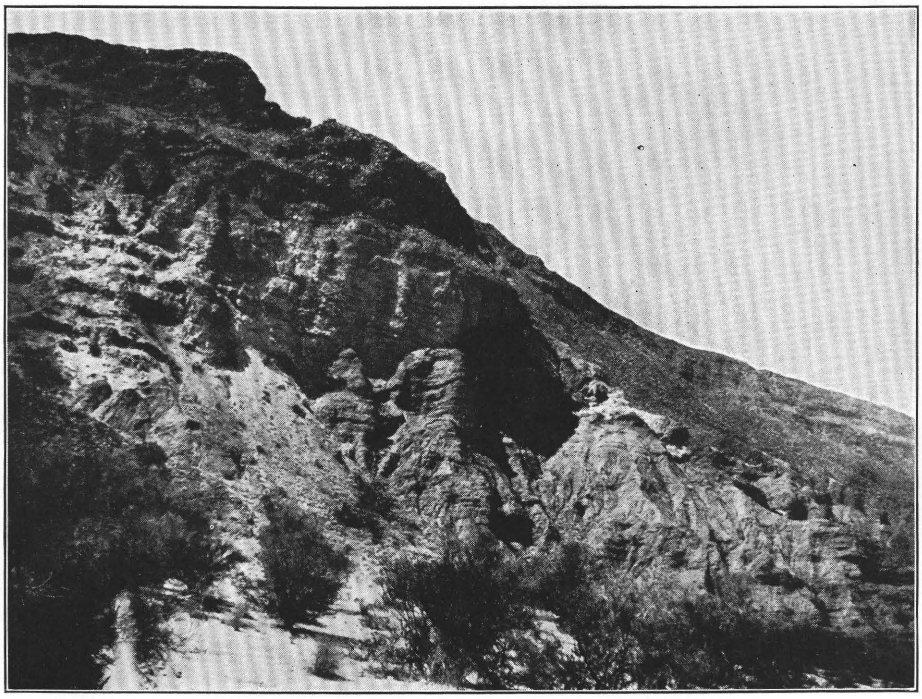


*B*. GONZALES WELLS, DOME ROCK MOUNTAINS, YUMA COUNTY, ARIZ.

The mountains in the background show the typical appearance of rocks of the basal complex.



*A.* A PLUG OF LATITE OF TERTIARY AGE IN THE DOME ROCK MOUNTAINS, ABOUT 4 MILES SOUTHWEST OF QUARTZSITE, YUMA COUNTY, ARIZ.



*B.* BLACK BUTTE, CACTUS PLAIN, NEAR OSBORNE'S WELL, YUMA COUNTY, ARIZ.

An irregular intrusion of gabbro into Tertiary rocks.

The best exposures noted of the second type of metamorphic rocks of sedimentary origin are those in the Harcuvar, Harquahala, and Little Harquahala mountains, but they also occur in some of the other ranges. Interbedded limestones and quartzites are common, and the contrast in hardness between the rocks of these two types makes the bedding visible at considerable distances. The angles of dip in nearly all exposures noted are very moderate, and in most places the beds are nearly flat. Some of the lower beds in this series appear to be similar in composition to the underlying gneissic granite. They are doubtless metamorphosed arkosic sandstones derived from the ancient granitic rock. All the rocks of this series are notably metamorphosed, but many of them are not markedly schistose. Bancroft states that some of the calcareous rocks are dolomites. It is quite possible that more detailed work will result in further subdivision of this series. No attempt has been made to measure the thickness, but it is certainly considerably over 500 feet.

These rocks rest unconformably on the granitic gneisses which are so widespread in this region. The best exposure of the unconformity found is in the Buckskin Mountains on the road between Midway and Butler Well. At this locality gray granitic gneiss, inclosing masses of sericitic and chloritic schist, crops out. The schistosity strikes N. 30° W. and dips steeply to the southwest. These rocks are overlain by a mass of distinctly bedded but metamorphosed quartzite and sandstone, with some fine-grained crystalline limestone. The sandstone, especially near the base, is composed of débris from the gneiss below. Schistosity has been developed, especially in the sandstone, but it is not nearly so pronounced as it is in the lower rocks. The parting planes are parallel to the bedding. The beds have been crumpled, but not greatly. The maximum dip observed is 15°, and most of the beds are nearly flat. The average strike is N. 55° W., and the general dip is southwesterly. The section of the mass here exposed is over 150 feet thick. The contact between it and the gneiss and schist is somewhat irregular and is evidently an erosional contact. Both the older and the younger rocks are cut by small dikes of metamorphosed trap and by a dike composed entirely of microcline.

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The known occurrences of the least metamorphosed sediments of the basal complex comprise those at the Socorro mine, in the Harquahala Mountains, and those in the northern portion of the Plomosa Mountains. Bancroft[6] has studied the section at the Socorro mine and gives the following description of it:

> Coarse-grained granite which shows some schistosity is the basal rock in this locality and is similar to the pre-Cambrian granite so universally present in this area. Resting unconformably upon the granitic rock is a series of slightly metamorphosed sediments, of which about 150 feet of fine-grained grayish-red quartzite forms the base. This is overlain by several hundred feet of yellowish-brown limestone, the upper portion of which contains intercalated argillites and quartz-mica schists. Strata of schistose shaly limestone and a rock very closely resembling a dolomite (containing, however, fragments of quartz) were noticed near the contact of the quartzite and the overlying limestone.

In the Plomosa Mountains, near the Little Butte mine, there are limestones similar to those at the Socorro mine, but their relations to the underlying rocks were not determined. At no place were any of these comparatively slightly metamorphosed sedimentary rocks observed in contact with any of the highly metamorphosed sedimentary rocks in the region, and the relations between them were therefore not determined. The lithologic character of the least metamorphosed rocks is similar to that of some of the Paleozoic sedimentary rocks at Globe, Ariz. For this reason and because of their relation to rocks that are almost certainly pre-Cambrian and their comparatively small metamorphism, it seems probable that they are of Paleozoic age. The lack of fossils renders positive correlation impossible.

There can be little doubt that the granitic gneisses and associated metamorphosed sedimentary rocks just described, with the possible exception of the youngest of the sedimentary rocks, are of pre-Cambrian age. The fact that no fossils which can be used to determine the age of the beds have yet been found in any of the rocks examined during the present investigation makes all the determinations of the age of formation somewhat uncertain. However, it can not be questioned that these metamorphic rocks are very old. Some of them might conceivably be Paleozoic, but the

[6] Bancroft, Howland, op. cit., pp. 111-112.

absence of fossils is a strong argument against this possibility, for most of the Paleozoic rocks of the region are fossiliferous. The fact that all these rocks except the youngest group are very much more metamorphosed than the known Paleozoic formations to the north and east is another strong reason for believing that they are pre-Cambrian rather than Paleozoic. There is no reason for believing that there has been more metamorphism in this area since Paleozoic time than has occurred in the Ray and Globe mining districts. The limestone and quartzite of the youngest group are not much if any more metamorphosed than similar rocks of Paleozoic age at Ray and Globe.

## TERTIARY FORMATIONS.

### GENERAL FEATURES.

Lavas occur throughout the area covered by this report and extend far beyond its limits. The series consists of a number of flows of varying thickness and of widely different superficial characteristics, associated with some tuffs and agglomerates and a very subordinate amount of sedimentary rock. It reaches its maximum development in the S. H. Mountains, where the total thickness is cerainly more than 2,000 feet. A number of the individual flows are several hundred feet thick.

Volcanic rocks similar in occurrence and general characteristics to rocks of this series have been reported from a number of localities in the Southwest. Such rocks are known in the Patagonia district, in southern Arizona;[7] in Mohave County, Ariz.,[8] to the north of the region covered by this report; in the Papago country,[9] just south of this region; in eastern California,[10] and in southern Nevada.[11] Similar rocks occur at Globe, in central Arizona,[12] and at many other places. These rocks have all been referred to the Tertiary, and most of them are supposed to be Miocene. This supposition is based principally on their field relations to rocks of known age, the paleontologic evidence within the rocks themselves being scanty or lacking.

Overlying the Tertiary beds and associated with the unconsolidated or partly consolidated Quaternary sand and gravel are basalt flows of early Quaternary age. These will be discussed under the Quaternary formations. The faulted and uplifted basalts that cap many of the mountains, however, are considered to be of Tertiary age.

The amount of sedimentary material associated with the Tertiary lavas is small compared to the total thickness of the lavas. The sedimentary rocks are of geologic importance, however, for they furnish clues as to the conditions existing at the time these great flows occurred. They comprise sandstone, in part arkosic, shale, and calcareous beds.

### TERTIARY LAVAS.

*Distribution and character.*—The Tertiary lavas are almost as universally present in this region as the metamorphic complex just described. They were found in almost every mountain range examined during this investigation, the only exceptions being the Harquahala and Little Harquahala mountains. Some of the ranges, such as the S. H., Eagle Tail, and Castle Dome mountains, are composed exclusively of rocks of this series resting on a metamorphic basement which is visible in only a few small areas.

The lavas are for the most part light-colored acidic rocks, but some are basalts. They display a wide range and variety of coloration. This is particularly striking in the Eagle Tail Mountains, where more than 1,000 feet of nearly horizontal lava flows, with interbedded tuff, is exposed. Nearly every flow is different in color from those above and below it, and each stands out from the others with clean-cut boundaries. Among the colors are brilliant yellow, soft green, vivid red, somber brown and dun, and creamy white, with streaks of purple, heliotrope, and other hues. The petrographer who is interested in Tertiary igneous rocks would find much to interest him here and in the other ranges in this region where similar rocks occur.

[7] Schrader, F. C., Mineral deposits of the Santa Rita and Patagonia mountains, Ariz.: U. S. Geol. Survey Bull. 582, pp. 70–76, 1915.

[8] Schrader, F. C., Mineral deposits of the Cerbat Range, Black Mountains, and Grand Wash Cliffs, Mohave County, Ariz.: U. S. Geol. Survey Bull. 340, pp. 57–59, 1907.

[9] Bryan, Kirk, The Papago country, Ariz.: U. S. Geol. Survey Water-Supply Paper — (in preparation).

[10] Brown, J. S., The Salton Sea region, Calif.: U. S. Geol. Survey Water-Supply Paper — (in preparation). Thompson, D. G., The Mohave Desert region, Calif.: U. S. Geol. Survey Water-Supply Paper — (in preparation).

[11] Ball, S. H., A geologic reconnaissance in southwestern Nevada and eastern California: U. S. Geol. Survey Bull. 308, pp. 31–34, 1907.

[12] Ransome, F. L., Geology of the Globe copper district, Ariz.: U. S. Geol. Survey Prof. Paper 12, pp. 88–95, 1903.

In most places the basalts appear to be the youngest of the flows, for they cap the others and form the summits of the mountains. Everywhere in the region the Tertiary basalts are subordinate in amount to the acidic flows. Thicknesses of 300 feet of basalt are rare, but 1,000 feet or more of acidic lava occurs at numerous places. The Tertiary basalts are best developed in the Gila Bend Mountains north of Point of Rocks.

Interbedded with the acidic flows are beds of siliceous agglomerate and rhyolitic tuff. The tuff is white or cream-colored, and the beds, which are in places scores of feet thick, are conspicuous. They have a wide distribution throughout the region.

The flows and tuffs are cut by pipes, dikes, and sills of felsitic igneous rock similar in general composition to the siliceous flows. The quantity of Tertiary intrusive rock exposed is very much less than that of the effusives. No large intrusive masses of this age are known anywhere in the region. A number of plugs or volcanic necks occur in the Plomosa, Dome Rock, and Eagle Tail mountains and some of the other ranges. A conspicuous plug in the Dome Rock Mountains is shown in Plate XLII, *A*. Court House Rock, a well-known landmark on the north side of the Eagle Tail Mountains, is a good example of such an intrusion. It is composed of cream-colored lava, in part weathered to a yellowish brown, and towers 1,000 feet sheer above its base, which is circular and only a few hundred feet in diameter. With the exception of a few cracks, mostly vertical, the walls are smooth and almost vertical nearly to the summit, where the cylindrical column has been partly broken by weathering. This peak is reported to have been scaled, truly a notable feat of mountain climbing. The range itself takes its name from a similar but even higher peak near its east end, whose summit is broken up into three points, showing a fancied resemblance to an eagle's tail sticking straight up into the air.

About 6 miles west of Osborne's Well, on the north side of one of the outlying hills of the Buckskin Mountains, is a scarp in which a peculiar exposure of igneous rock can be plainly seen. It is shown in Plate XLII, *B*. This is an intrusion of Tertiary age which differs in several respects from any seen elsewhere in the region. Microscopic examination shows that the rock is a gabbro of coarse granulitic texture. The igneous mass has a very irregular outline, and the greatest extension exposed is in a horizontal direction. On the west are beds of brown sandstone dipping about 10° S. and striking roughly east. The contact with the gabbro is very irregular, and the sedimentary rocks are somewhat baked along it. Directly overlying the igneous rock is a basalt flow which caps the hill and is only 50 feet or so thick. When seen from a distance the lower part of the igneous mass seems to have a rough horizontal stratification, probably due to jointing. The upper part does not exhibit this apparent stratification but weathers in rounded masses 2 or 3 feet or more in diameter. The rock in these masses is full of grains of calcite, which give it a pseudoamygdaloidal appearance. The texture differs somewhat from that of the underlying portion, being on the whole coarser.

This irregular mass of gabbro was clearly intruded into the brown sandstone, which is almost certainly of Tertiary age. The basalt above is probably also Tertiary. There is no evidence to suggest that any other rock covered the basalt at the time the gabbro was intruded below it, but it is somewhat difficult to understand how a rock so coarsely crystalline as the gabbro could be intruded within 50 feet of the surface.

It should be noted that Bancroft[13] considered all the basalt in this part of Arizona to be Quaternary. Basalts occur on the summits of a number of mountains in the area. The amount of erosion since they were poured out is measured in thousands of feet, so that if these basalts are Pleistocene, some of the most imposing mountain ranges in the area have been produced in large part at least during later Pleistocene or Recent time. At Point of Rocks, on Gila River in the western part of Maricopa County, basalt flows capping unconsolidated gravel of the valley abut against the eroded edges of lava mountains. Hence, the basalt flows that cap these mountains must be older than the lava in the valley. As the latter caps unconsolidated gravel it is clearly Quaternary, and it is so greatly dissected by erosion and so much weathered that it is clearly early Pleistocene. From these facts it is evident that the older basalt capping the mountains belongs to the Tertiary. In many

[13] Bancroft, Howland, op. cit., pp. 32–33.

places, however, it is very difficult or impossible to determine the age of a particular flow.

*Petrography.* — Petrographic examination shows that there is considerable similarity in type in these lavas throughout the area. Most of the flows and most of the intrusive rocks that cut them and are associated with them are latites and quartz latites; some are soda rhyolites. The tuffs examined are rhyolitic. Associated with these siliceous and sodic rocks, especially in the upper part of the series, are flows and dikes of basalt.

The latites are fine-grained rocks, in places porphyritic and commonly showing flow structure and perlitic growths. They are composed essentially of alkali plagioclase and orthoclase, with hornblende, biotite, and quartz usually present in subordinate amounts. Apatite and epidote were also noted in some specimens.

Most of the specimens of basalt examined are of the usual types, composed essentially of calcic plagioclase, augite, and olivine, with subordinate amounts of magnetite. They are somewhat porphyritic, all the minerals mentioned above, except the magnetite, occurring to a greater or less extent as phenocrysts. The groundmass is a fine-grained mass of plagioclase laths, showing in places parallel arrangement due to flowage, with granular augite and magnetite. Much of the olivine is altered to iddingsite.

Two specimens of basalt from the immediate vicinity of Woolsey Tank, in the Gila Bend Mountains, differ from those above described in that the feldspars are much more sodic. Their composition approaches that of oligoclase or albite-oligoclase. Stratigraphically these flows certainly are near the top of the series of Tertiary lavas, and they may even be of Pleistocene age. In the Buckskin Mountains near Osborne's Well Blanchard[14] found a rock which appears to be of a similar type.

### TERTIARY SEDIMENTARY FORMATIONS.

*Distribution and character.*—Limestone and calcareous conglomerate occur in at least three widely separated localities in this area. Further work would probably disclose many other outcrops. The known localities are Osborne Wash, in the vicinity of Osborne's Well, near Parker; Saddle Mountain; and the Clanton Hills and the valley north of them. Sandstone was found in Antelope Hill, in several places in the Gila Bend Mountains, near Osborne's Well, in the Clanton Hills, and in small amounts elsewhere. Shale is associated with some of the sandstone in the Gila Bend Mountains.

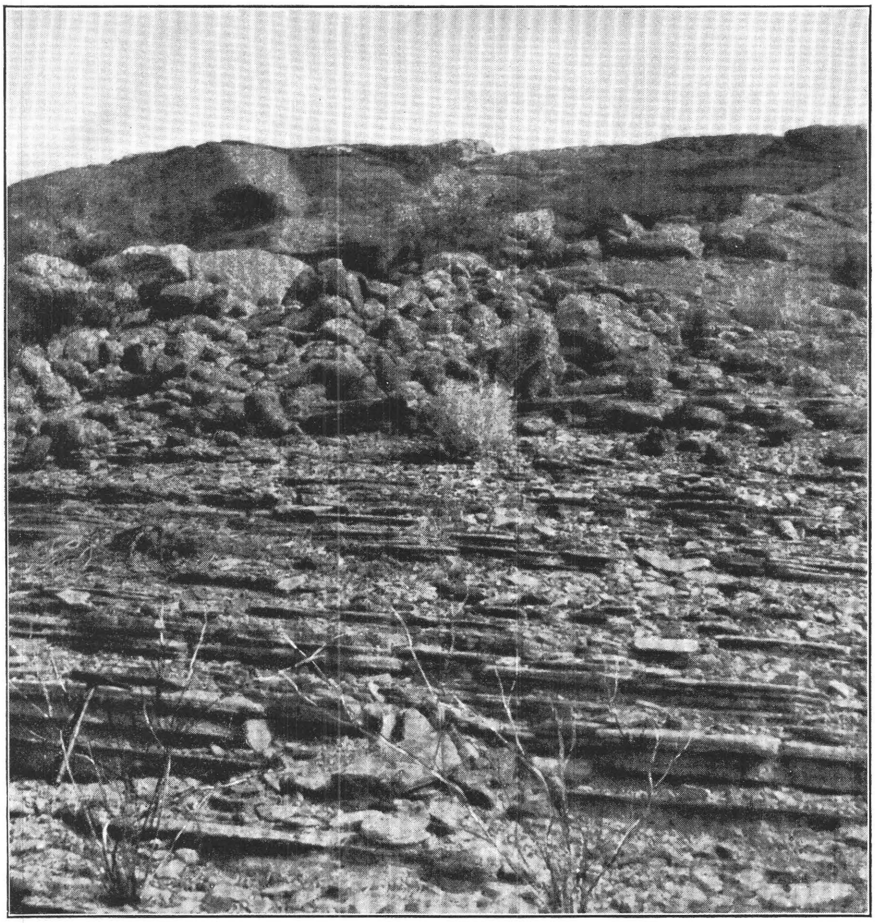
Antelope Hill, at the south end of the concrete bridge across Gila River near Wellton, is composed of grayish arkose, a sandstone formed from granitic débris. The rock is, as a whole, somewhat coarser grained near the base of the hill than farther up the slope. The average diameter of the grains ranges from 1 to 6 millimeters. The beds have a very gentle southerly dip. The hill is about 580 feet high, so that fully 500 feet of sandstone is exposed. Related but coarser sandstone and conglomerate occur farther south.[15]

Red sandstone crops out in several places in the Gila Bend Mountains, notably at and near Woolsey Tank, where there is a bed 30 feet thick of sandstone interbedded with the limestone. Near the Dixie mine, in the Gila Bend Mountains, red and purplish shale is associated with the sandstone. Plate XLIV, *A* (p. 191), shows Tertiary sandstone in these mountains overlain by Pleistocene gravels.

The relations of these sedimentary rocks to the Tertiary lavas show clearly that they are of similar age. They have been disturbed, like the lavas, by post-Tertiary faulting, so that the beds now dip in various directions. The Clanton Hills, about 25 miles north of Palomas, consist almost exclusively of flat-lying gray cherty fine-grained limestone with numerous concretions, some of which resemble fossils in superficial appearance. Some of the beds contain small and indistinct fossils. (See pp. 189–190.) At the west end of the hills is exposed a bed of reddish sandstone composed of quartz grains in a calcareous cement, about 30 feet thick. There has been some faulting accompanied by considerable brecciation in the limestone. Subsequent to the faulting hot solutions circulated through the fault breccias, as is shown by iron stains and by marked silicification of the limestone fragments. No definite evidence of valuable mineralization was found.

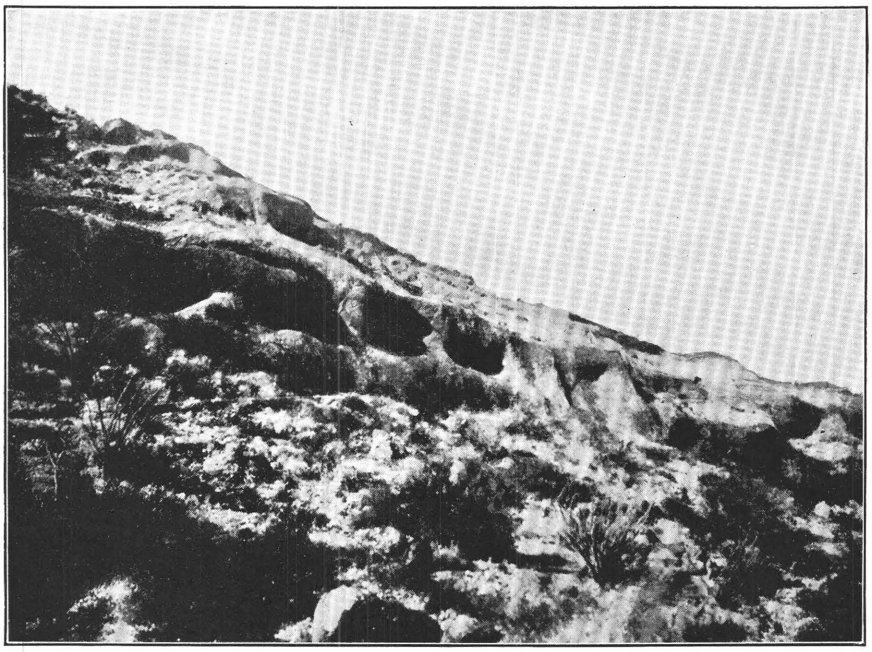
[14] Blanchard, R. C., op. cit., pp. 26–27.

[15] Bryan, Kirk, The Papago country, Ariz.: U. S. Geol. Survey Water-Supply Paper — (in preparation).



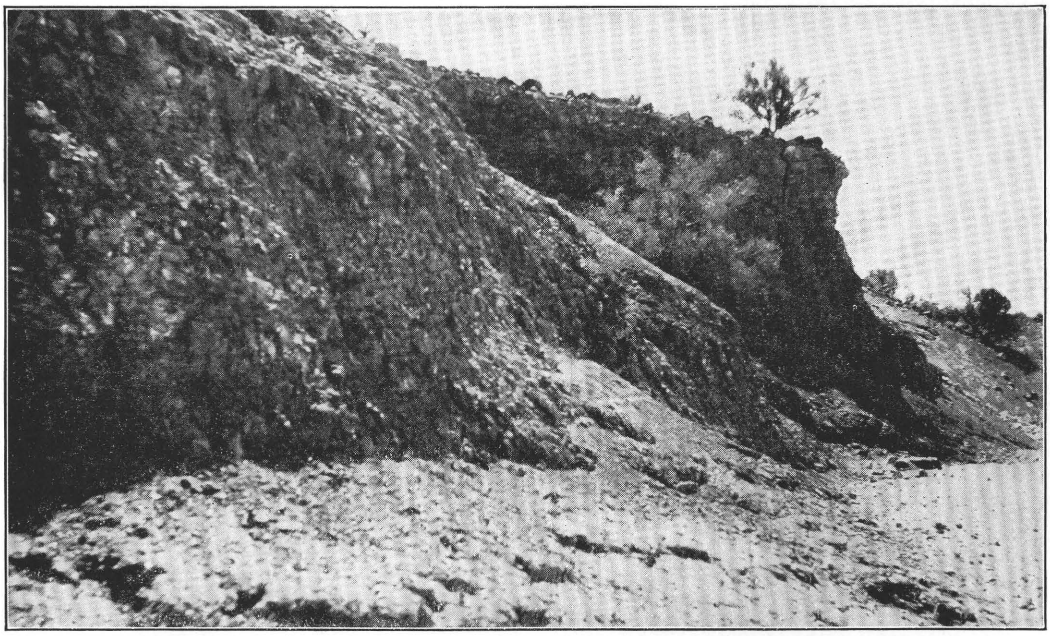
*A.* OSBORNE WASH, ABOUT 2 MILES SOUTHWEST OF OSBORNE'S WELL, YUMA COUNTY, ARIZ.

A typical exposure of Tertiary limestone overlain by basalt.



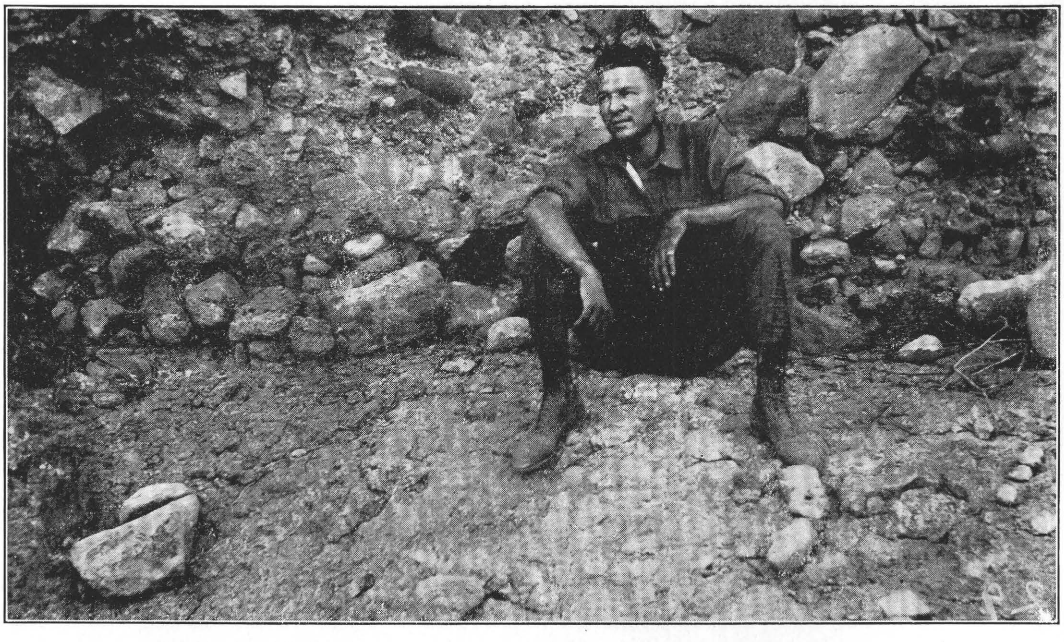
*B.* SADDLE MOUNTAIN, MARICOPA COUNTY, ARIZ., LOOKING SOUTH.

Showing pockets or caves in Tertiary calcareous agglomerate or conglomerate.



*A.* BANK OF WASH NEAR WOOLSEY TANK, GILA BEND MOUNTAINS, MARICOPA COUNTY, ARIZ.

An exposure of tilted Tertiary sandstone unconformably overlain by tilted Quaternary gravel.



*B.* WOOLSEY TANK, GILA BEND MOUNTAINS, MARICOPA COUNTY, ARIZ.

Coarse gravel with calcareous cement, of Quaternary age, resting on the surface of Tertiary basalt.

Near Osborne's Well there are considerable exposures of sedimentary rocks. Time did not permit a detailed examination of them, but the scattered observations made may be of interest. To the west and south of the well are hills with cliffs cut by the large wash that passes between them. These cliffs expose conglomerate with a calcareous matrix, capped by a basalt flow. The calcareous rock is well bedded. The pebbles in it are in no place very abundant and in the lower portion are lacking altogether. Farther north up this wash are outcrops of red sandstone with concretions, a minor amount of quartz sandstone, and a few small beds of conglomerate. These rocks rest unconformably on gray granitic gneiss. The gneiss, which is very probably pre-Cambrian, is intruded by a light-colored granite, which looks very fresh and is not in the least gneissic in texture. This granite contains a little specularite and is apparently associated with certain small veins that contain quartz, specularite, and small amounts of sulphides and have been prospected to some extent in this vicinity. The granite, in common with similar rocks in the region associated with mineral veins, is probably Mesozoic. The sandstone rests unconformably on this granite, as well as on the older gneiss. A distinct though narrow bed of basal conglomerate containing granite pebbles occurs between the granite and the sandstone. A short distance farther north red vesicular basaltic or andesitic lava is interbedded with the red sandstone.

Exposures of sedimentary rocks are found for about 8 miles west of Osborne's Well along the road to Parker. There are numerous outcrops of thin-bedded limestone similar in appearance to the matrix of the conglomerate at the well, but entirely free from any but very small pebbles. Several of these outcrops are capped with vesicular olivine basalt. (See Pl. XLIII, *A*.) They contain rather numerous small and poorly preserved fossils (see next section) and a few small angular fragments of quartz and feldspar. Blanchard [16] considers these calcareous beds to be tuffaceous and states that the beds underlying the basalt at Osborne's Well have a groundmass of glass.

Interbedded with the lavas of Saddle Mountain, in Maricopa County, are considerable thicknesses of fragmental rocks ranging from agglomerate and breccia of distinctly igneous character to rocks that have angular fragments of lava about an inch in diameter in a white calcareous matrix. In certain cliffs there are peculiar hollows in beds of conglomerate and agglomerate, some of which almost amount to caves. (See Pl. XLIII, *B*.) The hollows appear to be due to a sort of concave exfoliation. They are not the result of solution or erosion.

*Fossils.*—The only fossils collected during this investigation were found in the limestone at two localities—in Osborne Wash near Osborne's Well and in the Clanton Hills. In Saddle Mountain there are beds of calcareous conglomerate which are lithologically very similar to those near Osborne's Well, but no specimens were collected from this locality, and it is therefore impossible to say whether these beds contain any small organic remains such as were found in the limestone near the well. The conglomerate of Saddle Mountain contains small bodies which are, superficially at least, similar to those in the limestone from the two localities mentioned, which W. H. Dall, of the United States Geological Survey, calls "pseudomorphs of what were probably a smooth cypridian crustacean."

Specimens from Osborne Wash and from the Clanton Hills were submitted to Mr. Dall for identification of the fossils. A specimen collected by John S. Brown, of the United States Geological Survey, from Imperial County, Calif., was submitted at the same time. This specimen, which closely resembles the specimen obtained near Osborne's Well, came from ledge in the west bank of an arroyo at the south entrance to a pass through the Palo Verde Mountains on the road from Glamis to Palo Verde, in either sec. 18 or 19, T. 10 S., R. 27 E., San Bernardino base line and meridian. Mr. Dall states that the specimen obtained near Osborne's Well and the one obtained by Mr. Brown in California "contain the same fossils and were doubtless laid down under practically identical conditions, whether absolutely contemporaneous or not." He found in these two specimens

small oval bodies representing pseudomorphs of what were probably a smooth cypridian crustacean, * * * also imprints of fragments of a gastropod which resemble analogous fragments of *Melania*, or *Goniobasis*, and a small triangular bivalve which appears to be most like a minute

[16] Blanchard, R. C., op. cit., pp. 24-26.

*Corbicula*, and not (as one might expect) belonging to the more common group of *Sphaerium* or *Pisidium*. There is also the imprint of a small leaf resembling a willow, and numerous lime tubes which seem to have been formed around roots or small vegetable stems.

Microscopic examination of the specimen found near Osborne's Well shows that it is very porous and is composed almost exclusively of calcareous matter in fragments of diverse shapes, with a few angular fragments of quartz and feldspar. The lime tubes mentioned by Mr. Dall are prominent in the thin section.

In a specimen of thin-bedded limestone from the east end of the Clanton Hills Mr. Dall found pseudomorphs of cypridian crustaceans like those he found in the other specimens mentioned. In one of the calcareous beds in Osborne Wash Blanchard[17] also found fossils, which Mr. Dall identified as the gastropod *Bittium* and a probable young *Corbicula*. He states: "There is nothing incompatible between the presence of *Bittium* with *Goniobasis* and *Corbicula* in the same deposit. All are prone to inhabit brackish water, especially near seashores." He also says: "There is no clue to the age of the deposit except that it is doubtless Tertiary."

## QUATERNARY FORMATIONS.

### SEDIMENTARY FORMATIONS.

*Definition.*—The unconsolidated and poorly consolidated gravel, sand, and silt that fill the valleys and floor the flood plains of the rivers in this desert region are of Quaternary age. Basalts which are clearly also Quaternary are interbedded with or rest upon these sediments.

*Distribution and character.*—The valleys throughout this area, like nearly all other desert valleys in the Southwest, are deeply filled with detrital material, for the most part unconsolidated or poorly consolidated, derived from the mountains. The thickness of this material in the valleys has not been determined. It is certainly to be measured in hundreds if not in thousands of feet, as is indicated by records of wells in a number of the valleys.

The character of the material varies greatly, as is to be expected in sediments laid down by generally short and usually disconnected streams under arid conditions. In the flood plains of Gila and Colorado rivers and in certain clay flats, or playas, in interior valleys there are very fine silts or clays, but the major portion of the fill in the valleys is sand and gravel, in places very coarse. Much of it is poorly assorted, consisting of coarse sediments in a clayey matrix. The surface layers in most of the valleys contain silty soil more or less mixed with gravel. This soil, where it has been properly irrigated, has proved to be highly productive. In Castle Dome Plain, Palomas Plain, and to a less general extent in a number of the other valleys in the area the wind has removed the surface silt, leaving a residual floor of gravel. Sand dunes are common in Cactus Plain and also occur in Eagle Tail Valley.

In almost every place where the fill is indurated to any extent the cement is a calcareous material called "caliche" and known also as cement or hardpan. Lee[18] has described the mode of occurrence of caliche and discussed the theories as to its origin. He concludes that the caliche in Salt River valley, which is essentially similar to that in the lower Gila region, has been formed in part by the deposition of carbonates and other salts held in solution in the ground water and in part by the evaporation of water percolating downward from the surface. On the old road across the Gila Bend Mountains, west of Woolsey Tank, occur gravel beds with a calcareous cement which has set so firmly as to form a hard though friable rock. (See Pl. XLIV, *B*.) These beds are exceptionally indurated, but caliche beds so hard that it is very difficult to penetrate them with pick and shovel are common in a number of places in the region. Such beds are known elsewhere in the Gila Bend Mountains, in Nottbusch Valley, in Castle Dome Plain, and in other localities. Wells sunk in La Posa Plain and McMullen Valley usually penetrate beds of caliche below unconsolidated gravel and sand. On the flanks of the Plomosa Mountains, on the east side of La Posa Plain, lie thick deposits of caliche-cemented gravel, some of which is auriferous.[19] Similar deposits occur on the flanks of the Dome Rock Mountains west of this plain.

Beds of green and yellow banded clay are exposed in the terraces of Colorado River in the Colorado River Indian Reservation near Parker.

[17] Blanchard, R. C., op. cit., p. 39.

[18] Lee, W. T., Underground waters of Salt River valley, Ariz.: U. S. Geol. Survey Water-Supply Paper 136, pp. 107-111, 1905.

[19] Bancroft, Howland, op. cit., p. 88.

Fossil fresh-water shells have been found in some of these beds. E. L. Jones, jr.,[20] who made an examination of the reservation for the United States Geological Survey in 1914, states that these are lake beds.

Along washes within the mountains and on the borders of the ranges are beds of gravel and sand similar to those of the valley fill. These beds are cut by the present washes. Although they are clearly similar to the material in the modern streamways and were deposited under conditions very similar to those existing to-day, the position of many of these beds indicates that they were laid down in streams whose courses had little or no relation to those of the present streams. The gravel and sand are everywhere somewhat consolidated. In the wash that parallels the new road where it emerges from the mountains on the west side the unconsolidated or slightly consolidated gravel of the valley fill can be seen lapping up on the gently inclined and smooth surface of gravel with a calcareous cement. This gravel is continuous with gravel of the type just described occurring in the mountains proper. Similar exposures were noted near the road between Wenden and Butler Well, on the north side of Cunningham Pass, in the Harcuvar Mountains. Gravel of similar appearance, which is being eroded by the present streams, was noted in Osborne Wash, north of Osborne's Well, in the Buckskin Mountains.

The partly consolidated detrital beds in the mountains are in places cut by normal faults and tilted to angles of 20° and even more. The best exposures found are in the Gila Bend Mountains. (See Pl. XLIV, *A*.) Tilted blocks of gravel were noted near both of the roads that cross this range, but they are especially well exposed along the part of the old road that lies in the mountains. Outcrops of such material were found also along the large wash followed by the old road on the west side of the mountains. Slight folding in gravel beds was observed in some outcrops near Woolsey Tanks, along this road. Tilted gravel and sand are exposed at the north end of the Gila Mountains near Dome. Some of the more consolidated alluvium in the Dome Rock and Buckskin mountains is probably tilted. Beds of gravel and sand that have been disturbed by earth movements doubtless exist elsewhere in the region but were not noted during this investigation.

It is evident that Quaternary sediments belonging to at least three periods of deposition occur in this area. These are (1) the somewhat consolidated beds exposed in and near the mountains, which have been disturbed by faulting, (2) the unconsolidated or only locally consolidated flat-lying valley fill, and (3) the recently deposited material in the washes and the playas of the desert valleys and in the flood plains of the larger streams. This conclusion is in accord with the results of Lee's work [21] in adjoining areas and in portions of the area here considered. He has given formational names to the two older Quaternary formations in the vicinity of Colorado River but not to the recent material flooring the river flood plains, etc. The oldest group of gravels and sands he calls the Temple Bar conglomerate. The unconsolidated material resting upon the Temple Bar conglomerate and exposed in terraced bluffs along Colorado River and elsewhere he calls the Chemehuevis gravel. The Temple Bar conglomerate is lithologically similar to the oldest of the three Quaternary formations herein described, but the thicknesses observed by Lee along the upper Colorado are far greater than any found in this region. The two may perhaps be of similar age and history. The Gila conglomerate, described by Gilbert,[22] is similar to the Temple Bar, being a thick formation of coarse alluvium in the upper Gila Valley. The correlation of these formations awaits the complete solution of the physiographic history of southwestern Arizona in Quaternary time.

### QUATERNARY BASALT.

Associated with the gravel and sand of the valley fill in places in this area are flows of olivine basalt. Such rock caps the fill, is interbedded with it, and cuts it in the form of dikes and other intrusive masses, generally small and irregular. The basalt masses that rise above the present surface of the fill have produced

[20] Personal communication.

[21] Lee, W. T., Geologic reconnaissance of a part of western Arizona: U. S. Geol. Survey Bull. 352, pp. 17, 18, 1908; Underground waters of the Salt River valley, Ariz.: U. S. Geol. Survey Water-Supply Paper 136, pp. 111–114, 1905.

[22] Gilbert, G. K., U. S. Geog. and Geol. Surveys W. 100th Mer. Rept., vol. 3, pp. 540–541, 1875.

land forms of two general types. These are flat mesas formed by flows that have spread out over the surface of the fill, as at Point of Rocks and Enterprise dam, both on Gila River, and groups of low, more or less conical hills, of which the Bouse Hills, near Bouse, Yuma County, and the Palo Verde Hills, northwest of Arlington, Maricopa County, may be mentioned as examples. The mesas consist of flows 100 feet thick or less, with a few thicker ones. The hills are in general not over 200 or 300 feet high, and many are less than this. The conical shape of many of them suggests that they are volcanic plugs, but all are dissected by erosion, and nowhere was a definite crater found. All the basalt masses, in both mesas and hills, are eroded and have a weathered appearance. The basalt in this area is not nearly as fresh in appearance as much of that in California.[23] The relation of the basalt to the valley fill proves it to be Quaternary, but it is probably not younger than early Pleistocene.

### STRUCTURE.

Normal faults are the most pronounced structural features of the rocks of this region. Thrust faults are not known anywhere in it, and only minor folds appear to have been formed since pre-Cambrian time. There seem to have been three general periods of faulting—(1) prior to the eruption of the Tertiary lava, (2) subsequent to the eruption of the Tertiary lava, and (3) subsequent to the deposition of the older Quaternary alluvium. These periods of movement are not sharply separated from one another. Indeed, it is probable that movement along fault planes has been in progress almost continuously from the beginning of pre-Tertiary faulting to the present day. A few of the mountain ranges in the region show no evidence of being faulted, either because they had a different origin or because erosion has entirely removed the evidence.

#### FOLDS.

The small blocks of early pre-Cambrian sedimentary rocks included in the gneiss in several localities are notably schistose. As regional schistosity can not be produced without folding, such deformation must have taken place early in pre-Cambrian time. The later pre-Cambrian rocks are in large part not schistose, and over large areas their strata are flat or dip at gentle angles. Certainly no close folding has taken place in these strata since their deposition. The tipping of the beds in some localities is the result of faulting. As the rocks show evidence of widespread dynamic metamorphism they must have been subjected to great pressures, which probably resulted in broad and gentle doming.

In the Eagle Tail Mountains and probably in some of the other ranges the beds of Tertiary lava are curved in a way to suggest gentle local folds. This apparent bending may be and in most places probably is a result of original deposition and not of subsequent folding. Certainly no large amount of folding has affected the Tertiary lavas.

In the Gila Bend Mountains some of the beds of the older Quaternary alluvium have been gently folded, but most of the Quaternary deposits are undisturbed by folding.

#### FAULTS OLDER THAN THE TERTIARY LAVA.

When Tertiary volcanism began the surface of the region was irregular. Some of the mountain ranges which are present to-day existed then, although they may not have been as high or as rugged as they now are. The Harquahala and Harcuvar mountains and the Granite Wash Hills contain no known areas of lava and probably never were capped by such material. They are the result of some cause which antedates the lava. No evidence of close folding can be found in these ranges. It is possible, even probable, that their uplift was caused by faulting. There are several other ranges in the region that probably belong in this class, but so little is known about them that this is not certain.

The bold, almost precipitous northwestern face of the Harquahala Mountains has an appearance that suggests a fault scarp modified by erosion. The abrupt truncation of almost flat beds of pre-Cambrian sedimentary rocks in the southwestern slopes of the Granite Wash Hills near Vicksburg and elsewhere is also suggestive of faulting. Southwest of these hills, only a mile or so from their bases, are small hills of basalt of Tertiary or Qua-

[23] Darton, N. H., and others, Guidebook of the western United States, Part C, The Santa Fe Route: U. S. Geol. Survey Bull. 613, pp. 158 et seq., 1915.

ternary age. The rock is more weathered than the basalts of known Quaternary age and is believed to be Tertiary. It was clearly erupted after the Granite Wash Hills came into existence.

Large portions of the Vulture Mountains, the White Tank Mountains in Maricopa County, the Palomas Mountains, the Maricopa Mountains, and other ranges lie above any known lava flows and probably never were covered by such flows. The character of the topography of areas of the basal complex from which the lavas have but recently been removed and the irregular lower contact of the lavas that are exposed in many places in the mountains show that the surface upon which they were poured out was hilly if not actually mountainous. This is especially well shown in the Gila Bend and Eagle Tail mountains.

In adjoining parts of Arizona there is conclusive evidence of pre-Tertiary faulting. Mountain building [24] attended by faulting took place during the Mesozoic era in what is now Cochise County. Bryan [25] has found evidence of a similar period of faulting in Pinal and Pima counties. Ransome [26] showed that faults of pre-Tertiary age probably exist in the Globe district, and this inference has been confirmed by later work in the Old Dominion mine.[27]

### FAULTS YOUNGER THAN THE TERTIARY LAVA.

There is abundant evidence, both within and near the region covered by this report, of normal faulting subsequent to the eruption of the Tertiary lavas. The lavas have been broken into numerous blocks that dip in various directions and are bounded by faults with various strikes. Almost every range containing Tertiary lavas has obvious examples of such fault blocks. In some localities, as at Saddle Mountain, there are more or less heterogeneous groups of fault blocks. In others the whole mass of lavas composing the range has been lifted, relative to the blocks on either side, with but little change in the horizontal attitude of the beds. The Eagle Tail Mountains and probably also the S. H. Mountains are of this character. The structure in both ranges is complicated by cross faults which have broken portions of the large block into smaller tilted blocks. Probably the Plomosa, Big Horn, Castle Dome, and other ranges are built up, in part or wholly, of such horst-like blocks broken by cross faults and carved by erosion, but the blocks of lava are now comparatively small, and many of them are tilted, so that the evidence as to the character of the originally dominant structure is obscure. Probably the faults of this period followed in part the lines of weakness developed during the pre-Tertiary crustal movements, but it is also probable that faulting along entirely new planes took place. Most of the ranges either trend approximately N. 50° W. or N. 50° E. or show a combination of these two directions. The strike of the ranges near Colorado River is more nearly north than that of most of those farther east. This is true both of those that strike west of north and those that strike east of it. The trends of the ranges doubtless correspond to the strikes of the major faults in them. Minor cross faulting in other directions also took place.

### QUATERNARY FAULTS.

Probably no formations of known Quaternary age in this region are involved in large-scale faults. Minor earth movements broke and tilted the partly consolidated strata of older Quaternary alluvium in the Gila Bend Mountains and elsewhere. Probably some movement took place along the fault planes formed during the previous period of crustal disturbance. Lee [28] found evidence of considerable Quaternary faulting at Mesa and Tempe. This movement lowered some of the valley fill in this vicinity below sea level, as is shown by the log of a deep well at Mesa. Ransome [29] and others have shown that the Gila conglomerate is faulted in many places in the mountains east of Phoenix.

[24] Schrader, F. C., Mineral deposits of the Santa Rita and Patagonia Mountains, Ariz.: U. S. Geol. Survey Bull. 582, p. 77, 1915.

[25] Bryan, Kirk, The Papago country, Ariz.: U. S. Geol. Survey Water-Supply Paper — (in preparation).

[26] Ransome, F. L., Geology of the Globe copper district, Ariz.: U. S. Geol. Survey Prof. Paper 12, p. 104, 1903.

[27] Bjorge, G. N., personal communication.

[28] Lee, W. T., Underground waters of Salt River valley, Ariz.: U. S. Geol. Survey Water-Supply Paper 136, p. 115, 1905.

[29] Ransome, F. L., op. cit., p. 104.

## GEOLOGIC HISTORY.

### EARLY PRE-CAMBRIAN TIME.

The remnants of the oldest pre-Cambrian rocks in this area are so few, so widely scattered, and so intensely metamorphosed that almost nothing can be learned from them as to the events of that ancient time. The rocks referred to are the micaceous and chloritic schists, quartzitic schists, and metamorphosed limestones included in gneiss in the Buckskin and Gila Bend mountains. (See p. 184.) Some of these rocks have the megascopic appearance of highly altered sediments, but it is by no means certain that that is their origin. The large amount of chlorite in some of the schists suggests an igneous origin, but nothing more definite is known regarding them. All that the record shows is that in early pre-Cambrian time certain rocks, principally of sedimentary but perhaps also in part of igneous origin, existed here. These rocks were buried, metamorphosed, and finally intruded by batholithic masses of granite and kindred rocks. The period of intrusion was followed by a very long period of erosion. Nearly all the ancient schists were removed, and the granitic rock was exposed. Meanwhile the granites had been rendered gneissoid, and the blocks of other rocks included in them had been highly altered by dynamic metamorphism.

### LATE PRE-CAMBRIAN TIME.

The next event recorded was sinking of the land and influx of the sea. A thick series of sandstone and limestone with some shale was laid down in this sea.

Many dikes, principally of diabase and pegmatite, are associated with the metamorphic formations. Some of these are to be correlated in age with the ancient batholithic intrusions and are older than the younger pre-Cambrian sedimentary rocks. Others clearly cut and are therefore younger than the later sedimentary rocks. The field work was not sufficiently detailed to make it possible to differentiate these dike rocks. Bancroft has found evidence in the northern portion of the area indicating that volcanism occurred during the period of marine sedimentation. (See p. 184.)

### PALEOZOIC AND MESOZOIC TIME.

No sediments of known Paleozoic or Mesozoic age have been found in the region. Limestones and quartzites of possible Paleozoic age occur in the Harquahala Mountains and elsewhere. (See p. 185.) These rocks represent either sedimentation near the end of pre-Cambrian time or a continuation of marine sedimentation in the Paleozoic, but the evidence at hand is not sufficient to determine their age definitely. If any other Paleozoic or Mesozoic sediments were ever deposited in this region they have since been almost or entirely removed by erosion. It is possible that small amounts of such rocks occur in those parts of the region that were not visited during this investigation. Enough is known, however, to justify the belief that no large areas of such rocks are present anywhere in the region covered by this report.

The region was again uplifted at some time after the period of marine conditions recorded by the pre-Cambrian sedimentary rocks. Erosion was resumed and was long continued. If the marine sediments covered the whole region at the end of pre-Cambrian time, they have been completely removed over large areas and the gneisses once more laid bare. There is abundant evidence, however, that the surface over which the Tertiary lavas flowed was by no means a plain. The country was rolling and hilly. Some of the small mountain ranges that are present to-day existed then, although it is probable that they were not as high or as rugged as they are now.

Granitic stocks or small batholiths accompanied or immediately followed by dikes of various types were intruded into the rocks of this region at some period after the pre-Cambrian and before the Tertiary. The writers who have previously described such rocks consider them to be Mesozoic. This correlation seems to be probable and entirely in accord with the facts so far as they are known. Rocks of this type have been reported from the Dome Rock Mountains,[30] the S. H. Mountains,[31] and the Harcuvar Mountains [32] and

[30] Jones, E. L., jr., Gold deposits near Quartzsite, Ariz.: U. S. Geol. Survey Bull. 620, p. 48, 1916.

[31] Jones, E. L., jr., A reconnaissance in the Kofa Mountains, Ariz.: U. S. Geol. Survey Bull. 620, p. 155, 1916.

[32] Bancroft, Howland, Reconnaissance of the ore deposits in northern Yuma County, Ariz.: U. S. Geol. Survey Bull. 451, pp. 29–30, 1911.

were noted during the present investigation in the Buckskin Mountains. A number of similar intrusions are known in adjoining regions.

The pre-Cambrian rocks were considerably metamorphosed during the period between their deposition and that of the Tertiary lavas. The metamorphism probably took place in pre-Cambrian time, for Paleozoic rocks in adjoining regions show no evidence of having been affected by it. There has been no close folding since the deposition of the later pre-Cambrian rocks. Thick masses of these rocks are now exposed which show no folding and little tilting. Faulting took place at some period prior to the eruption of the Tertiary lavas, and it is probable that during that period the major areas of uplift which form the present areas of these rocks may have been blocked out, at least in part.

### TERTIARY TIME.

The Tertiary was a period of pronounced volcanism, in which great sheets of lava were piled up in flow upon flow. Agglomerate and tuff are associated with the lavas, but in very subordinate amount. Quiet outflows rather than eruptions of explosive violence were the rule. Bancroft [33] states that volcanic plugs are present in several places in the area in northern Yuma County which he examined and are apparently more numerous near the lower part of Williams River than elsewhere. These plugs may represent remnants of Tertiary volcanoes. Plugs of latitic rock occur near Saddle Mountain, west of Quartzsite, in the Dome Rock Mountains, and at a few other places in the region covered by this report, but such remnants of Tertiary volcanoes are rare. Quite possibly most of the eruptions were of the fissure type, and no volcanoes, except a few small ones, ever existed here. Probably lava flowed over much of this region during the Tertiary period, covering most of the hills then existing. Apparently, however, some ranges were never capped completely by the lava. The Harquahala, Little Harquahala, and Harcuvar Mountains belong to this class, and portions of the Buckskin Mountains and of some of the other ranges may also have escaped being covered. Felsitic Tertiary intrusive rocks and possibly some lavas occur in the Dome Rock Mountains, but this range consists almost exclusively of rocks of the basal complex. If the range was ever lava capped, all the lava has since been removed by erosion. Comparatively little is known in regard to the geology of the Laguna, Trigo, and Chocolate mountains. Possibly parts of these ranges escaped the general flooding of the region by the sheets of lava. Probably there was more than one period of extrusion, as has been found to be recorded elsewhere in similar rocks. Much more detailed work is required to determine this point.

The amount of sedimentary rocks of Tertiary age found in the area is small indeed compared to the many hundreds of feet of lavas. Unquestionably volcanism rather than sedimentation was the dominant feature of the period. Much of the Tertiary sedimentary rock is believed to be of terrestrial origin and was probably deposited under conditions not very different from those of the present day. This fact is better shown in the exposures of Tertiary formations south of the area covered by this guide, where stream-laid conglomerates occur.[34]

The calcareous sediments found in several places within this area and in adjoining parts of California tell a very different story. (See pp. 188–190.) These beds were unquestionably laid down in large bodies of quiet water. They are lacustrine or estuarine. A glance at the map will show that the exposures of these deposits are scattered over a region covering about 2,000 square miles. Only one of them, that near Osborne's Well, is in an area covered by an accurate topographic map, hence the exact altitudes of the others are not known. The best estimates available, however, show that all, including the California area, are at altitudes of approximately 700 feet above sea level. Unfortunately, the paleontologic evidence at hand is not conclusive as regards the character of the waters in which these beds were deposited. It is possible that they were laid down in lakes lying between the mountain ranges. Much more probably, however, they were deposited in an estuary or estuaries extending northward from the Gulf of California. In late Miocene or Pliocene time the gulf had a much greater extension to the north than at

[33] Idem, pp. 30–31.

[34] Bryan, Kirk, The Papago country, Ariz.: U. S. Geol. Survey Water-Supply Paper — (in preparation).

present, flooding southern California in the region of the Salton basin.[35] Possibly the calcareous beds in the region covered by this report mark the northern extension of this incursion of marine waters.

There was much normal faulting in Tertiary time, some of it on a large scale, and probably there was more than one period of faulting. It resulted in the formation of structural valleys between the upthrown blocks. Folding either did not occur or was of very minor amount.

### QUATERNARY TIME.

Our knowledge of Quaternary events in this region is more detailed and complete than that of the older geologic periods. Doubtless there were several divisions of Tertiary time besides those mentioned above. The great masses of lava, for example, probably were not all poured out during one continuous period of eruption. There were interruptions and alternations of conditions. The record of these events is so fragmentary and obscure, however, that it was impossible to work out the details of the Tertiary history. The record of Quaternary events is naturally much more completely preserved, though there is much that is still uncertain or entirely unknown regarding the history of this period. One of the greatest difficulties encountered in interpreting the record is that of differentiating between the older and the younger valley fill, which are lithologically very similar.

Some uncertainty exists as to the division between the Tertiary and Quaternary in this region. Lee[36] believes that the uplift that initiated the cutting of the Grand Canyon of the Colorado marks the beginning of the Quaternary period. This uplift was very probably essentially contemporaneous with that which resulted in the deep cutting of the desert valleys. However, Lee elsewhere[37] makes the suggestion that the lower portion of the fill in Salt River valley may be Tertiary. He considers that this lower portion may be lacustrine in origin and notably older than the detrital material above it. Deep wells show that there is a considerable thickness of clay or other fine material beneath the coarser detritus in Salt River valley. Records of wells in Buckeye and Arlington valleys and at Gila Bend show that similar conditions exist in those localities also. Considerable clay was encountered in several of the Southern Pacific Railroad wells on the Gila west of Gila Bend. It is possible that fossil or other evidence may eventually be found which will show that these beds are Tertiary, but until further facts are discovered the most logical conclusion appears to be to consider the deep cutting of the valleys, originally in large part of structural origin, as the first event of the Quaternary period in the region under discussion. Any sediments, whatever their origin, lying in these valleys must then be considered of Quaternary age. The mere fact that the lower part of the fill is apparently of lacustrine origin does not affect the problem of its age. Beds of unquestionably Quaternary age and very probably lacustrine origin occur near Parker, on Colorado River. A temporary lake[38] is believed to have existed in Arlington Valley in recent geologic time.

After the valley cutting the conditions were so altered that the streams began to aggrade, and the recently excavated valleys were filled to great depths with detrital material. Basalt flows, the continuation of the basaltic effusions at the end of the Tertiary, occurred at this time. As has already been stated, volcanism did not continue as late in this region as it did in some other portions of the Southwest, notably southern California. It continued intermittently to a time considerably later than that in which the first valley fill was deposited.

When the valleys had been very largely filled with detritus, renewed uplift occurred. In places the recently deposited sediments were faulted and somewhat folded. Degradation recommenced, and much of the material with which the valleys had just been filled was swept out of them.

Before all of the first valley fill had been removed aggradation was resumed and the

[35] Kew, W. S. W., Tertiary echinoids of the Carrizo Creek region in the Colorado Desert: California Univ. Dept. Geology Bull., vol. 8, pp. 39–60, 1914.

[36] Lee, W. T., Geologic reconnaissance of a part of western Arizona: U. S. Geol. Survey Bull. 352, pp. 62–63, 1908.

[37] Lee, W. T., Underground waters of Salt River valley, Ariz., U. S. Geol. Survey Water-Supply Paper 136, p. 114, 1905.

[38] Ross, C. P., The lower Gila region, Ariz.: U. S. Geol. Survey Water-Supply Paper — (in preparation).

younger fill was deposited. Volcanism of minor extent occurred during this epoch. Near Bouse, Yuma County, volcanic ash occurs in the fill not far from the present surface. This deposit is probably comparatively recent. Several of the lava flows may be of corresponding age.

In comparatively recent time erosion of the younger fill has commenced, as is shown by terraces cut in it. The present flood plains of the streams lie between the lowest of these terraces. Along both Colorado and Gila rivers other terraces can be discerned above these, but they are discontinuous and apparently not significant.

At the present time both rivers are aggrading in their lower courses. Their channels are gradually being filled by the deposition of fine silts. Both rivers are well known for the large quantities of silt carried by their waters during floods. At all times they are remarkably muddy.

### MINERAL DEPOSITS.

This part of Arizona has been extensively prospected. Mineral deposits are now known to occur in every mountain range and in many of the groups of hills within the region. The only hills in which mineral deposits have not been, and in all probability will not be found, are those composed exclusively of Quaternary basalt.

The types of deposits and the minerals found are many and diverse. Mining has been carried on in this region for gold, silver, copper, lead, zinc, mercury, iron, and manganese. There has been some prospecting for tungsten, but no mining for this metal has been done. Fluorite occurs in the Castle Dome district and possibly elsewhere but so far as known has not been developed. Gypsum occurs in some places in the region, but no deposits of commercial importance are known.

Mining is in progress in several of the mountain ranges in this region, but there are no large mines operating at present. In the past the Vulture mine, in the range of the same name; the mines about Kofa, in the S. H. Mountains; the Harqua Hala or Bonanza mine, in the Little Harquahala Mountains; and other less well-known properties have shipped considerable gold ore. Silver and lead were mined for some years in the Castle Dome Mountains. Gold placers were formerly worked along Colorado River near La Paz and Ehrenberg, in and near the Dome Rock and Plomosa Mountains, and at Gila City on Gila River, at the site of the present town of Dome. Some placer mining is still in progress in the Plomosa and Dome Rock mountains, but elsewhere activity of this sort has almost entirely ceased. The lack of water appears to be the principal obstacle to the successful development of the placers. In the old vein mines the richer and more accessible portions of the ore bodies have been worked out, and lack of transportation facilities and of capital have prevented further development. The Harqua Hala mine is now being reopened for copper. It is possible that many of the mines now abandoned could again be made profitable producers by extending the workings deeper.

At present (1918) there is considerable activity in the small copper mines in the vicinity of Cunningham Pass, in the Harcuvar Mountains. Mining for copper and other metals is being carried on in the Buckskin and Plomosa mountains and to a small extent elsewhere. More or less desultory prospecting is in progress in all the mountain ranges. In 1918 plans were being discussed for a reopening of some of the mines in the vicinity of Kofa.

A detailed discussion of the geologic features of the ore deposits in the region is beyond the scope of this paper, but descriptions of some of the mines will be found in the final report [39] now being prepared. Bancroft [40] has described the deposits in the northern part of the region, and the deposits noted in the southern part appear to be in general similar to the types he describes. According to him there were three periods of mineralization—pre-Cambrian, Mesozoic, and Tertiary. He describes numerous types of deposits belonging to these periods, also the placers in the vicinity of Quartzsite. The reports of the governor of the Territory of Arizona contain many references by W. P. Blake, Territorial geologist, to deposits in this area. Jones has described deposits in the Dome Rock Mountains [41] and near Kofa, in the S. H. Mountains.[42]

[39] Ross, C. P., The lower Gila region, Ariz.: U. S. Geol. Survey Water-Supply Paper — (in preparation).

[40] Bancroft, Howland, op. cit.

[41] Jones, E. L., jr., Gold deposits near Quartzsite, Ariz.: U. S. Geol. Survey Bull. 620, pp. 45-57, 1916.

[42] Jones, E. L., jr., A reconnaissance in the Kofa Mountains, Ariz.: U. S. Geol. Survey Bull. 620, pp. 151-164, 1916.