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G. M. Butler, *Director*

A RESUMÉ OF ARIZONA GEOLOGY

By N. H. Darton
Geologist, United States Geological Survey

Prepared under a coöperative agreement between
The Arizona Bureau of Mines
and
The United States Geological Survey

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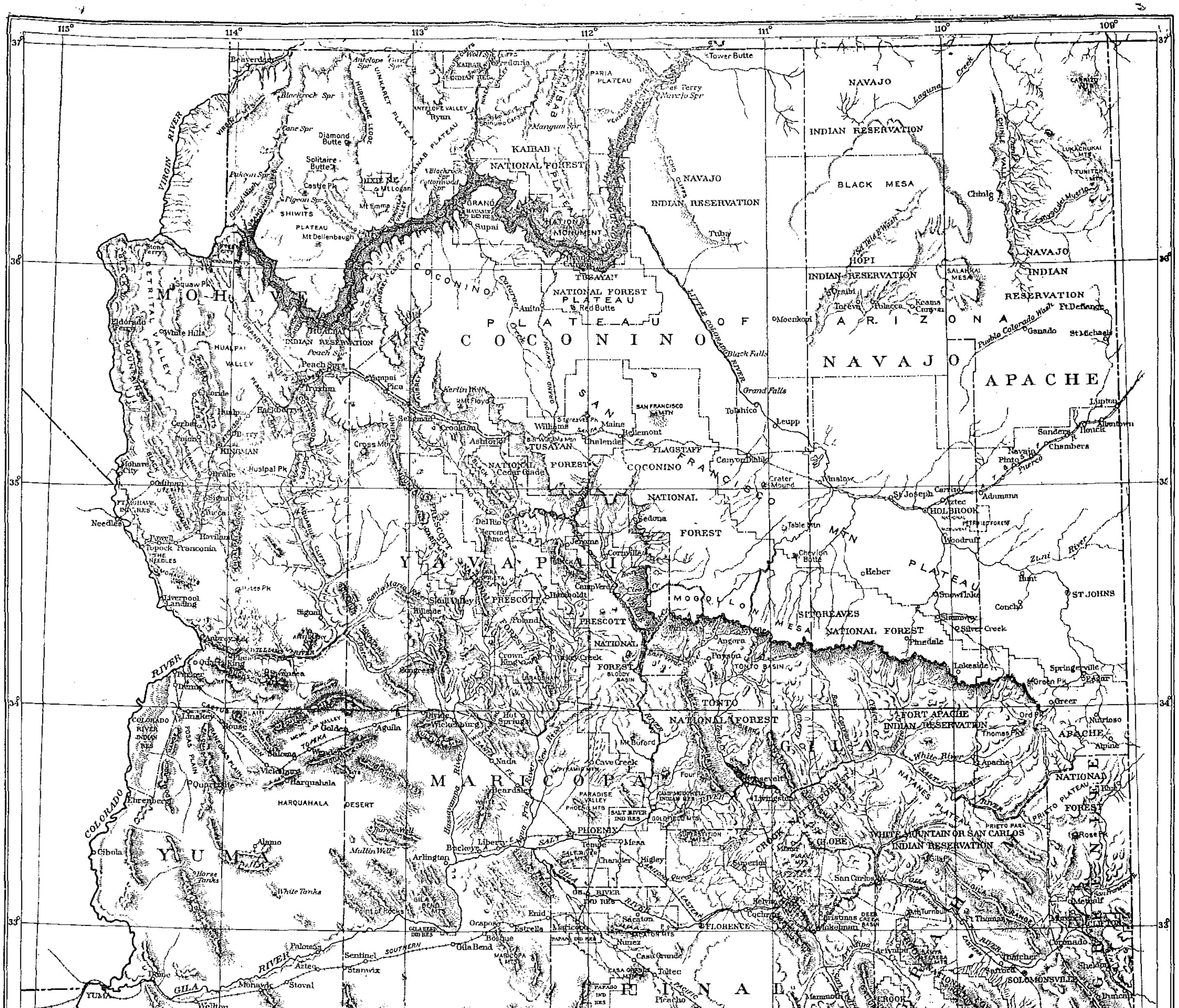
MAP OF ARIZONA
By U. S. GEOLOGICAL SURVEY
Scale 1/3,500,000
25 0 25 50 Miles
MOHAVE
COCONINO
YAVAPAI
NAVAJO
APACHE
MARICOPA
YUMA
GILA
PINAL
PIMA
GRAHAM
COCHISE
SANTA CRUZ
GREENLEE
NAVAJO INDIAN RESERVATION
HOPI INDIAN RESERVATION
FORT APACHE INDIAN RESERVATION
WHITE MOUNTAIN OR SAN CARLOS INDIAN RESERVATION
KAIBAB NATIONAL FOREST
TUSAYAN NATIONAL FOREST
COCONINO NATIONAL FOREST
PRESCOTT NATIONAL FOREST
TONTO NATIONAL FOREST
SITGREAVES NATIONAL FOREST
CROOK NATIONAL FOREST
CORONADO NATIONAL FOREST
COLORADO RIVER
GILA RIVER
VIRGIN RIVER
LITTLE COLORADO RIVER
SALT RIVER
BLACK MESA
MOGOLLON MESA
SAN FRANCISCO MTN
HARQUAHALA DESERT
UNITED STATES
MEXICO
BOUNDARY LINE
PHOENIX
PRESCOTT
FLAGSTAFF
TUCSON
YUMA
FLORENCE
GLOBE
KINGMAN
HOLBROOK
ST JOHNS
TOMBSTONE
SOLOMONSVILLE
Winslow
Williams
Needles
Nogales
Bisbee
Douglas
Willcox
Benson
Clifton
Safford
Jerome
Mesa
Tempe
Chandler
Wickenburg
Parker
Ehrenberg
Ft Defiance
Ganado
Tuba
Chinlo
Moenkopi
Leupp
Payson
Snowflake
Springerville
Show Low
Pinedale
Lakeside
Heber
Roosevelt
Superior
Casa Grande
Gila Bend
Ajo
Quijotoa

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PREFACE

Through a coöperative agreement made with the Director of the United States Geological Survey in 1919, the Arizona Bureau of Mines was able to utilize the services of Dr. N. H. Darton in connection with the preparation of a Reconnaissance Geological Map of the State, upon which the Bureau was working. Dr. Darton had previously spent a great deal of time in the field in Arizona and adjoining states, and his long and varied experience in areal mapping made his assistance peculiarly valuable. He spent about twenty months in Arizona in 1919, 1921, and 1922; and his help made it possible to finish the field work for the map late in 1922. Because no general description of the geology of Arizona had ever been published, and because he had naturally gathered a great many new and valuable data on the subject during his field work, it was suggested by the Director of the Arizona Bureau of Mines that Dr. Darton should prepare a résumé of the geology of the entire State. The Director of the United States Geological Survey graciously assented and permitted him to devote much of his time to this project during the winter and spring of 1923, and furthermore, allowed him to use many unpublished data relating to the geology of Arizona.

It should not be assumed that this work is a compendium or monograph on Arizona geology, since this subject is so large and complex that it would fill several volumes the size of this one. Furthermore, many important problems remain unsolved, and a great deal of field work must yet be done before they can be solved. While well-informed geologists are in general agreement concerning most phases of the subject, it should be understood that in controversial matters the opinions expressed are solely those of the author.

If detailed descriptions of certain areas in which the reader may be especially interested are not given, it should be remembered that no claim for completeness is made by the author of this bulletin. In some instances it was known that other geologists had recently done detailed work in certain areas, and that they intended to publish descriptions of these districts in the near future. Then, too, the data available were too meager to serve as a basis for a detailed description for some areas, although sufficient for the purpose for which they were gathered, namely, the preparation of a reconnaissance geological map.

The lack of reference to ore deposits may be disappointing to many readers; but it should be realized that the field work was done solely for the purpose of securing data relating to the areal geology, and that the time available was insufficient to make any studies of ore deposits. Furthermore, it was known that a colleague of the author has in prepara-

tion a work on the ore deposits of Arizona, and it seemed undesirable to duplicate the work that he has laid out.

Notwithstanding the limitations mentioned, it is believed that this volume will prove very acceptable to mining men, students, and even the general public and that it will serve splendidly as a basis for further and more detailed work.

G. M. BUTLER.

INTRODUCTORY

This bulletin contains the principal data available as to the succession of rocks in Arizona and the general structural features in most portions of the State. It presents many new facts obtained in a reconnaissance of various districts during 1919 to 1922 to obtain data for parts of the Arizona Bureau of Mines geologic map of the State, and much material compiled from various published reports. No attempt has been made to utilize old material which, having been replaced by better data, is now only of historic value. Details from published reports are omitted or generalized as far as possible, as persons interested in more extended descriptions of stratigraphy or structure can consult the original sources of information indicated by the footnote references. In districts where the published data are meagre, or where they are here published for the first time, more details are given.

Some descriptions of local geology are incomplete because of lack of knowledge.

The bulletin consists of two parts: The first, a résumé of the characteristics of the various formations, with all available new light on their classification; and the second, brief descriptions of many districts, mountains, plateaus, and other features, arranged under counties.

PART I—STRATIGRAPHIC GEOLOGY

PRE-CAMBRIAN CRYSTALLINE ROCKS

General relations.—The basement of old crystalline rocks on which the Paleozoic and later rocks have been deposited outcrops extensively in some of the mountains of the western, southwestern, and southern parts of Arizona, and doubtless it underlies the sand and gravels in many parts of the desert valleys in the Southwest. They are also revealed in the bottom of the Grand Canyon for much of the distance from the mouth of Marble Canyon to the Grand Wash Cliffs, and their outcrop extends far southward along these cliffs and the Cottonwood and Aquarius cliffs and Juniper Mountains. The principal crystalline rocks are gneiss, schist, and granite. Some of the granitic rocks in various districts are of post-Paleozoic age but where relations are not exposed it has not been possible so far to distinguish these younger intrusives. In the northern part of Yuma County there are extensive areas of schists with limestones which were hitherto regarded as pre-Cambrian, but it has been found that they are in part at least of Paleozoic age. Old quartzite appears at various points, notably in the Mazatzal Mountain region and in the Verde Valley, and an outcrop of this rock occurs in the axis of the Defiance Uplift, about 75 miles northeast of Holbrook. The latter is an old ridge which extends northwest from Zuni Mountains in New Mexico and apparently persisted through a large part of Paleozoic time, for Permian rocks now abut against it. In other parts of northern Arizona the old crystalline rocks are directly overlain by late Cambrian sandstone, except in places in the Grand Canyon where several thick wedges of tilted sandstones, limestones, and shales of the Grand Canyon series intervene. The latter series is classed as Algonkian.

Vishnu schist.—The crystalline schists, granite, etc., revealed in the Grand Canyon have been referred to by Powell, Dutton, Walcott, Noble, Darton, and various other writers, all of whom have assigned them to the Archean. That they are much older than the Grand Canyon series is indicated by the great unconformity between them, in which the schists and granites have been planed to a relatively smooth surface and have contributed largely to the basal conglomerate of the Grand Canyon series.

Noble and Hunter[1] have described the rocks of the upper Granite Gorge from its beginning near longitude 112° to a point below the mouth of Shinumo Creek, a distance along the river of about 40 miles. About half of the rocks in this area were found to be gneiss, mostly of igneous origin and representing granite, diorite, and minor amounts of

[1]Noble, L. F., and Hunter, J. F., A Reconnaissance of the Archean Complex of the Granite Gorge, Grand Canyon, Arizona: U. S. Geol. Surv. Prof. Paper 98, pp. 53-113, 1916.

basic rocks. About 30 percent are mica schists, which appear to have been sediments, 10 percent are basic intrusive rocks, and 10 percent are siliceous intrusive rocks. Part at least of the gneiss is intruded in the schist, but part of it may be altered granite. The relations of some of the other igneous masses are in doubt, but there are many bodies of pink granite and dikes of pegmatite cutting the gneiss and schist. These granitic rocks are conspicuous features in the gorge, but constitute only a small proportion of the crystalline rocks.

Pinal schist.—The pre-Cambrian schists in the Globe-Ray region have been designated Pinal schist by Ransome,[2] and the name has also been used in the Clifton, Bisbee, and other areas in southeastern Arizona. The schists are believed to be metamorphosed sediments, but they have associated with them more or less greenstone and gneiss which were originally igneous. They are cut by granites and other igneous rocks, some of them pre-Cambrian and others of Mesozoic and later age.

Northwestern Arizona.—The pre-Cambrian crystalline rocks constituting the greater part of the Cerbat, Hualpai, Peacock, and Black mountains, the White Hills, the lower slopes of the Grand Wash, Cottonwood and Aquarius cliffs, and the walls of Boulder and Pyramid canyons in Mohave County have been described by Schrader.[2] He found that they comprised granite and granitoid rocks, gneisses, and schists of various kinds. The granites appear to be pre-Cambrian, although some of them may be younger.

Central Arizona.—Ransome[3] has described the pre-Cambrian rocks of the Mazatzal Range, where he found gneissic diorite and large bodies of granite. "On the north slope of Mount Ord the granite is succeeded by a belt of schistose and slaty rocks which crosses the range obliquely with a northeast-southwest trend. As exposed in the Mazatzal Range this belt has a width roughly estimated at 5 miles. To the northeast, where it crosses Tonto Basin and extends past the north end of the Sierra Ancha, the area of schistose rocks is probably at least 15 miles wide." Associated with these rocks are great masses of quartzite with some conglomerate and shale clearly pre-Apache in age. They constitute Mazatzal Peak and most of the northern part of the range and are present on the north side of Delshay Basin and at Natural Bridge where "uptilted hard conglomerate and quartzite rest on granite and are unconformably overlain by the horizontal Paleozoic beds. The older rocks in places project as hills through the Cambrian sandstone into the overlying Devonian (?) limestone."

[1]Ransome, F. L., Geology and Ore Deposits of the Globe Copper District, Arizona: U. S. Geol. Surv. Prof. Paper 12, p. 23, 1903.

[2]Schrader, F. C., Mineral Deposits of the Cerbat Range, Black Mountains and Grand Wash Cliffs, Mohave County, Arizona: U. S. Geol. Surv. Bull. 397, 1909; Abstract, U. S. Geol. Surv. Bull. 340, pp. 53-83, 1908, and Geology and Ore Deposits of Mohave County, Arizona: Am. Inst. Min. Engr., Trans., vol. 56, pp. 195-236, 1917.

[3]Ransome, F. L., Quicksilver Deposits of the Mazatzal Range, Arizona: U. S. Geol. Surv., Bull. 620 (f), pp. 114-117.

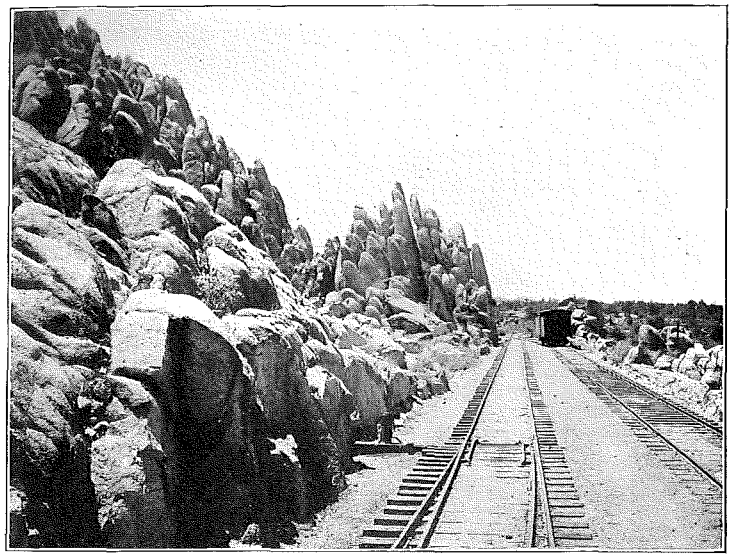


Plate 1a. Pre-Cambrian granite 6 miles northeast of Prescott, Arizona Looking south. Shows strong cleavage, nearly vertical.

"Some of the quartzite beds of the Mazatzal Range are infolded with the schists" but the larger bodies include beds of conglomerate containing schist fragments. Ransome pointed out the fact that these hard rocks constituted a prominent ridge in early Paleozoic time.

Further data regarding these quartzites and their relations in the Mazatzal Mountains, Natural Bridge, and Del Rio regions have been given by Wilson,[1] a résumé of which is presented on page 248.

Eastern Arizona.—Quartzite of pre-Cambrian age is bared in a small area in Quartzite Canyon 3 miles northwest of Fort Defiance, overlain and surrounded by red beds of the Supai formation. It has been described in detail by Gregory.[2] He found that it includes crushed pebbles of slate and quartzite, mostly from one-quarter inch to 2 inches long, and shows considerable cross-bedding. I found that it is closely similar to pre-Cambrian quartzites that underlie Cambrian rocks in various other portions of the Southwest. It marks the summit of a ridge of crystalline rocks which continued into Permian time, when it was finally buried beneath Supai sediments. The relations are similar to those found in the uplift of Zuni Mountains, not very far southeast in New Mexico, where pre-Cambrian granite appears extensively, overlain immediately by red beds

[1]Wilson, E. D., Proterozoic Mazatzal Quartzite of Arizona: Pan American Geol., vol. 38, pp. 299-312, 1922.

[2]Gregory, Herbert E., Geology of the Navajo Country: U. S. Geol. Surv. Prof. Paper 93, p. 17, 1917.

of Permian age. Granite of the same character as that in Zuni Mountains was found in drill holes recently made for oil, one a few miles northeast of the quartzite outcrops in Quartzite Canyon, where its depth was 147 feet, and the other in Nazlini Canyon, about a mile east of Nazlini Store, where it was found at a depth of 803 feet under a thick mass of red beds of the Supai formation.

Yavapai schist.—The pre-Cambrian crystalline rocks of the south-central part of Yavapai County have been mapped and described in detail by Jaggar and Palache.[1] They comprise Yavapai schist and various penetrating intrusives, including large stocks of granite (Bradshaw) and a variety of other rocks, some of which perhaps are Mesozoic or younger. The monzonite porphyry and quartz diorite and some rhyolite dikes are regarded as doubtful in age. The Yavapai schist is an altered sedimentary rock undoubtedly older than the Grand Canyon series. The most abundant rock is an argillaceous phyllite grading into slate, mica-schist, and chlorite-schist, with local inclusions of gneiss, granitite, hornfels, and epidote- and hornblende-schists and various other metamorphic rocks. There are also members of quartzite with conglomerate lenses, which in places are at least 900 to 1,000 feet thick. The presence of pebbles of schists and quartzite in these conglomerates indicates that they were derived from still older Algonkian strata. The total thickness of all these strata appears to be 6,000 to 8,000 feet.

The pre-Cambrian rocks in the Jerome area have been briefly described by Reber.[2] The principal feature is a greenstone complex, apparently overlain by sedimentary rocks and all penetrated by quartz porphyry (granite) and augite diorite. The greenstones are largely volcanic flows and fragmental material with some water-worn grains, and the associated strata comprise slates, schists, fine-grained quartzite, and conglomerates. Some of the latter contain well rounded pebbles in tuffaceous matrix, and a bed or lens of marble 20 feet thick. The quartz porphyry is believed to be the same as the Bradshaw granite of the Bradshaw quadrangle.

Southwestern Arizona.—In the Buckskin Mountains, a range occupying the northern part of Yuma County, there is a considerable variety of gneiss of pre-Cambrian age, but I believe that the associated limestone and at least a portion of the schist probably are altered Paleozoics. The character of these rocks in the western part of this range has been described in considerable detail by Blanchard.[3] Gneiss is the prevailing rock, but some large pegmatite dikes also occur. It is stated that certain small bodies of dolomitic marble, differing from the altered limestone, are included in the gneiss, but these may be downfaulted blocks of altered Paleozoic rocks.

[1]Jaggar, T. A., Jr., and Palache, Charles, Description of Bradshaw Mountains Quadrangle: U. S. Geol. Surv. Geologic Atlas, Bradshaw Mountains folio 126.

[2]Reber, Louis E., Jr., Geology and Ore Deposits of the Jerome District: Am. Inst. Min. Engr., Trans., vol. 66, pp. 5-6, 1922.

[3]Blanchard, R. C., The Geology of the Western Buckskin Mountains, Yuma County, Arizona, 80 pages, 1913.

The schists, limestones, and most of the granite of northern Yuma County and the adjoining corners of Maricopa and Yavapai counties have been classed by Bancroft[1] as pre-Cambrian in age, but I have found

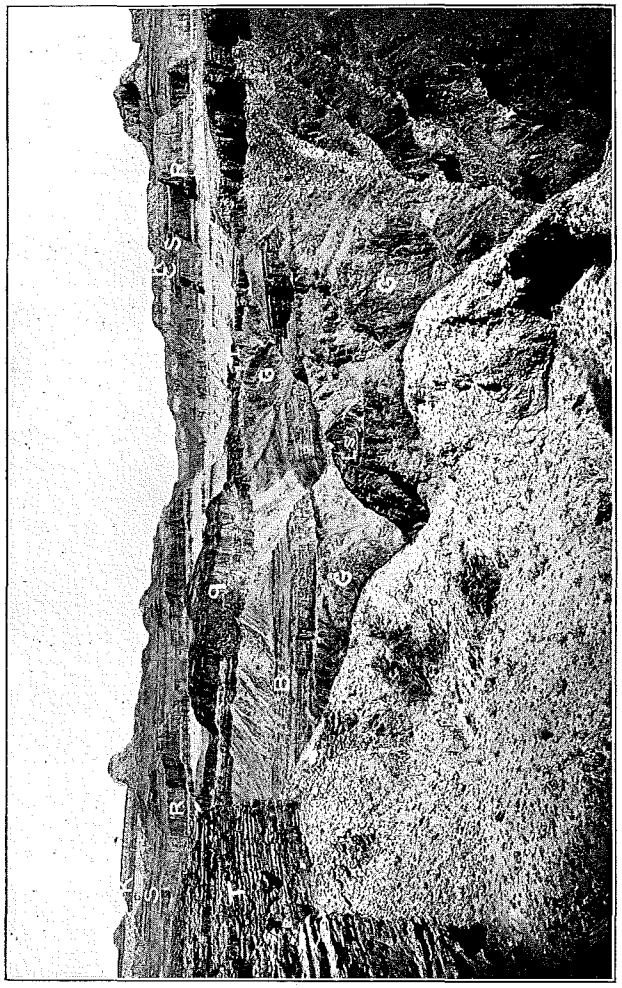


Plate 1b. The Unkar rocks as seen from the trail down to the river. Bright Angel Canyon in center. Buddha Temple to left, Brahma Temple to right. granite and gneiss; B, basal limestone and conglomerate (Unkar); Ls, limestone (Unkar) on south side of river against fault; B, red shales (Unkar); q, red quartzite (Unkar); T, Tapeats sandstone; R, Redwall limestone; C, Coconino gray sandstone; K, Kaibab limestone.

Carboniferous fossils in the limestones at various places and at least part of the schists also are Paleozoic. It is not unlikely that much of the granite and schist in Harquahala, Huarcuvar, Dome Rock, Plomosa, Will-

[1]Bancroft, Howland, Reconnaissance of the Ore Deposits in Northern Yuma County, Arizona: U. S. Geol. Surv., Bull. 451, 1911.

iams, and Buckskin mountains and some minor ridges are pre-Cambrian, but close study will be required to differentiate these rocks from younger ones. Bancroft found masses of younger granite in the southwestern

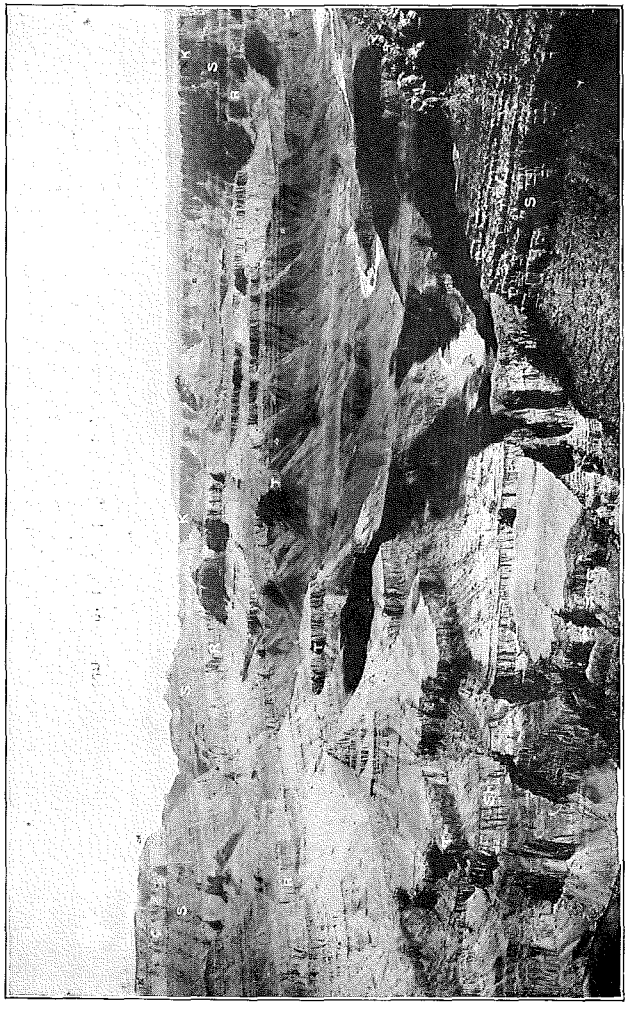


Plate 2. Unkar and Chuar groups in Grand Canyon near Grand View and the mouth of the Little Colorado River. Looking northeast from near Grand View. Painted Desert and Echo Cliffs in distance. Ch, Chuar Butte near mouth of Little Colorado River; C-R, Cape Royal; Sh, Shinumo quartzite overlain by sandstone and shales; C-C, base of Chuar group; T, Tapeats sandstone; R, Redwall limestone; S, Supai formation and Hermit shale; C, Coconino sandstone; K, Kaibab limestone.

part of the Huarcuvar Range and in the pass east of Vicksburg, and Jones[1] regarded certain granites in Dome Rock Mountains and the ridges north in the Colorado River Indian Reservation as post-Paleozoic.

[1]Jones, E. L., Jr., Gold Deposits near Quartzsite, Arizona, U. S. Geol. Surv. Bull., 620c. pp. 45-57, 1916

The older granites appear to merge into gneiss, of which there is a large amount in many of the ridges. There are also dioritic rocks and intrusive pegmatite and aplite which may be pre-Cambrian. The metamorphosed sediments regarded as pre-Cambrian by Bancroft consist of two types, one the quartzites, limestones, and dolomites, of which only a small amount remains, and the second a thick succession of argillites and arenaceous shales metamorphosed into fine-grained quartz mica schists. This complex includes interbedded amphibolites which represent local flows and intrusions which have been metamorphosed along with the rest of the series. This succession of schists differs considerably from others in the State, and its thickness is too great to represent any known shale succession in the Paleozoic. Possibly it may be a metamorphosed representative of part of the Grand Canyon series. Some of the schists, however, are so intimately associated with Carboniferous limestone now in large part altered to marble, that a part at least are of Paleozoic age.

The schists on the western side of Plomosa Mountain and in the ridges north of Tyson Wash in the Colorado River Indian Reservation have been examined by Jones.[1] He found that they range from fine-grained, silvery-white sericite schists to coarse-grained biotite schists with interbedded thin marble beds. They are cut by bodies of amphibolite and quartz diorite probably originally diabase and diorite, and by post-Paleozoic granite. He follows Bancroft in believing that these schistose rocks are of pre-Cambrian age, but no evidence is presented.

Some features of the older rocks in the central part of Yuma County and the western part of Maricopa County have been described by Ross.[2] Many of the mountains in that region consist wholly or in part of gneisses, granites and schists of probable pre-Cambrian age. As the field work was largely reconnaissance, younger metamorphic rocks and post-Paleozoic granites were not separated from the pre-Cambrian rocks. In the northern part of the Buckskin Mountains, northeast of Bouse, granitic gneiss was noted, overlain unconformably by metamorphosed quartzite, sandstone, and limestone, the sandstone containing debris from the underlying gneiss. In Gila Bend Mountains small masses of fine-grained mica schist and quartzose schist were found to be included in gneiss, and in the southern end of the Big Horn Mountains near Palo Verde mines are chloritic schists believed to belong to the "most ancient of the schistose rocks." I found schist in the south end of Trigo Mountains, in the eastern part of Cemetery Hills, and in the northern part of the Big Horn Mountains, which appears to be old, probably of pre-Cambrian age.

Jones[3] reports granite cut by diorite dikes on the north side of the Kofa Mountains, but presents no evidence to show that it is not part of the pre-Cambrian basement. He describes slate and schist of supposed

[1]Jones, E. L., Jr., *op. cit.*, (Bull. 620-c), p. 47.

[2]Ross, C. P., Geology of the Lower Gila Region, Ariz.: U. S. Geol. Surv., Prof. Paper 129 (h), pp. 183-197, map, 1922.

[3]Jones, E. L., Jr., A Reconnaissance in the Kofa Mountains, Arizona: U. S. Geol. Surv., Bull. 620 (h), p. 155, 1915.

pre-Cambrian age at the south end of these mountains between the North Star and King of Arizona mines, but gives no evidence as to their age.

The prevailing country rock about the Monte Cristo mine, 12½ miles

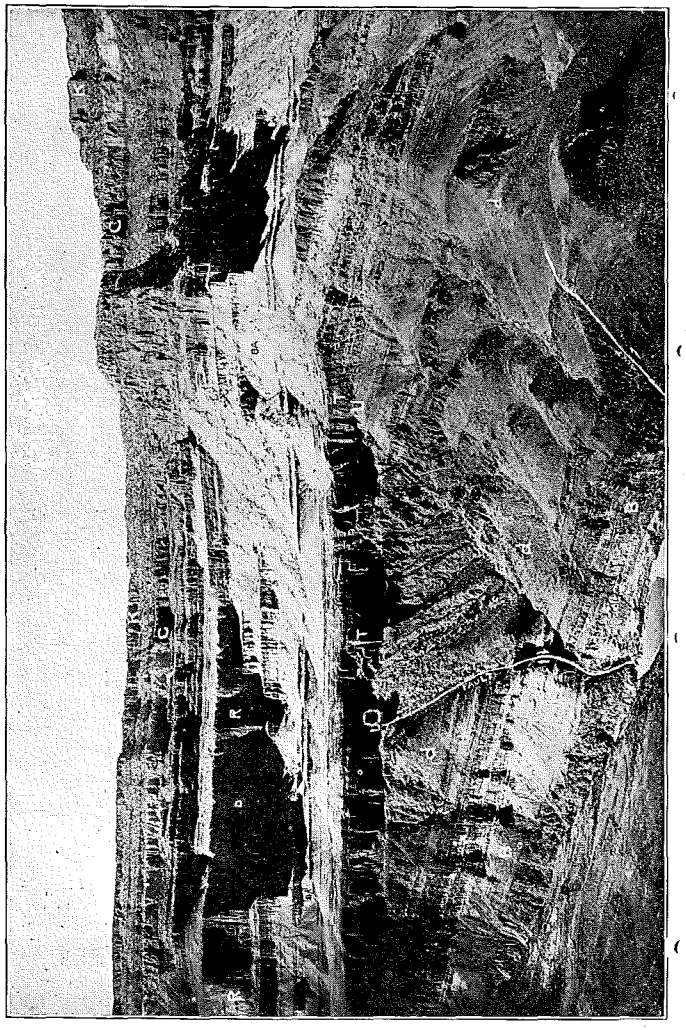


Plate 3. Grand Canyon series and overlying rocks in north wall of Grand Canyon just west of Shinumo Creek, looking northwest. Powell Plateau in distance to left, Masonic Temple to right, Colorado River in foreground. Gr, granite, etc. (pre-Cambrian); B, Bass limestone; H, Hakatai shale; d, diabase intrusion; Sh, Shinumo quartzite; U, unconformity; T, Tapeats sandstone; BA, Bright Angel shale; M, Muav limestone; R, Redwall limestone; S, Supai formation and Hermit shale; C, Coconino sandstone; Kaibab limestone. Photo by Carkhuff.

northeast of Wickenburg, is stated by Bastin[1] to be granite gneiss, with some diorite gneiss, cut by dikes of pegmatite and diabase.

Many data regarding the distribution and relations of pre-Cambrian

[1]Bastin, E. S., Primary Native Silver Ore near Wickenburg, Arizona: U. S. Geol. Surv., Bull. 735 (E), p. 132, 1922.

rocks in southwestern Arizona have been given in a recent report and map by Bryan.[1] In most parts of the area time was not available for the separation of the older from the younger crystalline rocks, or the detailed mapping of the Paleozoic rocks. The older rocks are largely schist, gneiss, and granite, but younger granite also occurs in places. The northern part of the Gila Mountains is stated to consist mostly of coarse biotite granite and micaceous and hornblende schist and gneiss. In Salt River Mountains chloritic schist prevails, and there are many transitions from schist to gneiss. Fine-grained biotite-granite and phyllite also occur.

A small area of schist, presumably pre-Cambrian, has been noted by Jenkins and Wilson[2] in the Tucson Mountains west of Tucson. It closely resembles the Pinal schist of the region to the north, and is overlain by quartzite at the base of the Cambrian. Granite exposed south of the schist area may also prove to be pre-Cambrian, but its relations are not evident.

GRAND CANYON SERIES

In his great voyage of exploration down the canyon of the Colorado River Major J. W. Powell[3] discovered a thick series of sedimentary rocks lying unconformably on granite and schist, and overlain unconformably by sandstone at the base of the Tonto group. To this series in 1876[4] he gave the name Grand Canyon "group." Walcott[5] later studied these rocks, and in 1882 and 1883 divided the "group" into two divisions, which later[6] were termed the Unkar and Chuar groups and finally referred to the Algonkian. These two groups, with a total thickness of nearly 12,000 feet, are revealed in the depths of the Grand Canyon at various points between Tapeats Creek and Nunkoweap Valley, the largest areas being in the big bend of the canyon near the mouth of the Little Colorado River (Pl. 46) and in Bright Angel and Shinumo valleys. Smaller exposures occur in Hindu and Ottoman amphitheatres, Vishnu Creek, West Vishnu Creek, Phantom Creek, and opposite Havasupai Point.

Chuar group.—The upper group, named Chuar, appears only in the Chuar, Kwagunt, and Nunkoweap valleys and their vicinity, that is, in the

[1]Bryan, Kirk, Erosion and Sedimentation in the Papago Country, Arizona, With a Sketch of the Geology: U. S. Geol. Surv., Bull. 730 (b), 1922.

[2]Jenkins, O. P., and Wilson, E. D., A Geological Reconnaissance of the Tucson and Amole Mountains: Univ. of Ariz., Bull. 106, p. 10, 1920.

[3]Powell, J. W., Exploration of the Colorado River of the West: Washington, 1875.

[4]Powell, J. W., Geology of the Eastern Portion of the Uinta Mountains, 1876, p. 70.

[5]Walcott, C. D., Pre-Carboniferous Strata in the Grand Canyon of the Colorado: Am. Jour. Sci., vol. 26, p. 437-442, 1883.

[6]Walcott, C. D., Algonkian Rocks of the Grand Canyon of the Colorado: Jour. Geol., vol. 3, pp. 312-330, pls. 6, 1895, and Pre-Cambrian Igneous Rocks of the Unkar Terrane, Grand Canyon of the Colorado, Arizona: U. S. Geol. Surv., 14th Ann. Rept., Pt. 2, pp. 497-519, 1895.

portion of the Grand Canyon between latitudes 36° 06′ and 36° 17′. It consists of the following succession:

SECTION OF CHUAR GROUP

(Condensed from description by C. D. Walcott)

	Feet
Sandstone, massive, reddish-brown, becoming shaly near the middle and passing down into reddish, sandy shale, and shale with few thin compact sandstone layers	200
Shale, black, thin layers, crumbling on exposure, with two 50-foot members of massive gray limestone on lower half	525
Limestone, hard, buff, with irregular oölitic cherty bands predominating in places	4
Shale, black, with few compact layers and thin, earthy limestone	33
Limestone, gray, with Stromatopora? (probably Cryptozoon)	8
Shale, black above, variegated below, showing light drab, pea-green, vermilion, chocolate, and buff colors, with few thin layers of sandstone	740
Limestone, concretionary, massive	10– 25
Shale, reddish-brown on reddish-brown sandstone thinly bedded in its lower part	165
Shale, brown, sandy, passing down into chocolate and dark purer shale, alternating with brown and greenish, sandy shale; layer of oölitic iron ore near top	300
Shale, in part sandy with thin layers of limestone, one 4 feet thick near bottom containing Stromatopora	325
Shale, chocolate-brown, dull and yellowish-green, sandy and clayey, with thin sandstone layers and 21 feet of limestone in thin layers near middle and base	625
Shale similar to above but with less sand and more clay and lime, 54 feet of limestone included	500
Shale, dark and slabby, gray limestone, with 5-foot bed of gray to buff, friable sandstone near base	22
Shale, black, with chocolate and greenish sandy layers and hard beds of sandstone, local thin gypsum deposits	100
Shale, brown, sandy, including three feet of compact, mottled buff limestone	18
Shale, black, brown, and chocolate above; chocolate, green, maroon, and drab below, and with layers of sandstone and sandy shales toward base	830
Sandstone, brown, in beds 8 to 18 inches, passing down into sandy and pure shale with layers of buff and chocolate sandstone and drab shale passing down into ripple-marked sandy shale	110
Limestone, in part chocolate with irregular and concretionary and bituminous layers near base	50
Shale, mostly pure and dark with one member of deep maroon; drab, yellowish green and dark shales with a dark chocolate member lying on 100 feet of drab and dark greenish shale, with some sandy layers and thin sandstones; carries locally a 6-inch bed of limestone near base	450– 650
Average total	5120

Walcott found fossils in the Chuar rocks which suggested early Cambrian age for the group,[1] but it was thought that the great unconformity between the Chuar succession and the overlying Tonto indicated greater

age, so that the group is classed as Algonkian. These fossils were found midway in the lower portion of the shales and limestone of the Chuar succession. They included a "minute discinoid or patelloid shell, a small Lingula-like shell (which may be a species of Hyolithes), and a fragment of what appears to be the pleural lobe of a segment of a trilobite belonging to a genus allied to Olenellus, Olenoides, or Paradoxides. There is also a Stromatopora-like form that is probably organic."

Unkar group.—As described by Walcott, the Unkar rocks in the portion of the Grand Canyon in and near Unkar Valley, present the following section:

SECTION OF UNKAR GROUP FROM UNKAR VALLEY TO A POINT SOUTH OF VISHNU TEMPLE

(Condensed from Walcott)

	Feet
Limestone, massive gray to reddish (magnesian), passing down into limy sandstone	50– 150
Sandstone, light gray, yellowish-brown; purplish-brown and partly cross-bedded below	125
Sandstone and sandy shale, reddish-brown, ripple-marked	200
Basalt in 6 to 8 flows, 70 to 175 feet thick, separated by thin layers of sandstone	800
Sandstones, shaly, vermilion, rather fine-grained, ripple-marked and shrinkage cracked, with intercalated beds of greenish-gray color, underlain by 700 feet of vermilion beds, mostly massive with sandy shale partings	1730
Sandstone, chocolate-colored, of which 800 feet afe in a cliff of 5 massive members (slightly micaceous) separated by partings of shaly sandstone, chocolate above and greenish below	925
Sandstone, more or less shaly	125
Sandstone, friable and sandy, and micaceous shale	300
Sandstone with twisted and gnarled layers in top 15 feet; color gray with reddish spots; shaly in places	150
Sandstone, gray, hard compact	90
Sandstone, massive compact, brown, buff, and purplish-brown (cliff)	1200
Sandstone, reddish-brown to vermilion, friable, shaly	200
Sandstone, brick red, shaly	250
Sandstone, brown, friable, shaly, ripple marks and shrinkage cracks, with lower part more massive and fine conglomerate 10 feet at base	380
Limestone, light gray, with layers of shale	8
Sandstone, brown, with 2-foot bed of conglomerate	30
Limestone, reddish, cherty above; light gray and compact near base; 5-foot member of dark reddish-brown slate in middle	31
Basalt in one body	80
Limestone, light gray, compact, interbedded layers of chert or sandstone near base	26
Conglomerate, largely of pebbles of underlying pre-Unkar rocks on which it lies unconformably	30
Thickness of Unkar beds	6830

[1]Walcott, C. D., Pre-Carboniferous Strata in the Grand Canyon of the Colorado: Am. Jour. Sci., 3rd ser., vol. 26, p. 441, 1883.

Iddings[1] has described the petrography of the igneous rocks of the Unkar succession. The igneous members in the upper part, which have an aggregate thickness of nearly 800 feet, are basalts, in part amygdular, which doubtless were surface flows. The "dolerite," 80 feet thick, in the lower limestone south of Vishnu Temple (opposite Grand View and Red or Congress Canyon), appears to me to be an intrusive sill of diabase invading Bass limestone and not a member of the effusive succession; otherwise it might represent the basalt flow which is so general on the Mescal limestone in central Arizona, and be of aid in correlating the Apache group with the Unkar group.

Noble[2] has made a detailed study of the Unkar strata about Shinumo Creek in the Grand Canyon, where about 4,000 feet of beds are revealed in a wedge-shaped mass lying on the old schist and diorite. An unknown, but probably small amount of the upper part of the group, is not exposed. The following formations were differentiated and named:

FORMATIONS OF UNKAR GROUP IN SHINUMO QUADRANGLE

	Feet
Dox sandstone: Micaceous shaly sandstones, red and vermilion above, gray green, purplish-green, and brown below; cross-bedded and ripple-marked, with shaly partings of green or gray color and some sandy layers; near base gnarled and twisted sandstone	2300
Shinumo quartzite: Alternating sandstones and quartzites, the sandstone mostly purple-brown, and quartzite white and hard, forming two principal cliffs, some sandstone layers gnarled and twisted	1564
Hakatai shale: Mostly red shale, upper part sandy, with 100 feet of blue shale below middle; some beds altered to jasper	580
Bass limestone: White limestone with blue shale intercalations in upper third, and of calcareous, red shales near lower part	335
Hotauta conglomerate, composed of local pebbles and arkosic, mostly reddish matrix, varying in hardness	1– 6

The lower strata are invaded by thick sills of diabase, and four thin sills of this rock were observed in the Dox sandstone. Asbestos (chrysotile), developed in certain beds of the Bass limestone by metamorphic action of the diabase, is exposed on Hakatai Creek, where the deposit has been prospected. The conditions under which this asbestos occurs are precisely similar to those in the Hance asbestos locality opposite Grand View, and apparently also the same as in the Sierra Ancha-Chrysotile area in central Arizona.

[1]Iddings, J. P.: U. S. Geol. Surv., 14th Ann. Rept., Pt. 2, pp. 520-524, 1895.

[2]Noble, L. F., The Shinumo Quadrangle, Grand Canyon District, Arizona: U. S. Geol. Surv. Bull. 549, pp. 100, pls. 17, map, 1914.

I have examined the Unkar rocks in the canyons of Bright Angel Creek and Phantom Creek and vicinity, opposite El Tovar, where a very complete section is exposed. At the base, lying on the old Vishnu schist, is a coarse conglomerate 3 to 15 feet thick, grading up into 40 feet of red shale, and a body of Bass limestone, cut off by a sill of diabase which displaces the strata for some distance along Bright Angel Creek. The limestone is massive and hard, but made up of alternating thin beds of limestone and chert, closely similar in character to the Mescal limestone. Above the basalt there is a thick mass of red shale (Hakatai), but the full thickness is masked by the sill and by a small fault along the east side of the canyon. The next member is a massive, hard, gray sandstone on which are Ribbon Falls. The thickness is several hundred feet, but it is much less than that of the Shinumo quartzite as described above by Noble. It is penetrated by dikes and thin sills of diabase. Above are 250 feet of gray and red shales with thin, sandy and sandstone layers, and in places under the Tapeats sandstone, 300 feet or more of red shale, two members of which probably represent the Dox sandstone of Noble.

CAMBRIAN(?) ROCKS

Apache group.—In central Arizona the Pinal schist and old granites are overlain by a succession of about 1,000 feet of sandstone, conglomerate, shale, and limestone, which have been defined as the Apache group.[1] This group consists of the following formations:

FORMATIONS OF THE APACHE GROUP IN CENTRAL ARIZONA
(Ransome)

Formation	*Character*	*Thickness*
Troy quartzite	Largely quartzite, light colored, cross-bedded, pebbly streaks	160–1000
Basalt flow	Vesicular lava, present at many places	0– 75
Mescal limestone	Thin-bedded, hard, with intercalated cherty layers	225– 300
Dripping Spring quartzite	Fine-grained arkosic quartzite and sandstone, mostly massive, and reddish-brown, locally thin-bedded	450– 700
Barnes conglomerate	Smooth, mostly rounded pebbles in hard, arkosic matrix	5– 50
Pioneer shale	Shale, mostly brownish-red and hard	150– 250
Scanlan conglomerate	Pebbles, mostly local, generally grades up into arkosic sandstone	0– 30

These formations, especially the lower ones, are generally invaded by thick sills of diabase which in places have metamorphosed certain layers of the limestone into asbestos (chrysotile). Ransome found the group extensively exposed in the vicinity of Globe and Ray, where he has

[1]Ransome, F. L., Geology of the Globe Copper District, Arizona: U. S. Geol. Surv. Prof. Paper 12, 1903; and some Paleozoic Sections in Arizona and Their Correlation: U. S. Geol. Surv. Prof. Paper 98, pp. 136-141, 1916.

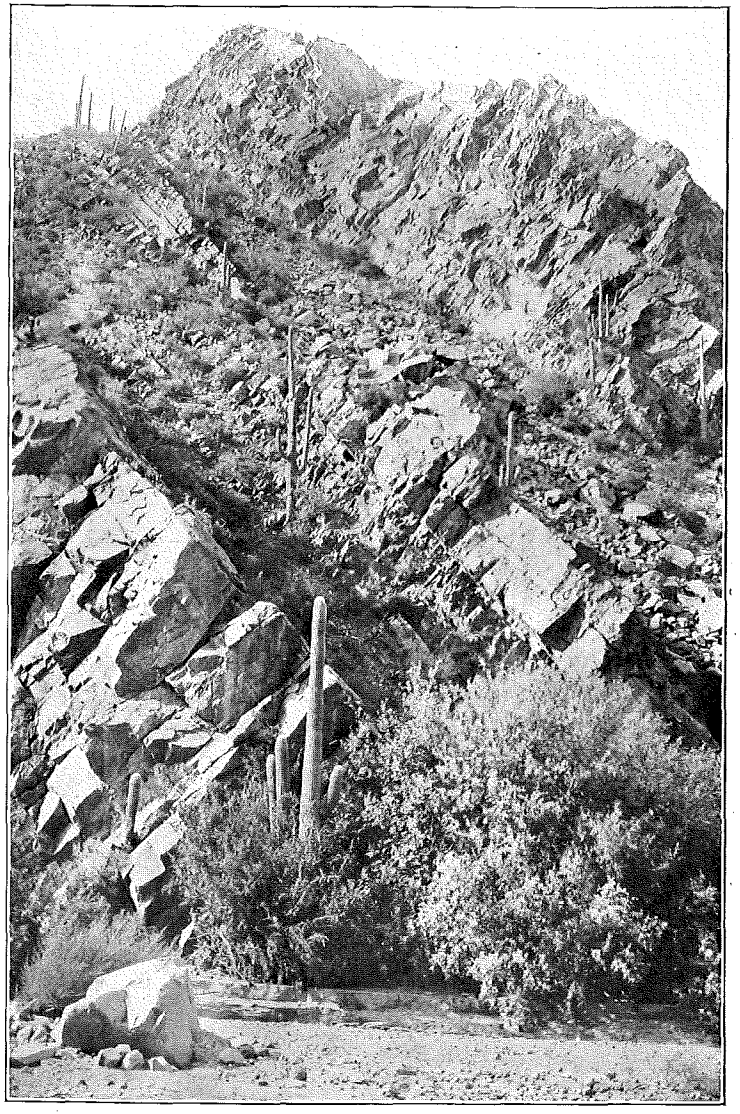


Plate 4a. Granite overlain by Scanlan conglomerate, Pioneer shale, Barnes conglomerate, and Dripping Spring quartzite, canyon of Camp Grant Wash 2½ miles west of Arivaipa School, 11 miles south of Winkelman, Arizona. Looking north.

mapped it in detail, and also at Roosevelt Dam and in the Sierra Ancha. Some features of the group have been noted by Reagan[1] in the Apache Indian Reservation, and by Lee[2] and Walcott at Roosevelt Dam. In 1921 and in 1922 I traced the Apache rocks northward up Canyon Creek, Cherry Creek, across the headwaters of Verde River to the base of the Mogollon Plateau, eastward up Salt River nearly to the mouth of Carrizo Creek, southeastward along the foot of Natanes Plateau to the canyon of Blue Creek, and southward into the canyon of Gila River southeast of Globe. Other areas were found in the western part of the Galiuro Mountains, on the northern and southern slopes of the Santa Catalina Mountains, and in the Vekol Mountains. Lausen and Wilson have mapped[3] the group between Globe and Florence, E. Sampson has mapped[3] it in the Salt River Valley above the mouth of Canyon Creek, Tolman[3] has mapped it on the north slope of Santa Catalina Mountains, and Kirk Bryan[3] has mapped it in the San Pedro Valley region.

In most of the area above noted the group lies nearly horizontal but locally it is tilted in flexures which involve the overlying formations. It is generally directly overlain by the Martin limestone (Devonian), but in the vicinity of the Santa Catalina Mountains and in the Vekol Mountains it is overlain by Abrigo limestone. In the canyons of the Gila River, 25 miles southeast of Globe, it is overlain by sandstone with Abrigo fossils. In nearly all cases its attitude is essentially the same as that of the overlying strata, but I found discordance in some local uplifts in the mountains southeast of Globe.

The quartzites, both Troy and Dripping Spring, make great cliffs and high canyon walls, which are in large part the cause of the rugged topography of Gila County. The high mountain front of Sierra Ancha is made up of these rocks, and the canyon of the Gila River southeast of Globe exposes sections of them fully a half-mile deep. The Salt River Canyon for 15 miles above the mouth of Canyon Creek is mostly box canyon in these quartzites and they are extensively exposed in high cliffs in the canyons of Cherry and Canyon creeks. It seems likely that they have been penetrated by deep borings south of Holbrook.

The stratigraphy of the Apache group is remarkably uniform throughout. The Pioneer shale, with the Scanlan conglomerate at base, is somewhat variable, and locally, only the Barnes conglomerate is present. The latter, although thin, is persistent and characteristic and a very conspicuous feature in nearly all exposures. Ransome mentions 175 feet of arkosic basal beds in the Pioneer in Apache Mountains south of Globe, and I found that this feature extends far northward. However, reddish-brown, smooth-surfaced shale with light buff spots is the characteristic feature of

[1]Reagan, A. B., Geology of the Fort Apache Region in Arizona: Am. Geol., vol. 32, pp. 265-308, 1903.

[2]Lee, W. T., Underground Waters of Salt River Valley, Arizona: U. S. Geol. Surv. Water-Supply Paper 136, pp. 96-97, pl. IX, 1905.

[3]Manuscript maps used in geologic map of Arizona.

the greater part of the Pioneer. This formation is 255 feet thick below Roosevelt Dam. Both Pioneer shale and Barnes conglomerate were found to thin out and disappear near the Gila River southeast of Globe. The Dripping Spring formation, mostly fine-grained quartzite, varies in thickness, and is generally invaded by great sills of diabase, which in the Sierra Ancha and in Salt River Canyon are several hundred feet thick. The formation is from 400 to 500 feet thick in the Ray-Globe region. To the eastward it disappears under an overlap of the Troy quartzite onto granite in the Mescal Mountains near longitude 110° 32½′ southwest of San Carlos. A characteristic exposure is shown in Plate 4b. The Mescal limestone varies greatly in thickness and character. It attains its maximum development at Roosevelt Dam, where it is 300 feet thick and consists of hard limestone mostly in massive beds. Much of the dam is built in this formation. (See Plate 5b.) Here, as at many other localities, it is over-

Plate 4b. Banded Dripping Spring quartzite, Mescal Range. Photo by Ransome.

lain by a thin bed of vesicular basalt which was poured out as a lava flow after the deposition of the limestone. This basalt was also noted at Chrysotile, where it is more than 100 feet thick, on all the slopes of the Sierra Ancha, and at places in the Salt River region. It is conspicuous on the south slope of the Mescal Mountains on the main road from Globe to Tucson, and according to Ransome, it is general in the Ray quadrangle. The many thin, intercalated beds of chert in the Mescal limestone are a characteristic feature. The limestone is thick and pure on Salt River, in the Sierra Ancha, and about Chrysotile, with a thickness of 150 feet or more, and certain thin layers are altered to chrysotile (asbestos) in

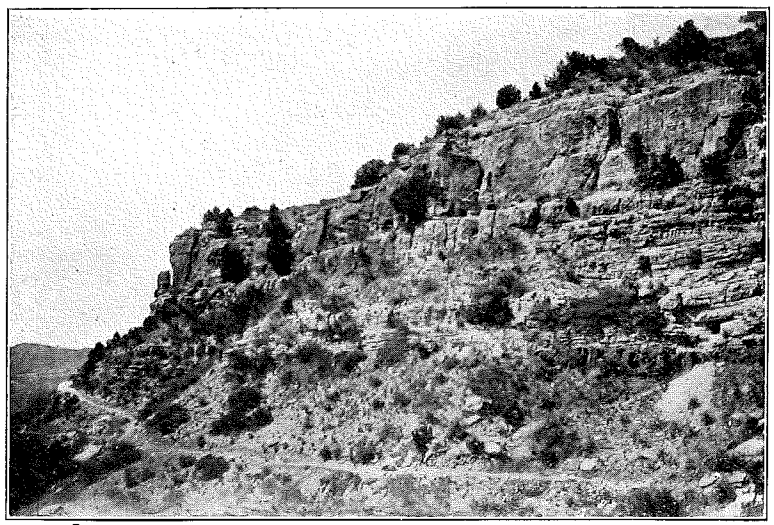
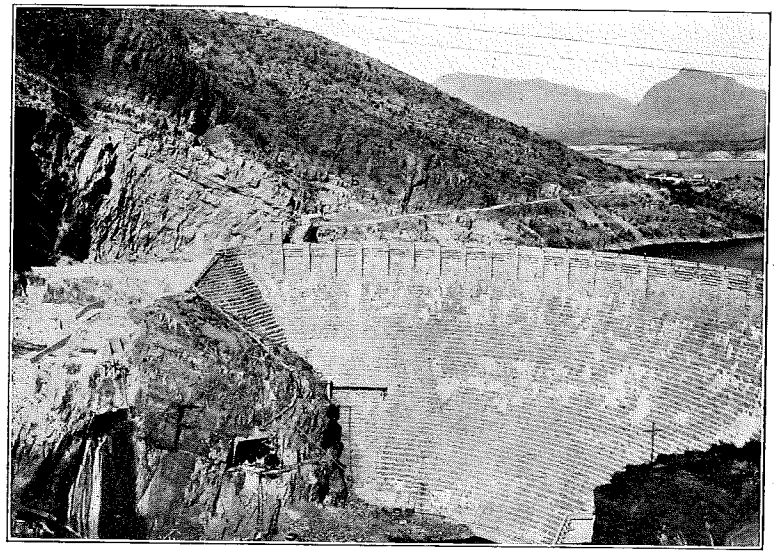


Plate 5a. Mescal limestone in small canyon just south of the Regal Asbestos Mine, Gila County, Arizona. Looking north toward the Salt River.



Looking north. (b) Sheet of basalt lava at top of Mescal Limestone.
Plate 5b. Mescal limestone overlain by Troy quartzite at Roosevelt Dam

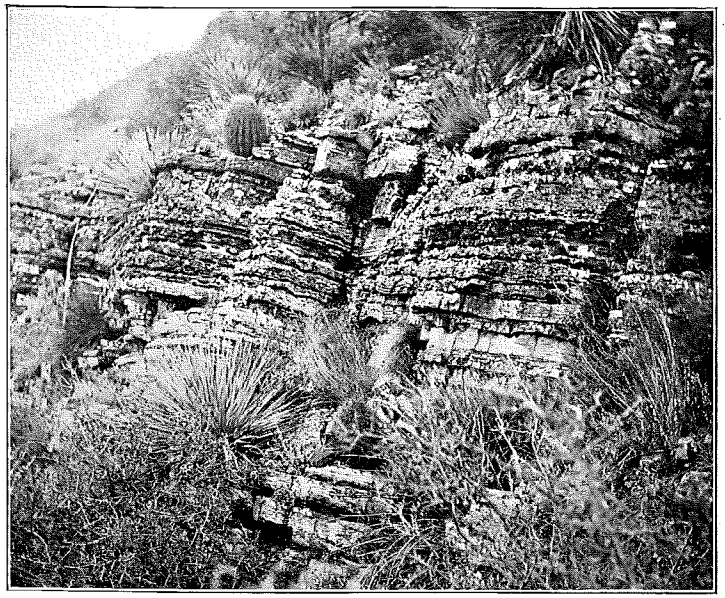


Plate 6a. Mescal limestone near Ray, Arizona. Shows interbedded cherty layers. Photo by Ransome.

connection with the sills of diabase which are intruded into the formation in this region. In and near the canyon of the Gila River southeast of Globe the Mescal limestone is only a few feet thick and highly siliceous, but it is strikingly different from the adjoining quartzites. It thins out not far east of that place and also in the northwestern slope of Galiuro Mountain. In Camp Grant arroyo, 12 miles south of Winkleman, however, it is well exposed, penetrated by diabase (see section in Fig. 87). According to Tolman[1] the formation occurs extensively on the north slope of the Santa Catalina Mountains. In the eastern part of the Mescal Mountains and in the Hayes Mountains it is locally absent due to erosion prior to Troy deposition. The Troy quartzite is especially prominent in the Sierra Ancha, where it attains a thickness of 1100 feet according to Ransome, including an upper member of 200 feet of sandstone, which may be separable. An exposure of a coarse, cross-bedded portion of the Troy quartzite is shown in Plate 7a. I found about 800 feet of "Troy" beds in the canyon of the Gila River 25 miles southeast of Globe, including a top member of slabby, rusty sandstone containing upper Cambrian (Abrigo) fossils. (See Figs. 75 and 76.)

In the eastern part of the Mescal Mountains and in the Hayes Mountains southeast of Globe, the basal member of the Troy is conglomeratic

[1]Manuscript map of Tucson quadrangle.

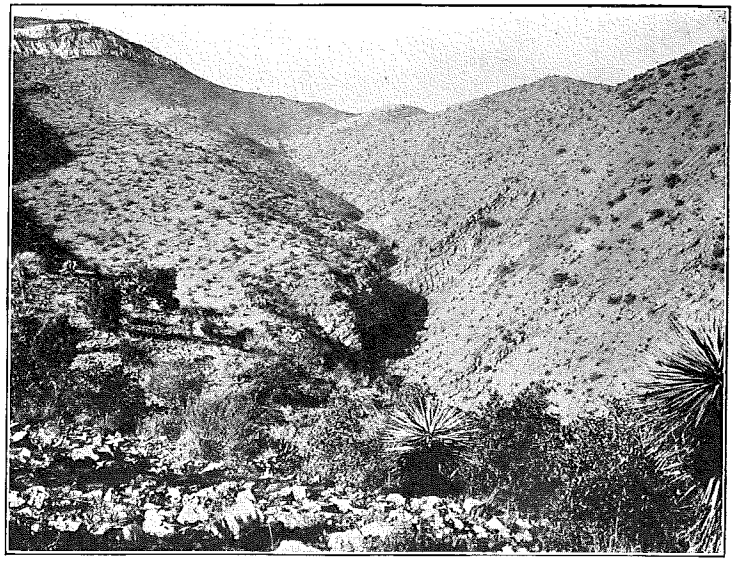


Plate 6b. Martin limestone, Abrigo limestone, and Bolsa quartzite at foot of Mt. Martin southwest of Bisbee, Arizona. Looking south. Photo by Ransome.

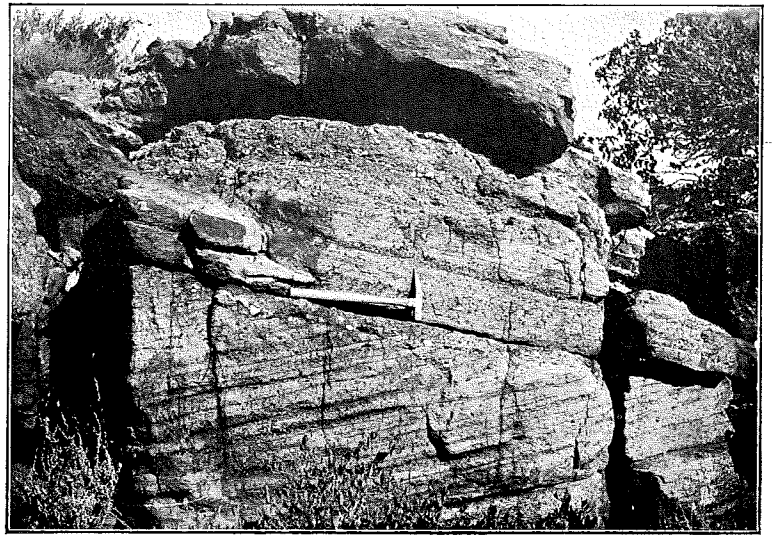


Plate 7a. Troy quartzite, Dripping Spring Range. Photo by Ransome.

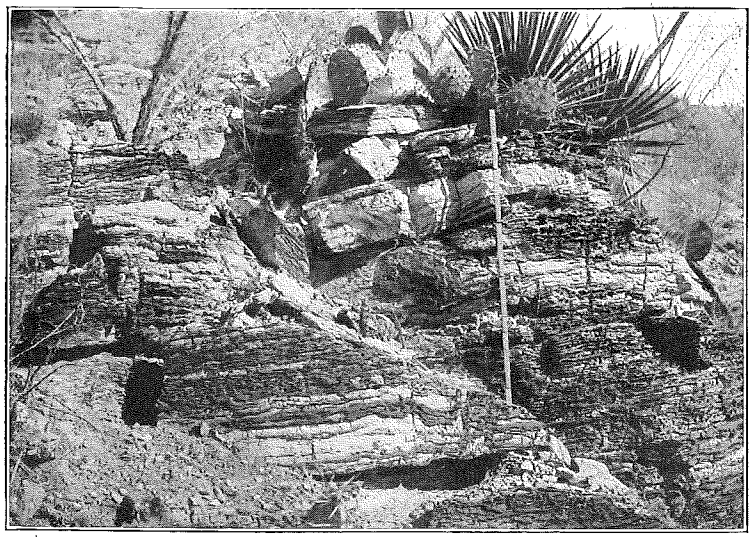


Plate 7b. Abrigo limestone east of Oregon Mine, near Tombstone, Arizona. Shows characteristic cherty layers. Photo by Ransome.

and lies on an eroded surface of the Mescal limestone or Dripping Spring quartzite, finally near longitude 110° 32½′ overlapping the latter and extending directly onto the granite (pre-Cambrian). In this region also it lies uncomformably on the very coarse-grained diabase which is intruded in thick sills in the underlying Apache strata. The basal conglomerate carries much chert, apparently derived from the Mescal limestone, and the latter formation was locally removed by channels prior to Troy deposition. The occurrence of cherts and basalt from the Mescal formation in the basal deposits of the Troy has also been observed by Mr. Carl Lausen in the ridges northeast of Globe.[1] They are of wide extent near Canyon Creek and in places on the Salt River. At one point on the north slope of the Mescal Mountains very near longtitude 110° 33½′, coarse conglomerate in the Troy lies against slightly tilted beds of Dripping Spring quartzite as shown in A, figure 76, page 256. These relations indicate that the material of the Troy quartzite was deposited after a long interval in which the Mescal and underlying sediments were converted into rock and stripped of overlying formations and also after the intrusion of the great diabase sills which are so characteristic in the earlier formation.

The Apache group has been classed as Cambrian by Ransome,[2] with

[1]Personal communication.

[2]Ransome, F. L., *op. cit.*, Prof. Paper 98, p. 164, and Paleozoic Section of Ray Quadrangle· Wash. Acad. Sci. Jour., vol. 5, pp. 380-388, 1915, and Ray folio, No. 217.

the suggestion that it may also include Ordovician and Silurian.[1] No fossils were found, but the correlation was based mainly on the resem-

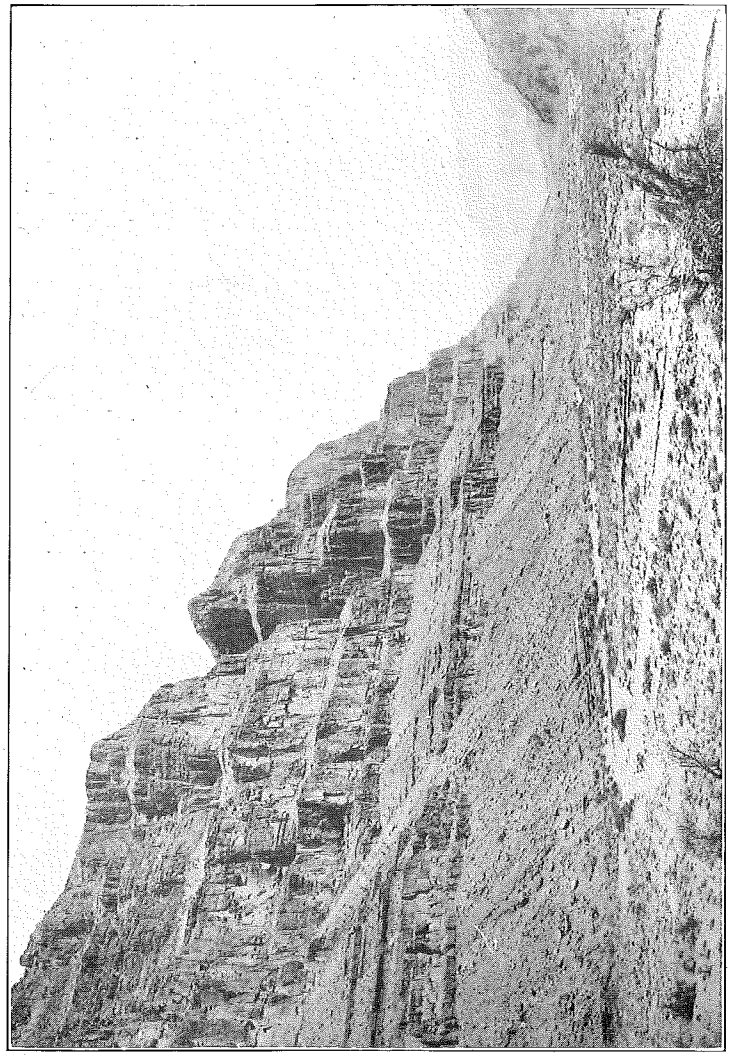


Plate 8a. Cliffs of Redwall limestone, and limestones and shales of Tonto group in west wall of Peach Springs Canyon. Looking north to mouth of Diamond Creek. Cliff of granite on east side of fault, to the left.

blance between the Abrigo and Mescal limestones, with their characteristic

[1]Ransome, F. L., The Copper Deposits of Ray and Miami, Arizona: U. S. Geol. Surv. Prof. Paper 115, Pl. XIII, 1919.

alternations of cherty layers, lying on a massive basal sandstone or quartzite, and conformable in general attitude with the overlying Martin and other limestones. This correlation would require the Troy quartzite to thin out to the south; but it certainly is not represented in the local 8-foot sandstone member at the top of the Abrigo limestone in the Bisbee region. Reagan,[1] who observed the Apache group in the Apache Reservation in 1903, and Walcott and Lee,[2] who examined the exposures at and near Roosevelt Dam at about the same time, regarded it as the same as the Grand Canyon series, an opinion in which I concurred in 1910, and still hold.[3] This correlation was based on the close resemblance of the rocks, although the strata in the Grand Canyon are steeply tilted and bevelled off beneath the nearly horizontal Tapeats sandstone (Upper Cambrian). I have spent much time in both areas in the past two years, and am strongly impressed by many features of close similarity of the strata. The Mescal and Bass limestones are much alike, the basal shales and conglomerates are similar to the Scanlan, Pioneer, and Barnes rocks, and the higher sandstones are like the Troy. The Dripping Spring quartzite probably is a local development in the central part of the State. The great sills of rather peculiar diabase with large, included augite nodules are closely alike. In both groups the heat of intrusion has converted some of the limestone into chrysotile. The vesicular flow of basalt on the surface of the Mescal limestone may possibly be represented by the closely similar lava flows of the Chuar.

The relations of the strata overlying the Apache group or constituting its upper members, however, present the best evidence. It is found that the "Troy" in most places includes in its upper part or is overlain by a much younger sandstone, doubtless equivalent to the Tapeats and the Bolsa-Abrigo beds. I observed that the Troy is very extensively developed on the Gila River in the numerous fine sections 25 miles southeast of Globe. Here, where it attains a thickness of about 800 feet, it is overlain by a slabby, irony sandstone containing Upper Cambrian *Lingulæ*, etc., doubtless representing the Abrigo limestone. This occurrence proves at least that the underlying succession of Troy, Mescal, Dripping Spring, etc., 1,800 feet thick in this canyon, is pre-Abrigo. The overlap relations in this region (see Fig. 76, p. 256) also show that the Troy lies uncomformably on the Dripping Spring quartzite and Mescal limestone, as well as on the great sills of diabase which invade these two formations. Moreover, to the eastward near the east end of the Mescal Mountains, its upper part overlaps the edge of the Dripping Spring quartzite and becomes the basal formation of the sedimentary se-

[1]Reagan, A. B., Geology of the Fort Apache Region in Arizona: Am. Geol., vol. 32, pp. 265-308, 1903.

[2]Lee, W. T., Underground Waters of Salt River Valley, Arizona: U. S. Geol. Surv. Water-Supply Paper 136, pp. 69-97, Pl. IX, 1905.

[3]Darton, N. H., A Reconnaissance of Parts of Northwestern New Mexico and Northern Arizona, U. S. Geol. Surv., Bull. 435.

ries, corresponding to the Bolsa quartzite of the region not far southeast of that locality. The relations in this region and elsewhere to the north

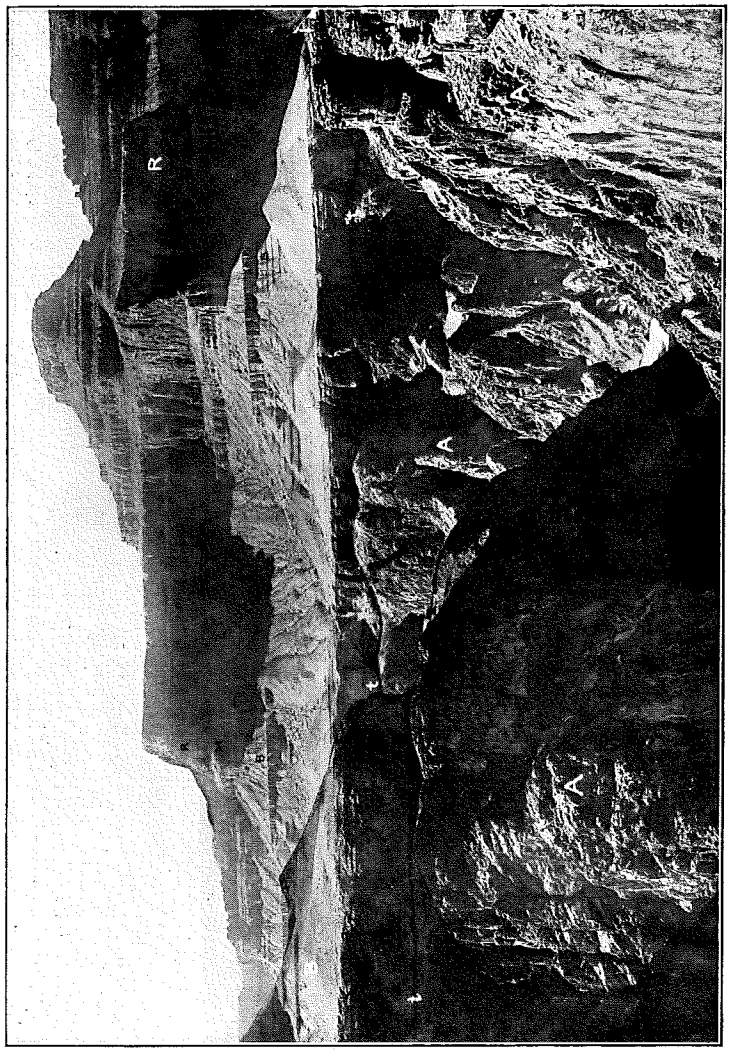


Plate 8b. Inner gorge of Grand Canyon of the Colorado River. A, pre-Cambrian schist overlain by Tapeats sandstone; t, contact, somewhat irregular; B, Bright Angel shale; M, Muav limestone; R, Redwall limestone overlain by Supai red beds.

indicate that there was a long interval between Troy and Mescal deposition, for chert from the latter and apparently also boulders of the Dripping Spring quartzite contributed to the basal conglomerate of the Troy.

CAMBRIAN SYSTEM

General Relations.—A large part of Arizona is occupied by rocks of Cambrian age, probably all late Cambrian. In various outcrop areas of the older crystalline rocks in the western, southern, and southwestern parts of the State the earlier Paleozoic strata have been removed by erosion, and they are also absent in the central and northeastern parts of the State where late Carboniferous rocks lie directly on the old granite and quartzites. There is

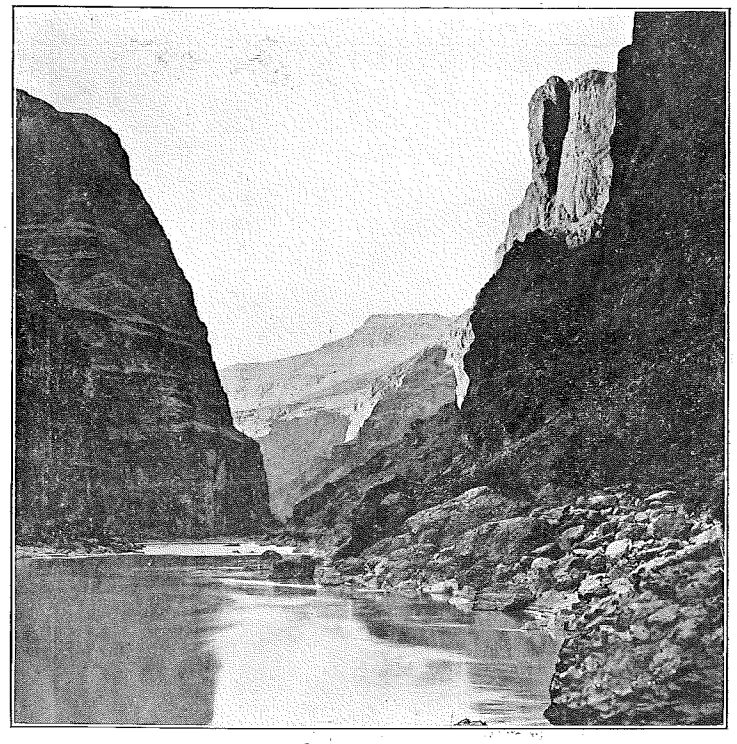


Plate 9a. Canyon of the Colorado River near the mouth of Kanab Creek. Looking west. The great cliff is Redwall limestone. In the distance are slopes of Supai formation, Hermit shale and Coconino sandstone; Kaibab limestone caps the plateau.

no direct evidence as to the original area of deposition, or the extent to which the sediments have been removed by erosion in the long interval of Ordovician, Silurian, and early Devonian time. It is evident, however, that ridges of the pre-Cambrian rocks persisted into or after Cambrian time, especially in the regions now occupied by the Defiance Uplift and in

the old quartzite ridge in the headwaters of Verde River. In many parts of Arizona the Cambrian rocks are deeply buried by later strata, volcanic rocks, and valley fill. They are extensively revealed in the Grand

Plate 9b. The Redwall cliff in Havasupai Canyon. Mooney Falls over travertine-covered cliff of lower Redwall beds. Slopes of Supai red beds. Distant point is outlier of high plateau of Kaibab limestone. Photo by R. E. Evans.

Canyon from the mouth of Marble Canyon to the Grand Wash Cliffs and thence southward for many miles in the Grand Wash Escarpment, Juniper Mountains, Verde Mountains, and Verde Breaks to the Jerome region.

Many detached outcrops occur in the high ridges in the southern part of the State from the Vekol Mountains eastward to the Chiricahua Mountains.

Tonto group.—The thousand feet or more of Cambrian strata exposed in the lower part of the Grand Canyon have long been known collectively as the Tonto group. The group has been divided by Noble[1] into the Tapeats sandstone at base, Bright Angel shale in middle, and Muav limestone at top. These formations are extensively exhibited from Marble Canyon to the lower end of the Grand Canyon, and in a wide area of the plateau country to the west and south. The two upper formations thin out in the Juniper Mountains south of Seligman, but the Tapeats sandstone is conspicuous in the Jerome region and its supposed representative reappears in the Tonto Basin. Possibly it extends much further southeast.

Throughout the Grand Canyon the general succession of strata in the Tonto group is remarkably uniform, but there is more or less variation in local members. Mr. Noble[2] has given a number of very detailed sections from Bass Trail south of Shinumo Creek to Cottonwood Creek. A condensed list of the more salient features of the section near the former place is as follows:

SECTION OF TONTO GROUP IN THE SHINUMO REGION

(After L. F. Noble)

		Feet
Muav limestone	Dolomite, buff, massive (cliff)	63
	Calcareous sandstone, fine-grained, buff, massive at top, platy below	72
	Limestone, thin-bedded, mottled, with thin members of intraformational conglomerate, platy micaceous and calcareous sandstone or shale	241
	Limestone, thin-bedded, gray to buff, mottled, partings of greenish, sandy shale near base	97
Bright Angel shale	Shale and thin-bedded sandstone, greenish and buff with beds of intercalated impure mottled limestone and snuff-colored dolomite at base	58
	Shale and sandstone, thin-bedded, greenish and buff, micaceous with 2 beds of snuff-colored dolomite and sandstone in middle portion	333
Tapeats sandstone	Sandstone, cross-bedded, white	35
	Sandstone, chocolate, with shaly partings	43
	Sandstone, chocolate, cross-bedded, mostly hard and massive, up to	250
		1192

[1]Noble, L. F., *op. cit.*, U. S. Geol. Surv. Bull. 549, pp. 61-65.

[2]Noble, L. F., A Section of the Paleozoic Formations of the Grand Canyon at the Bass Trail: U. S. Geol. Surv. Prof. Paper 131, p. 26, Pl. XIX, 1922.

In Gilbert's[1] section at the western end of the Grand Canyon 760 feet of strata are assignable to the Tonto group.

In most parts of the Grand Canyon and along the western and southern margin of the Arizona Plateau, the Tapeats sandstone lies on a wonder-

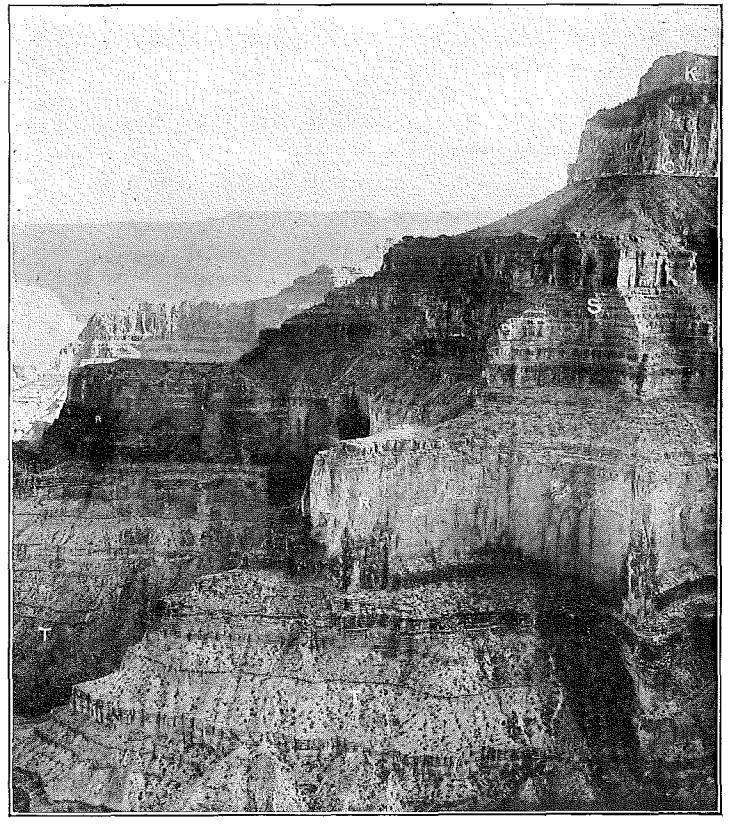


Plate 10. South wall of Grand Canyon of the Colorado River not far east of El Tovar, showing strata from Tapeats sandstone to Kaibab limestone. Looking east. K, Kaibab limestone; C, Coconino sandstone lying on Hermit shale; S, Supai red beds; R, Redwall limestone in 500-foot cliff; T, limestone (Muav) and shale (Bright Angel) of Tonto group. High plateau of Kaibab limestone in distance.

fully smooth surface of the old granite or schist. (See Pls. 2, 8, 45, 47.) From Tapeats Creek at intervals to Marble Canyon it lies across the planed-off edges of the tilted Grand Canyon series, but in places in that

[1]Report U. S. Geogr. Surv. West of 100th Mer., vol. 3 Geology, 1875, p. 163 and fig. 82.

area old ridges of the latter rocks, several hundred feet high, project above the sandstone into the overlying shales. Such a feature is shown in Plate 3. Noble[1] describes as follows a typical contact of this kind in the southern wall of Hotauta Canyon, near Colorado River, where the Tapeats sandstone abuts against a cliff of Shinumo quartzite: "At the base of the cliff huge, angular blocks of Shinumo quartzite are incorporated in the Tapeats sandstone in places where they fell and lodged; farther out lie masses of boulders, worn and rounded by the pounding of the waves, and these boulders run into lenses of fine, pebbly conglomerate, representing the shingle of the ancient beach dragged out by the undertow. No more striking example of a sea cliff could be imagined."

According to Noble, the buff, massive sandstone member at the top of the Muav extends 25 miles or more east, to beyond Pipe Creek, the overlying Devonian sediments lying on its eroded surface. The individual members of the Muav limestone show great persistence to the east of Cottonwood Creek, with some variations in thickness, there being a general diminution in total thickness of this and the other formations of the group to about 800 feet on Cottonwood Creek. At this place the Tapeats sandstone is 200 feet thick, and it lacks the shale partings in its upper portion. According to Walcott[2] the total thickness of the Tonto beds on Nunkoweap Valley is 1050 feet, of which 425 feet are now regarded as Muav.

Lee[3] found 80 feet of Tapeats sandstone at the mouth of the Grand Canyon with the overlying shales about 600 feet thick, while about 12 miles further southwest, at the base of the tilted block through which Iceberg Canyon is cut, the sandstone is 80 feet thick, and the overlying shale is only 200 feet. A few miles north of Music Mountain Lee found the sandstone 50 feet and overlying shale 300 to 400 feet thick. Near the south end of the Juniper Mountains the basal sandstone is about 100 feet and the shale about 225 feet thick.

At Cross Mountain 250 feet of Tonto beds are capped by the basal member of the Redwall. The upper half consists of limestones and shales with many fossils. Northeast of Mount Hope a basal sandstone about 100 feet thick is overlain by 150 feet of alternations of shale, sandy shale, and soft sandstone. Along the fault southwest of Seligman the upper member contains considerable limestone which disappears to the east; near Partridge Wash southwest of Ash Fork the strata between Redwall and granite are about 150 feet of sandstone, mostly coarse and cross-bedded and doubtless all Tapeats.

In the Jerome region Ransome[4] found that the Tapeats consist of 75 to

[1]Noble, L. F., *op. cit.*, U. S. Geol. Surv. Bull. 549, p. 62.

[2]Walcott, C. D., *op. cit.*, 10th Ann. Rpt., p. 584.

[3]Lee, W. T., *op. cit.*, U. S. Geol. Surv. Bull. 352, p. 19.

[4]Ransome, F. L., *op cit.*, U. S. Geol. Surv. Prof. Paper, 98k, p. 161.

80 feet of dark red, cross-bedded, pebbly sandstone, and Reber[1] found that its thickness varies from 0 to 100 feet in the extensive outcrops along the middle slopes of the plateau south and west of Jerome. The latter observer called attention to some red or greenish-yellow shale above the sandstone in this area which appears to be the remains of a greater mass, possibly the basal part of the Bright Angel shale.

In 1921 I examined the Tonto section in the upper part of the canyon of Bright Angel Creek. At this place the Muav limestone presents alternations of shale, limy shale, and slabby limestone, the latter weathering to a pale bluish-gray color, with brown reticulating stains and blotches

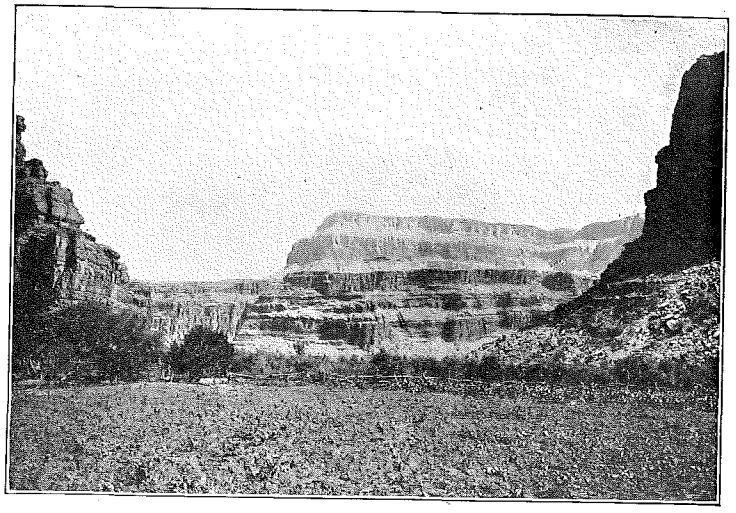


Plate 11a. Walls of Havasu (Cataract) Creek near Supai Indian village. Looking north to Urqualla Point. Type locality of Supai formation. Distant cliffs of Coconino sandstone capped by Kaibab limestone; shows softer member in middle of the latter.

on the surface; it strongly resembles the very characteristic El Paso limestone of New Mexico and the medial and upper members of the Longfellow and Abrigo limestones of southeastern Arizona.

Rocks of the Tonto group were examined at many places in the western part of the Arizona plateau. In Peach Springs Draw and the lower part of Diamond Creek the Tonto beds above the Tapeats sandstone are about 800 feet thick. They consist of shale with much limestone, a large part of which is the typical slabby, mottled kind, weathering to a bluish gray. These beds are exposed nearly continuously to and beyond Peach Springs, as well as in the Grand Wash Escarpment from Music Mountain northward to and beyond Colorado River. They are brought up by the fault at the foot of Aubrey Cliff west of Seligman, and exposed extensively

[1]Reber, L. E., *op. cit.*, pp. 7 and 11.

along Chino Wash and in Cross and Juniper mountains and Black Mesa. At all these places I found that the very peculiar and distinctive slabby, gray limestones are closely similar to the El Paso limestone of western New Mexico. They thin out and disappear in the lower part of the Chino Valley. In a boring at Peach Springs Station Tonto beds are about 1000

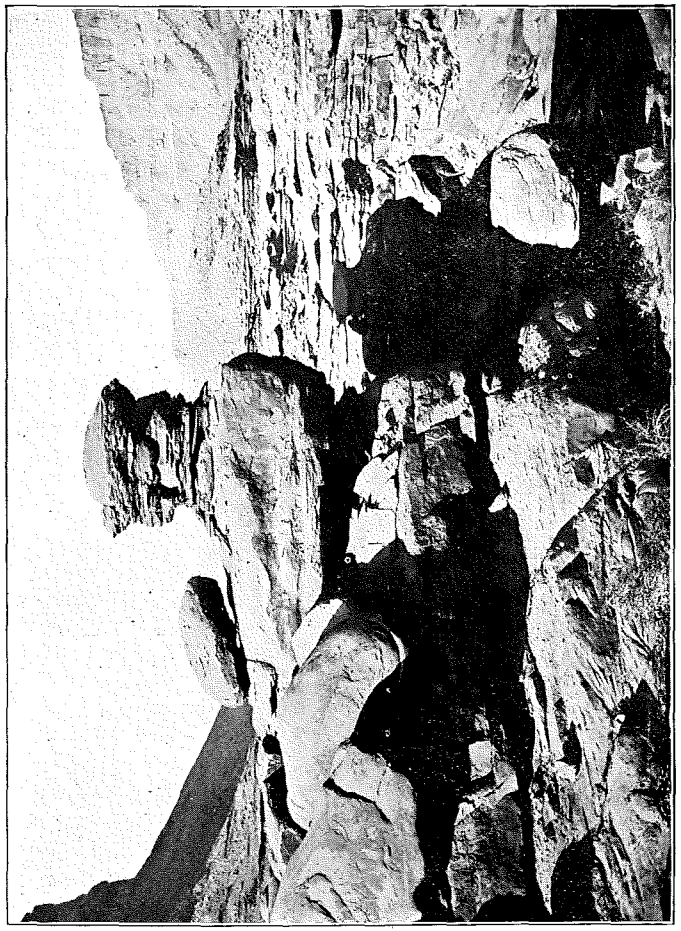


Plate 11b. Supai formation in valley of Kanab Creek. To right are slopes of Hermit shale and cliffs of Coconino sandstone and Kaibab limestone.

feet thick, for granite was reached at 1003 feet. The Tapeats sandstone appears to be the only representative of the group in the Tonto and upper Verde basins, and in the latter it abuts against pre-Cambrian quartzite in a buried ridge which protrudes near Pine and in the head of Tonto Basin. (See page 249.) East of this ridge are rocks of the Apache

group, of which the top sandstone (Troy, or overlying the Troy) may possibly represent the Tapeats. In this area, however, the underlying beds are Mescal limestone and Dripping Spring quartzite, as described on page 234.

Coronado quartzite.—The basal Paleozoic strata in the Clifton-Morenci district have been termed the Coronado quartzite.[1] They consist chiefly of heavy beds of quartzitic sandstone of brown, pink, or maroon tints, locally conglomeratic at the base, and varying in thickness from 100 to 250 feet. The formation caps Coronado Mountain and other summits of Coronado Ridge, and appears in various detached areas about Clifton and Morenci, the largest being in Copperplate Gulch southwest of Metcalf. It attains its maximum thickness of 250 feet near Morenci, but is less than 150 feet thick near the mouth of Apache Gulch due south of Morenci, where the basal conglomerate is lacking and the sandstone lies directly on the granite.

Some small shells, determined by C. D. Walcott as *Lingulella*, of Cambrian age, were obtained in olive shale 25 feet below the top of the quartzite on Chase Creek, a mile northeast of Morenci. In general the formation is to be correlated with the Bolsa quartzite and other sandstones at the base of the Paleozoic section in Arizona, but precise equivalence has not been established.

Bolsa quartzite.—Ransome has separated the basal sedimentary formation in the Bisbee[2] and Tombstone[3] regions as the Bolsa quartzite. It consists of silicified sandstone, with a thin bed of basal conglomerate lying on pre-Cambrian schists. The formation has a thickness of 430 feet in both districts. The basal conglomerate, from 6 inches to a foot thick, consists mostly of pebbles of white vein quartz from a half-inch to 2 inches in diameter; next above is coarse sandstone with scattered pebbles or pebbly streaks; the middle and upper members are thinner-bedded, finer-grained quartzites, which are overlain by the Abrigo limestone with apparent conformity.

No fossils were found in the Bolsa quartzite, but from its position below the Abrigo limestone it is believed to represent a portion of Upper Cambrian time and to be approximately, if not precisely equivalent to similar basal sandstone such as the Tapeats sandstone and the Coronado quartzite.

Schrader[4] has described outcrops of quartzite of supposed Cambrian age near Helvetia in the northern part of the Santa Rita Mountains,

[1] Lindgren, W., The Copper Deposits of the Clifton-Morenci district, Arizona, U. S. Geol. Surv. Prof. Paper 43, pp. 59-62, 1905.

[2] Ransome, F. L., Geology and Ore Deposits of the Bisbee Quadrangle: U. S. Geol. Surv. Prof. Paper 21, 1904, and Bisbee Folio, Geologic Atlas of the U. S., No. 112

[3] Ransome, F. L., Paleozoic Sections, U. S. Geol. Surv. Prof. Paper, 98k p. 145, 1916, and Bull. 710, p. 101.

[4] Schrader, Frank C., Mineral Deposits of the Santa Rita and Patagonia Mountains, Arizona: U. S. Geol. Surv., Bull. 582, pp. 44-47.

where I have found that part of the overlying limestone is unmistakable Abrigo. The quartzites, which rest on granite, are pink to dark red in color and in part conglomeratic, especially at the base, while the upper beds are slabby. The thickness as given by Schrader is 700 feet, but it appeared less to me. These rocks also crop out near Cuprite Mine, 6 miles northeast of Helvetia, and in Davidson Canyon 4 miles farther east, and

Plate 12a. Limestone member near lower part of Supai formation on Carrizo Creek above Saul's Store 25 miles northwest of Fort Apache, Arizona.

on the summit of San Cayetano Mountain 12 miles north of Nogales. Schrader suggests that some reddish and greenish shales just west of Old Baldy are of Cambrian age because they appear to be conformably overlain by Paleozoic limestones.

Abrigo limestone.—The lowest limestone succession in the Bisbee region has been designated the Abrigo limestone by Ransome,[1] with type locality in Abrigo Canyon, 3 miles southwest of Bisbee. The best exposure in

[1]Ransome, F. L., U. S. Geol. Surv. Prof. Paper 21 and Bisbee folio, *loc. cit.*

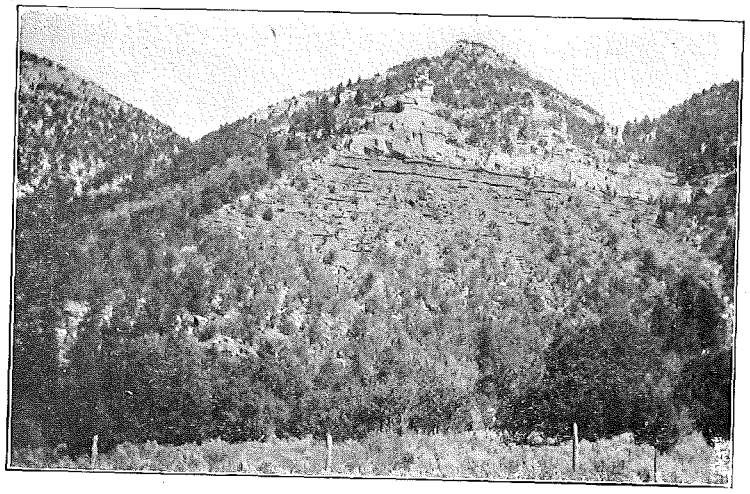


Plate 12b. Supai red beds, Coconino formation, and Kaibab limestone on uplifted side of fault 3 miles south of Ryan, Arizona, looking east. C, Coconino sandstone.

that vicinity is in the slope of Mount Martin, 1½ miles west of Bisbee, (as shown in Plate 6b,) where the thickness is 770 feet. The dip of the strata is the same as that of the overlying Martin limestone (Devonian), as well as of the underlying Bolsa quartzite.

The formation is characterized by slabby bedding, with many thin interlaminated layers of chert, as shown in Plate 7b. Much of the rock also weathers to a pale gray color. At the top is white quartzite about 8 feet thick, into which the limestone grades. The upper member of the latter is rather soft, sandy, thin-bedded, gray limestone, with one bed of harder, gray limestone about 40 feet below the top.

Ransome[1] has recognized the Abrigo limestone in the Tombstone region where the thickness is 700 feet, and as shown in Plate 7b, the same general characteristics are presented. The top quartzite is slightly thinner than at Bisbee.

In the north end of the Tucson Mountains (Picacho de la Calera—see section in Fig. 96), I found well characterized Abrigo beds containing Cambrian fossils. They are separated from the Pinal schist by 200 feet of quartzite, as described by Jenkins and Wilson. At this locality I also collected Devonian fossils from the overlying shaly limestone.

I also have found rocks closely resembling the Abrigo formation and undoubtedly equivalent to it, on the south side of the Santa Catalina Mountains near Shaw's Ranch, as well as on the northeast slope of that range, in the Vekol Mountains, and lying on Troy quartzite in the canyon

[1]Ransome, F. L., U. S. Geol. Surv. Bull. 710, p. 101.

of the Gila River just below Needle's Eye. At all these places Upper Cambrian fossils were collected.

Fossils and correlation.—Fossils from various horizons in the Tonto strata are now regarded as Upper Cambrian by C. D. Walcott and C. E. Resser.[1] The localities in the Grand Canyon from the Shinumo region to Cottonwood Creek have been described by Noble.[2] Some of the principal facts are as follows: In the exposures in the lower part of Kanab Creek Walcott[3] reported *Lingulepsis prima*, *Conocephalites*, and *Bathyurus* in upper beds (probably Muav) and *Hyolithes primordialis?*, *Lingulepsis prima?*, *Crepicephalus*, *Conocephalites*, and *Bathyurus* in lower members, probably middle Bright Angel shale. Walcott[4] reported the following fossils from near the base of strata evidenly Bright Angel shale in his section of Nunkoweap Valley: *Lingulella*, *Acrothele*, *Iphidea ornatella*, *Hyolithes*, *Leperditia* (three species), *Dilichometopus*, *Olenoides*, and *Ptychoparia*, and in the upper beds of mottled limestone (Muav), *Lingulepsis* and *Ptychoparia*.

Noble[5] reports from beds near the middle of the Muav limestone on Hermit Creek, the following fauna identified by Kirk: *Finkelnburgia sp.*, *syntrophia sp.*, *Anomocarella sp.*, *Pagodia? sp.*, and *Ptychoparia ? sp.*, and slightly lower in the formation at the same place, Schuchert obtained pygidia of *Saukia* and *Neolenus*, all of which are regarded as Upper Cambrian. Fossils obtained by Walcott from "300 feet above the base" of the group in Nunkoweap Valley were probably from the top or not far above the top of the Tapeats sandstone. They were as follows:[6]

Dolichometopus tontoensis	Obolus (Westoria) chuarensis
Micromitra pealei	Obolus (W.) englyphus
Micromitra (Paterina) crenistria	Linguella lineolata
	Linguella perattenuata
Micromitra (P.) superba	Billingsella obscura
Micromitra (Iphidella) pannula	Alokistocare althea

Fossils collected near Bisbee by Ransome are now regadred as Upper Cambrian. I collected from the middle of the formation at Bisbee the following fossils determined by Edwin Kirk: *Dikellocephalus*, sp. *Eoorthis Wichitaensis*, and *Obolus*, sp. an Upper Cambrian fauna.

Upper Cambrian fossils found in Abrigo beds, or strata equivalent to them, at various points in central Arizona, were determined as follows by C. E. Resser:[1]

Sandstone above Troy quartzite at Needle's Eye on Gila River, 23 miles

[1]Personal communication Nov. 5, 1924.

[2]Noble, L. F.: U. S. Geol. Surv. Prof. Paper 131-b.

[3]Walcott, C. D., The Permian and Other Paleozoic Groups of the Kanab Valley. Arizona: Am. Jour. Sci., 3d ser., vol. 20, pp. 221-225, 1880.

[4]Walcott, C. D., Fauna of the Lower Cambrian or Olemullus Zone: U. S. Geol. Surv., 10th Ann. Rept., pt. 2, p. 584, 1890.

[5]Noble, L. F., *op. cit.*, U. S. Geol. Surv. Prof. Paper 131, pp. 48-49.

[6]Walcott, C. D., Cambrian Geology and Paleontology: Smithsonian Misc. Coll., vol. 64, No. 5, pp. 373-374, 1916.

southeast of Globe: *Lingulepis spatula*, a species found by Walcott in the Bright Angel shale.

North slope Jerusalem Mountain, 25 miles southeast of Globe: *Obolus (Westonia) chuarensis*, Walcott and *Hyolithes* sp.

Shaw's Ranch, 5 miles east of Vail: *Hyolithes?*, *Linkulella sp.*, *Inouyia? sp.*, *Emmrichella? sp.*, and *Lisania? sp.*

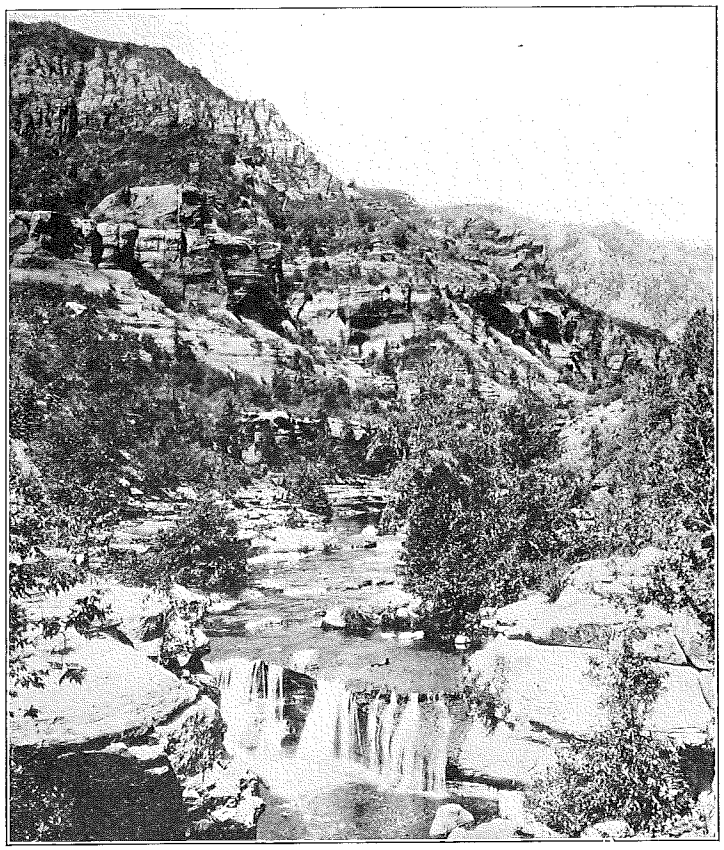


Plate 13. Supai red beds and Coconino sandstone. Oak Creek 5 miles above Sedona, Arizona. Looking north.

One half mile east of Shaw's Ranch: *Hyolithes n. sp.*, *Paragraulos? sp.*, and *Dicellomus? sp.*

North end of Tucson Mountain, 20 miles west of Tucson: *Lingulella sp.* and fragments of trilobites.

Vekol Mountains, 1 miles northwest of Reward Mine: *Dicellomus sp.* and *Lingulella sp.*

Mr. Resser suggests[1] the possibility that some of this material might prove to belong to the Ozarkian system of Ulrich.

In quartzites not far below the Martin limestone in Ash Creek, 8 miles east of Winkleman, C. P. Ross in 1922 collected fossils, determined by Edwin Kirk as *Obolus* sp. and *Lingulella* of the Upper Cambrian.

Limestone, 2 miles south of Tule Spring, 8 miles southeast of Oracle. Arizona: *Obolus* sp. and fragments of trilobites, "probably Upper Cambrian."

Resser[1] after a recent re-examination of the Bisbee material states that part of it is a fauna that appears elsewhere only in Montana and Wyoming and while for the present it may be considered as Upper Cambrian it may possibly be younger. Collections from Tombstone Gulch northwest of

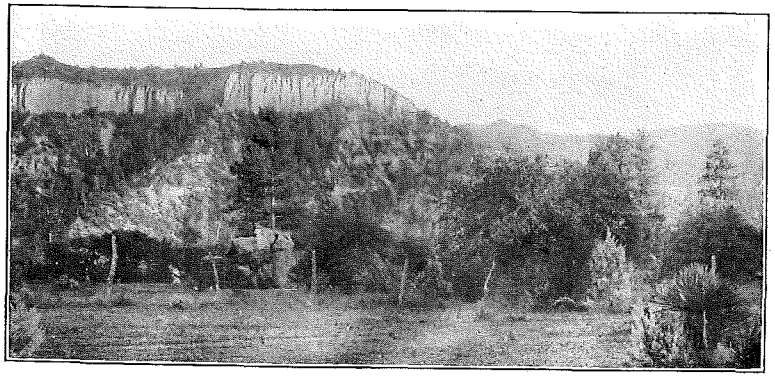


Plate 14a. Limestone member in upper part of Supai formation, east wall of canyon of North Fork of White River just above mouth of Diamond Creek. Looking east.

Bisbee contain Walcott's new genera *Maladia* and *Irvingella*, which are Upper Cambrian, and the Upper Cambrian form *Crepicephalus* was included in material from Moore's Gulch.

From an examination of the Tonto rocks at many localities on both sides of the Grand Canyon and along the slopes of the plateau west and south, I am greatly impressed with the close lithologic similarity of the limestone of the Muav formation with the Abrigo and Longfellow limestone in the southeastern part of Arizona and the El Paso limestone in southwestern New Mexico. If these limestones were of commonplace character the resemblance would be unimpressive, but they are very peculiar in aspect, especially in the outcrops. The combination of slabby bedding, light blue-gray weathering, and very peculiar brown reticulated

[1]Personal communication, February 7, 1924.

stains and thin layers of silica on the bedding planes common to these formations is unique in my experience. At all localities these El Paso limestone peculiarities are apparent in a considerable thickness of Muav beds. I found them at all points visited, not only in the Grand Canyon, but along the Grand Wash Cliffs, the Virgin Mountains, the Juniper Mountains, and Cross Mountain southwest of Seligman. Some members of the Abrigo show them not only at the type locality about Bisbee, but in the Whetstone, Dragoon, Tucson, Vekol, Patagonia, Swisshelm, Santa Catalina, and Chiricahua mountains. The greater part of the Longfellow limestone in the Morenci region has the same striking characteristics.

The evidence of fossils is not entirely adverse to this correlation. The El Paso has been classed as Lower Ordovician, but I believe that the lower member will yield Upper Cambrian fossils, as in the case of the lower beds of the Longfellow limestone. Fossils so far collected from the

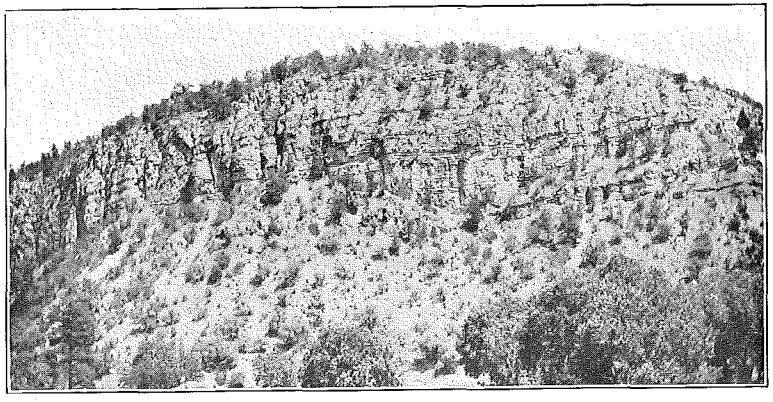


Plate 14b. Limestone member in upper part of Supai formation on Cedar Creek 15 miles northwest of Fort Apache, Arizona.

Muav and Abrigo limestones are Cambrian, but it is possible that higher beds may yield younger forms, or that upper beds of Ordovician age have been removed by erosion during the long period of Ordovician, Silurian, and early Devonian time. Moreover, some or all of the fossils so far reported may have greater stratigraphic range than has been supposed, at least some of them persisting into early Ordovician time in regions where physical conditions were not changed. It should be noted that many of the genera listed are queried and most of the species either queried or indeterminate. In a case of this sort I have more faith in the lithology than in the fossils. The Muav, Longfellow, Abrigo, and El Paso limestones appear to me to represent the same stratigraphic unit, with possibility that more or less of the upper beds are locally removed by erosion, especially to the west and northwest

where the Ordovician to Devonian hiatus is greatest. Owing to the possibility of this difference of upper limit of the several formations there can be no question as to the desirability of retaining the various local names for the several limestones, at least for the present.

EARLY PALEOZOIC UNCONFORMITY

(Ordovician to Early Devonian)

In a large part of Arizona there is a great hiatus in the early Paleozoic sedimentary succession, the later Devonian or Carboniferous formations lying unconformably on strata of the Tonto or the Apache group, or on the Abrigo or Longfellow limestones. The unconformity is marked by planation with some local channelling, but the underlying and overlying strata show no notable discordance in attitude. In some regions all the representatives of Devonian, Silurian, and much or all of the Ordovician are absent, but there are extensive areas of later Devonian in parts of

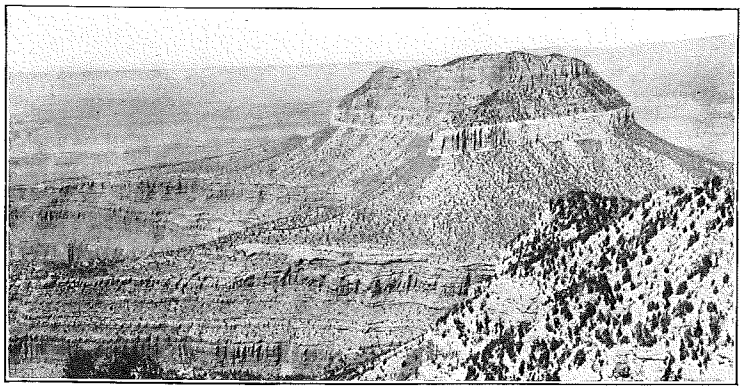


Plate 14c. Steamboat Rock, Tapeats Amphitheatre northwest of Powell Plateau. Looking northwest. Light cliff in middle is Coconino sandstone, with Kaibab limestone above and slope of Hermit red shale below. Photo by L. F. Noble.

northern and southeastern Arizona. Some of the earlier Ordovician is represented in the Longfellow limestone, and I believe in part, at least, of the Abrigo limestone. Apparently this unconformity is most pronounced in southwestern Arizona, where the hiatus is somewhat greater than in regions north and east. It is not unlikely that various formations of later Ordovician, Silurian, and Devonian age were deposited over a wide area of the Southwest and removed during subsequent periods of uplift.

The early Paleozoic unconformity is well exposed at the base of the Redwall limestone (Mississippian) in the Grand Canyon, where many

remnants of Temple Butte limestone (Devonian) lie on the Muav limestone (Upper Cambrian). Walcott[1] observed this in the Chuar and Kanab regions, and Noble[2] has described in detail such relations at various points between the Shinumo region and Grand View.

In mapping the geology of the Christmas Quadrangle southeast of Globe, I have found some very instructive exposures of the unconformity at the base of the Devonian (Martin) limestone. This formation lies on the Troy sandstone without notable difference in attitude but locally there are sharp unconformities with development of breccia in the base of the limestone. In the south slope of the Mescal Mountains near longitude 110° 43′ the Troy quartzite is entirely removed for a short distance and on the south slope of Hayes Mountain near longitude 110° 38′ the limestone extends across the edges of Troy quartzite, Mescal limestone, Dripping Spring quartzite, and Barnes conglomerate, and lies on the thick diabase sill which is intruded near the base of the Apache group. Huge boulders of all these rocks are included in a basal conglomerate. The deep planation at this place was caused by increased uplift due to pre-Devonian (Apache) diabase intrusion. Some features of these overlaps are shown in Fig. 76, page 256.

ORDOVICIAN SYSTEM

General statement.—Although the only Ordovician fossils so far observed by me in Arizona were obtained near Morenci and Dos Cabezas and probably in the Vekol Mountains, it is likely that limestones of that age underlie a considerable portion of the eastern part of the State, a continuation of the El Paso limestone of New Mexico. The strata yielding fossils at Dos Cabezas and in the Vekol Mountains appear to be an upper member of the Abrigo limestone, although the latter in its type locality near Bisbee has yielded only Upper Cambrian fossils.

In this limestone below the Martin (Devonian) beds, 2 miles west of the village of Dos Cabezas, I collected numerous fossils of Ordovician age, determined by Edwin Kirk as *Polygyrata rotuliformis* Meek and siphuncles of *Endoceras sp.*

Longfellow limestone.—Ordovician fossils were first discovered by Lindgren[3] in the vicinity of Morenci. The beds containing them, together with underlying strata containing probable Upper Cambrian fossils, were defined as Longfellow formation of Ordovician age. It consists of about 400 feet of limestone, more or less dolomitic in character, and more silicious in the lower than in the upper beds. "The upper 150 feet always form a prominent cliff of brownish limestone while the lower 250 feet contain more shaly strata usually forming a more gentle slope." It forms bluffs along San Francisco River above Clifton

[1]Walcott, C. D., *op. cit.*: Prof. Paper 131-b.
[2]Noble, L. P., *op. cit.*: Prof. Paper 131-b.
[3]Lindgren, W., *op. cit.*, Prof. Paper 43, pp. 62-66.

and occurs in faulted blocks at the foot of Copper King Mountain, east and south of Morenci, and north of Gold Creek on the slope toward Eagle Creek. Smaller areas appear at various points in the district. In a section in Chase Creek Canyon 2 miles north of Metcalf, where only 140 feet appear to be present, the upper part is heavy, brown limestone, the middle is gray, sandy limestone, and the lower member is limy shale.

The fossils obtained by Lindgren in yellowish-gray, shaly limestone about 25 feet above the base were determined by E. O. Ulrich as follows: *Raphistomina?*, *Ophileta sp.*; *Dalmanella cf.*, *D. hamburgensis*; *Camarella* or *Syntrophia sp.*; *Endoceras?*, *Asaphus*, early type; *Dikellocephalus?*, and a larger trilobite related to *Bolbocephalus*. Four miles west of Morenci flat gastropods similar to *Raphistomina* were obtained. The material was fragmentary and poorly preserved, but it is regarded as indicating early Ordovician (Beekmantown) age. In the lower shale, about 20 feet above the Coronado quartzite, were obtained *Lingulae* which Walcott regarded as probably Cambrian. This evidence appears to indicate that the Longfellow limestone represents sedimentation extending from late Cambrian into early Ordovician time, although it is quite possible that there exists an unconformity between the strata of these two periods.

I examined these rocks in 1919 and was deeply impressed with the strong resemblance of the Longfellow and El Paso limestones. Many of the Longfellow beds had the characteristic slabby bedding and light colored weathered surfaces covered with brown reticulations of a probable fossil seaweed, features which are highly distinctive. Moreover, the same fauna was present, including numerous fossils determined by E. Kirk as *Polygyrata rotuliformis*, *P. trohiscus*, and a probable *Endoceras*, all early Ordovician forms. I found precisely similar features in the limestones underlying Martin limestone a short distance west of Dos Cabezas, yielding the fossils above mentioned

SILURIAN SYSTEM

No strata of Silurian age have been found in Arizona and this period appears to be fully represented by the unconformity between the Abrigo-Longfellow-Muav limestones and the later (Devonian) Martin limestone. The nearest exposures of Silurian strata are at Silver City and several points in the southern part of Grant County,[1] New Mexico, and it is not unlikely that the strata extend under the desert fill and volcanic rocks in the extreme eastern part of Arizona. It is also possible that they are present in the Chiricahua Mountains, which I have not examined.

The Silurian reported by Reagan[2] in the Apache Indian Reservation was found to be Martin limestone. Fossils supposed to be "*Orthis davidsoni*" and "*Strombodes pentagonus*" are incorrect identifications of Devonian forms.

[1]Darton, N. H., Geologic Structure of Parts of New Mexico: U. S. Geol. Surv. Bull. 726 (e), pp. 274-275, 1922.

[2]Reagan, A. B., *op. cit.*, p. 278.

DEVONIAN SYSTEM

General relations.—Limestones of later Devonian age have been found at many places in Arizona. They have not been recognized in the southwestern corner of the State west of longitude 112°, but may be present in the succession of more or less metamorphosed limestones in that region. They were found on Canyon Creek, Gila County, a short distance below Ramer (Wallace) Ranch. The thickness here is about 60 feet and this is the easternmost exposure of the horizon in the base of the Mogollon Escarpment. They are absent in the northeastern part of the State where, in the Defiance uplift region at least, the Permian rocks lie directly against the pre-Cambrian, but their absence here may be due to removal by erosion in early or middle Carboniferous time. The strata so far recognized lie on an eroded surface of Upper Cambrian rocks, and in Gila County and some immediately adjoining areas, on the Troy quartzite of the Apache group. They are also absent in parts of the Grand Canyon district, but whether their absence is due to non-deposition or to removal prior to the deposition of the next succeeding limestone, is not ascertained. So far as observed the Devonian limestone is succeeded with apparent conformity by limestone of early Mississippian age, but whether or not there is transition from one to the other is not determined. It is very difficult to find a plane of separation. The Devonian strata in Arizona have been designated Temple Butte limestone in the Grand Canyon, Martin limestone in the central and southeastern part of the State, and Morenci formation in the Clifton-Morenci district.

Temple Butte limestone.—Remnants of Devonian strata have been found at several places in the Grand Canyon, where the formation is known as Temple Butte limestone, the type locality being in Temple Butte, a plateau remnant lying between Chuar Valley and Colorado River, a short distance below the mouth of the Little Colorado. Walcott[1] discovered these Devonian rocks in 1879[2] at Kanab Creek where they consist of purple and cream limestone and sandstone passing upward into gray calciferous sandstone. They lie on a very irregularly eroded surface of the Muav limestone, with thickness up to about 100 feet. In 1882-83 Walcott[3] found Devonian beds in the portion of the Grand Canyon east of the Kaibab Plateau. He writes: "In places the Devonian is entirely absent, either through erosion or non-deposition, so that the Redwall limestone rests directly on the massive calciferous strata of the Upper Tonto. It rarely has a thickness of more than 100 feet. When present it is unmistakably marked by the thin purplish-colored layers of fine-grained sandstone that pass into calciferous sand rock and limestone in

[1]Walcott, C. D., Study of a Displacement in the Grand Canyon: Geol. Soc. Am., Bull., vol. 1, p. 50, 1890.

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

[3]Walcott, C. D., Pre-Carboniferous Strata in the Grand Canyon of the Colorado, Ariz.: Am. Jour. Sci., 3d ser., vol. 26, pp. 437-442, 484, 1883; U. S. Geol. Surv., 4th Ann. Rpt., p. 47, 1884.

which cyathophylloid corals, casts of brachiopods and gasteropods, and plates of placoganoid fishes usually occur."

Later observations by Noble[1] have brought to light many occurrences of remnants of Devonian strata, mostly occupying channels in the eroded upper surface of the Muav limestone. There is, however, difficulty in assigning an upper limit to the Devonian beds, for there is no noticeable evidence of unconformity to represent the hiatus which no doubt exists. The only fossils found by Noble were in Sapphire Canyon, 12 miles west of El Tovar, where an irregularly bedded calcareous sandrock fills an eroded depression 50 feet deep. The stratigraphy shows much variation from place to place, the beds being in lenticular layers,

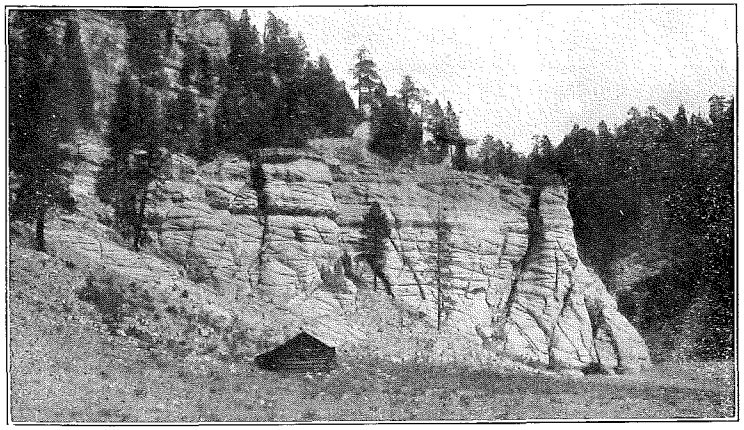


Plate 15a. Coconino sandstone showing characteristic cross-bedding. Walnut Canyon just east of fault 4 miles southeast of Flagstaff. Looking east.

commonly wedging out in less than 100 feet, with many local unconformities. The prevailing color is purplish or purplish-gray, while some beds are green or yellowish, and others are white or cream. In places the colors are blotched or streaked. The texture is mostly fine, and there is cross-bedding and a peculiar, gnarled structure. This latter feature was also reported in the exposures in Turquoise Canyon and on Slate and Hermit creeks, where the formation is a distinct bed 20 to 25 feet thick overlapping adjoining knolls of Muav limestone. Noble reports that at Bass Canyon the Devonian strata consist of 75 feet of thin-bedded, purplish to white, sandy limestone, mottled in places by worm markings and including a few layers of conglomerate. The next overlying bed is brecciated limestone at the base of Redwall cliff, which Noble places in the Redwall limestone. In this vicinity the basal contact is essentially

[1]Noble, L. F., *op. cit.*, U. S. Geol. Surv. Bull. 549, pp. 65-66; Prof. Paper 131-b, pp. 51-53.

smooth, but in Grand Canyon to the west and Ruby Canyon to the east there is marked evidence of erosion.

In the western slope of Cope Butte, near Hermit Trail, Noble reports 14 to 76 feet of gravelly, purplish and white calcareous sandrock lying in eroded hollows in Muav limestone. This is overlain by 1 to 3 feet of sandy conglomerate composed largely of fragments of calcareous sandstone with uneven wavy base believed to be the basal member of the Redwall limestone.

Morenci formation.—In the vicinity of Clifton and Morenci the shale and limestone lying between the Ordovician and Mississippian strata have been designated the Morenci formation.[1] They appear to me to be the same as the Percha shale exposed not far east in New Mexico, and are undoubtedly equivalent to the whole or part of the Martin limestone of central and southeastern Arizona. The rocks consist of 100 feet of dark fissile shale underlain at most places by 75 feet of fine-grained impure limestone. The best exposures are about Morenci, on San Francisco River above Clifton, near Garfield Gulch, in slopes north of Coronado Mountain, and at the head of the south fork of Sardine Creek. The formation is accordant in attitude with the inclosing limestones although separated above and below by unconformities representing long periods of time.

Martin limestone.—Fossils of Devonian age were discovered by Blake, Schrader, and others in central and southern Arizona. In studying the Bisbee region Ransome[2] separated the Devonian strata as the Martin limestone, with type locality in Mount Martin near Bisbee (see Pl. 6b), and he has also applied the name in the Globe and Roosevelt Dam districts. In the Bisbee region the Martin limestone is exposed at intervals in Escabrosa Ridge and the line of ridges extending from Mt. Reilly to Gold Hill, where it has been mapped in detail. The formation consists largely of dark gray, compact limestone in moderately massive beds, with some slabby and shaly members particularly in the lower part. The thickness is 300 to 350 feet. The formation is sharply separated from the Abrigo formation by an abrupt change in material from limestone to quartzite, but the upper limit is less well defined and is largely covered by talus. There is no appreciable discordance in attitude with the adjoining formations. The more massive beds of Martin limestone are a fairly fine-grained rock consisting of calcium carbonate with but little silica and only a very small amount of magnesia.

In the Jerome area Ransome[3] found well characterized Devonian limestone, probably equivalent in whole or in part to the Martin limestone, lying on the Tapeats sandstone. The rocks are thin-bedded light yellow and very compact for 150 feet, grading up into darker gray lime-

[1]Lindgren, W., The Copper Deposits of the Clifton-Morenci District, Arizona: U. S. Geol. Surv. Prof. Paper 43, pp. 66-69, 1905; also Clifton Folio.

[2]Ransome, F. L., U. S. Geol. Surv. Prof. Paper 21, 1904, and Bisbee Folio No. 112, 1904.

[3]Ransome, F. L., U. S. Geol. Surv. Prof. Paper 98k., *op. cit.*, p. 161.

stones, some of which are sandy. The light gray bed about 350 feet above the base yielded abundant fossils of the Martin fauna. Ransome suggests that the total thickness of the Devonian in the Jerome area may be 500

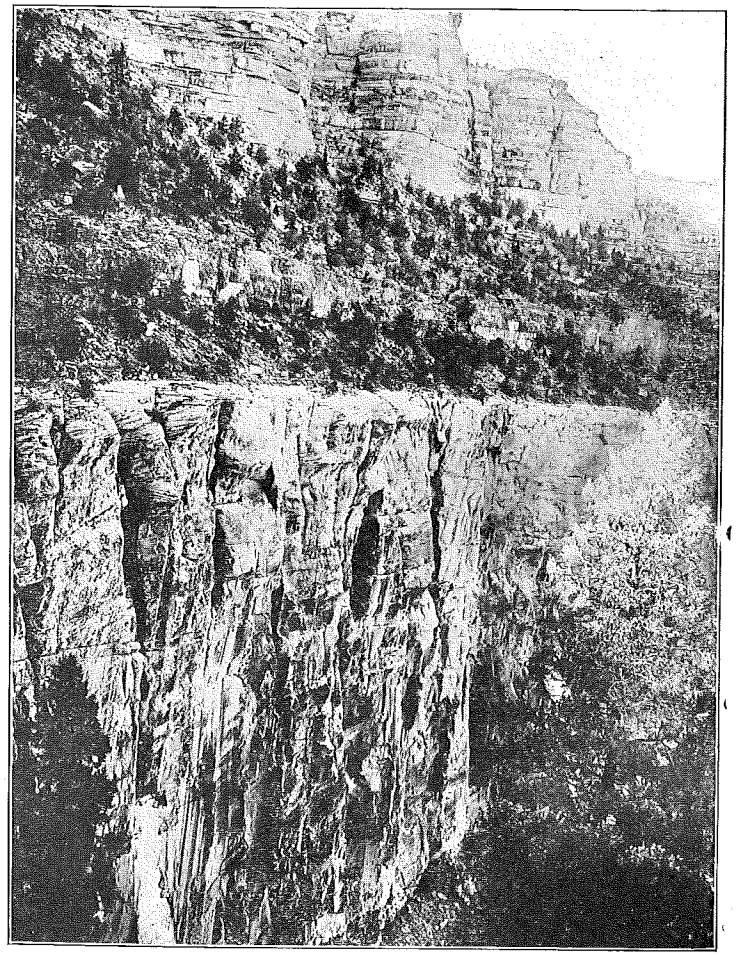


Plate 15b. Coconino sandstone cliff near El Tovar, a conspicuous feature all along the upper slopes of the Grand Canyon. It is 300 feet high and surmounted by slopes and cliffs of Kaibab limestone. The massive structure and cross-bedding of the sandstone are characteristic.

feet, but the upper limit at the base of the Redwall limestone is uncertain. In a section less than a mile northeast of Jerome, Reber[1] found

[1]Reber, L. E., Jr., *op. cit.*, p. 8.

the lower limestone member 300 feet thick, all somewhat magnesian, weathering to brownish color and with many sandy beds. Above this the limestone is white, fine-grained, non-magnesian, with cherty bands

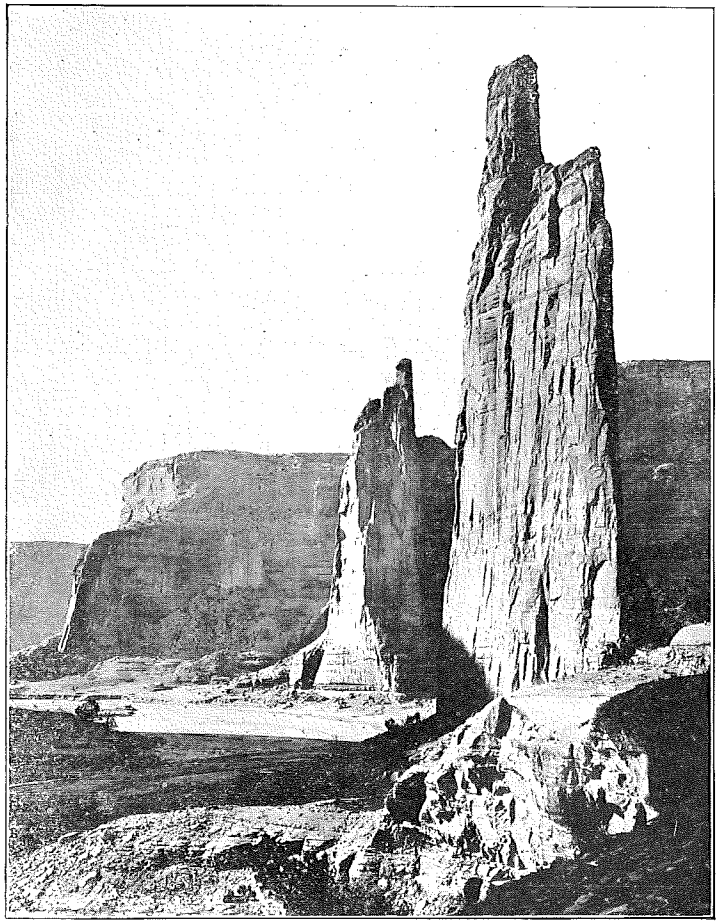


Plate 16. Coconino sandstone in walls of Canyon de Chelly, near mouth of Monument Creek east of Chinle, Arizona.

and free from sand, so it is suggested that the break between Devonian and Carboniferous is at the horizon of change of character of the beds.

Limestones of Devonian age occur at various places in the Empire Mountains, also in the Santa Rita Mountains near Helvetia and southwest of Greaterville,[1] and on the eastern slope of the Patagonia Mountains.

They also appear to extend along the northeast slope of the Canelo Hills.[2] They are mainly thin-bedded and of gray color, and while they contain characteristic fossils, their upper limit is somewhat uncertain.

I found distinctive strata containing Devonian fossils in a wide area of central and south central Arizona including the Salt River Basin, Black River Valley, Natanes and Mogollon plateaus, Galiuro, eastern Mescal, Whetstone, Dragoon, Santa Catalina, Tucson, and Slate mountains and possibly also the Sieretta Mountains. It seems likely that they will be discovered in the Vekol Range.

Fossils.—The Martin limestone yields fossils at most localities, especially the limy shale layers, from which in places numerous individual brachiopods weather out. Corals are also abundant, forming irregular pavements of considerable extent and in some cases weathering out on the slopes. Dumble[3] found Devonian fossils in the Dragoon and Whetstone mountains in southeastern Arizona, Reagan[4] discovered them in the Salt River region, and Blake[5] collected them in the Santa Rita Range.

The first large collection of Devonian fossils in central Arizona was made by Ransome[6] in 1900, from several localities in the Globe quadrangle. These, together with others collected by Mr. Ransome in the same general region, are combined in the following list:

Productella hallana,
Stropheodonta arcuata,
Stropheodonta demissa,
Stropheodonta varistriata calvini,
Leptostrophia cf. L. interestrialis,
Strophonella cf. S. ampla,
Schuchertella chemungensis,
Schizophoria striatula,
Atrypa reticularis,
Atrypa hystrix occidentalis,
Atrypa spinosa,
Camarotoechia sp.,
Pugnax pugnus,
Spirifer hungerfordi,
Spirifer orestes,
Spirifer whitneyi,
Recticularia fimbriata,
Cyrtina hamiltonensis,
Cyrtina cyrtiniformis,
Martinia subumbonata,
Schizodus sp.,
Dielasma cf. D. calvini,
Euomphalus cyclostomus?,
Bellerophon sp.,
undetermined crinoid stems, sponges, and corals.

These fossils were determined by H. S. Williams and E. M. Kindle, who regarded them as indicating Upper Devonian age and possibly also part of the Middle Devonian.

[1]Blake, W. P., Some Salient Features in the Geology of Arizona with Evidences of Shallow Seas in Paleozoic Time: Am. Geol., vol. 27, pp. 160-167, 1901.

[2]Schrader, F. C., *op. cit.*, pp. 47-49, and map, Plate II.

[3]Dumble, E. T., Notes on Geology of Southwestern Arizona, Trans. Am. Ins. Min. Eng., vol. 31, pp. 696-715, 1902.

[4]Reagan, *loc. cit.*, Am. Geol., vol. 32.

[5]Blake, W. P., Some Features in the Geology of Arizona, with Evidence of Shallow Seas in Paleozoic Time: Am. Geol., vol. 27, p. 164, 1901.

[6]Ransome, F. L., Geology of the Globe Copper District, Ariz.: U. S. Geol. Surv. Prof. Paper 12, pp. 40-42, 1903.

The following were collected by Ransome[1] and Kirk from Martin limestone at Roosevelt Dam:

Schuchertella,
Modiomorpha sp.,
Atrypa spinosa,
Schizophoria striatula var. australis,
Spirifer whitneyi var. animasensis,
Camarotoechia contracta
Cladopora sp.

A few poorly preserved fossils were obtained by Lindgren in the argillaceous limestone which constitutes the lower member of the Morenci formation in part of the Morenci region. H. S. Williams[2] found that these fossils included a *Schizophoria* cf. *ivanofi*, *Loxonema* sp., and probable *Zaphrentis* and *Pleurotomaria*.

The fossils collected from the Martin limestone at Bisbee were identified by Prof. H. S. Williams as follows:

Acervularia davidsoni, Milne-Edwards and Haime;
Pachyphyllum woodmani, White;
Cladopora prolifica, Hall and Whitfield;
Stromatopora erratica, Hall;
Cyathophyllum cæspitosum, Goldfuss;
Atrypa reticularis, Linné;
Cyrtia cyrtiniformis, Hall and Whitfield;
Dielasma calvini, Hall and Whitfield;
Schizophoria striatula, Echlotheim;
Productella speciosa, Hall;
Delthyris consobrina, D'Orbigny;
Spirifer cf. S. jeremejevi, Tschernyschew;
Spirifer hungerfordi, Hall;
Spirifer orestes, Hall and Whitfield;
Spirifer cf. S. euryteines, Owen, small specimen;
Spirifer whitneyi, Hall;
Stropheodonta demissa, Conrad;
Stropheodonta (fragilis) perplana, Hall;
Strophonella cælata, Hall.

Devonian fossils collected by E. Sampson[3] on the Salt River Draw at the head of the box canyon and on the south side of the Salt River at the mouth of Carrizo Creek comprise the following species, identified by E. Kirk:

Cladopora sp.,
Atrypa reticularis,
Spirifer whitneyi,
Spirifer hungerfordi,
Pugnax pugnus,
Gypidula comis,
Michelinia sp.,
Acervularia davidsoni,
Pachyphyllum near woodmani.

[1]Ransome, F. L., The Copper Deposits of Ray and Miami, Ariz.: U. S. Geol. Surv. Prof. Paper 115, pp. 46-47.

[2]Williams, H. S., *op. cit.*, Prof. Paper 43, p. 69.

[3]Personal communication.

Devonian fossils collected by me at various points in central Arizona were determined by Edwin Kirk, as follows:

1. Top limestone near fault on road 30 miles northeast of Globe, *Atrypa reticularis, Productella* sp., and *Gypidula cf. lotis.*
2. Black River Canyon, 2 miles below crossing of road from Ft. Apache to Rice, *Atrypa reticularis* and *Spirifer whitneyi.*
3. 100 feet above Troy quartzite northeast of Gilson Station, *Spirifer orestes.*
4. Northeast of Bottle Springs, 15 miles northeast of Young,
   Lot 1. *Schizophoria striatula* and *Spirifer* sp.
   Lot 2. *Atrypa reticularis* and *Stropheodonta* sp.
5. Lowest limestone on sandstone southwest of Tuttle Ranch, 8 miles southwest of San Carlos, *Stropheodonta* sp. and *Spirifer* sp.
6. 5 miles northwest of Tuttle Ranch, or 8 miles west of San Carlos, *Stropheodonta* sp. and *Zaphrentis* sp.
7. North end Tucson Mountain, 20 miles northwest of Tucson, *Atrypa reticularis.*
8. West side Sierrita Mountain, 30 miles southwest of Tucson, *Cladopora* sp.,
9. Arivaipa Canyon, near Buzan Ranch, *Camarotoechia endlichi, Productella coloradoensis, Athyris* sp. and *Spirifer whitneyi.*
10. Canyon Creek below Ramer (Wallace) Ranch, *Acervularia davidsoni, Atrypa reticularis, Spirifer whitneyi, Productella hallana* and *Schizoporia striatula.*
11. Slate Mountain south of Casa Grande, *Atrypa reticularis, A. hystrix, Spirifer whitneyi, S. pinonensis* and *Gypidula cf. comis.*
12. Dick Spring canyon, near head, 20 miles southeast of Globe, *Acervularia davidsoni, Pachyophyllum woodmani, Camarotoechia* cf. *endlichi, Atrypa reticularis, Productella* cf. *hallana, Spirifer whitneyi* and *S. pinonensis.*

Fossils collected by Schrader[1] in the Santa Rita Mountains at a point 2½ miles S. 20° W. from Greaterville were identified by E. M. Kindle as follows: *Acervularia inequalis H.* and *W. (A. davidsoni E.* and *H.); Amplexus* sp.; *Atrypa reticularis;* and *Spirifer hungerfordi,* a Martin limestone fauna.

Fossils have been obtained at various places in the Grand Canyon. Those discovered by Walcott[2] in the Kanab Creek section were "Placoganoid fishes of a Devonian type" and the beds in the region east of the Kaibab Plateau[3] yielded "cyathophylloid corals, casts of brachiopods, and plates of placoganoid fishes." Noble[4] found fish remains in Sapphire Canyon about 12 miles west of El Tovar, which were reported by J. W. Gidley as follows: "The material is too fragmentary to be determined specifically but the genus is *Bothriolepis,* possibly *B. nitidus,* a genus characteristic of the Upper Devonian and not known to occur below the Middle Devonian."

[1]*Loc. cit.,* p. 48.

[2]Walcott, C. D., Am. Jour. Sci., 3d ser., vol. 20, p. 225, 1880.

[3]Walcott, C. D., Am. Jour. Sci., 3d ser., vol. 26, p. 438, 1883.

[4]Noble, L., *loc. cit.* U. S. Geol. Surv. Prof. Paper 131-b, p. 52.

CARBONIFEROUS SYSTEM

Rocks of Carboniferous age underlie the greater part of northern and eastern Arizona and occur in many detached areas in the southwestern part of the State, and probably also in the southeastern part of California, indicating that at least part of the Carboniferous deposition extended over all of Arizona. Rocks of the later Mississippian appear to be lacking in all of this region, either through nondeposition or removal by erosion in mid-Carboniferous time. The strata exposed in the State comprise thick deposits of limestones of early Mississippian and Pennsylvanian age and extensive representatives of the Permian series. The latter series in the high plateaus consists, in ascending order, of the highly characteristic Supai formation, the Hermit shale, the Coconino sandstone, and the Kaibab limestone. In the southern part of the State the Permian is represented by limestone in the upper part of the Naco limestone and by portions of the limestone succession in the southwestern counties.

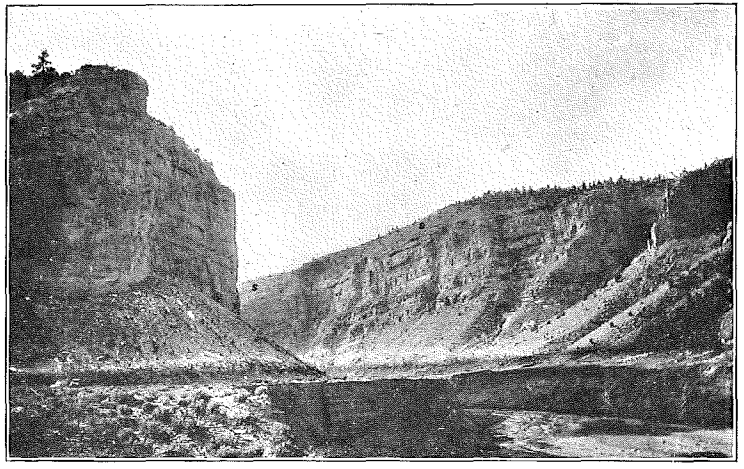


Plate 17a. Coconino sandstone overlain by Moenkopi and Shinarump (S) formations in canyon one-half mile west of Fort Defiance. Looking east.

MISSISSIPPIAN SERIES

Redwall limestone.—As originally defined[1] at the type locality in the Grand Canyon the Redwall limestone consisted of the strata in the great "Redwall ledge," about 650 feet thick, and some overlying thinner-bedded limestones possibly 100-150 feet thick. The latter contain a few intercalated beds of red shale and are known to be of Pennsylvanian age, while the greater part if not all of the main massive ledge is of lower Mississippian age. The plane of separation between the two

[1]Darton, N. H., A Reconnaissance of Parts of Northwestern New Mexico and Northern Arizona: U. S. Geol. Surv. Bull. 435, p. 21.

series is, however, not exactly located, and may be lower than formerly supposed. Recently the upper thin-bedded limestones of Pennsylvanian age have been placed in the Supai formation by Noble.[1]

The Redwall limestone is a prominent feature in northern Arizona for it constitutes the highest and most extensive cliffs in the Grand Canyon. It appears impressively in the canyon of the Virgin River, in the Virgin Mountains and in Grand Wash Cliffs in the northwestern part of the State, where its thickness approaches 2,000 feet. South of the Grand Canyon it makes a broad bench which extends from Grand Wash Cliffs to Juniper Mountains and Black Mesa and along the valley of the Verde through the northeastern part of Yavapai County. The outcrop zone thence skirts the base of the Mogollon Cliffs through northern Gila County and extends up the valleys of the Salt, White, and Black rivers and under the Natanes Plateau, nearly to longitude 110°; it is either very thin or absent on the upper part of Canyon Creek. In its southern and southeastern extension it thins greatly, being about 300 feet thick in Yavapai and Gila counties and it becomes much less massive, consisting of alternations of slabby, shaly, and moderately massive beds. In this region also the formation is underlain by limestone of Devonian age, the upper limit of which is not everywhere ascertained.

A recent boring at Pica which began on the top of the Redwall limestone penetrated 1190 feet of limestone, but this includes an unknown amount of Muav, maybe 400 feet. "Granite" was penetrated from 1715 to 1785 feet.

Hill[2] has given the following section of the Redwall limestone in the Grand Wash Cliff on the road from St. Thomas to the Grand Gulch mining region:

Section of lower cliff on east side of Grand Gulch on road to Grand Gulch Mine, beginning at top but 150 feet below the actual rim.

	Feet
Sandstone, buff	50
Limestone, pinkish arenaceous	100
Sandstone, brownish-red, massive, and cross-bedded, grading up into arenaceous limestone	200
Limestone, fine-grained, and pink at top, grading into coarse-grained red limestone at bottom	500
Sandstone, brownish-red, and calcareous sandstone	50
Limestone, crystalline, reddish-white, grading into sandy lime at top, base not exposed	650
	1,100

In the upper limestone were found fossils which G. H. Girty regards as upper Carboniferous. These were apparently near the base of the Supai formation.

The thick body of limestone in the lower part of the Paleozoic section

[1] *Loc cit.* U. S. Geol. Surv. Prof. Paper 131-8.
[2] Hill, J. M., The Grand Gulch Mining Region, Mohave County, Arizona: U. S. Geol. Surv. Bull. 580 (d), p. 45, 1914.

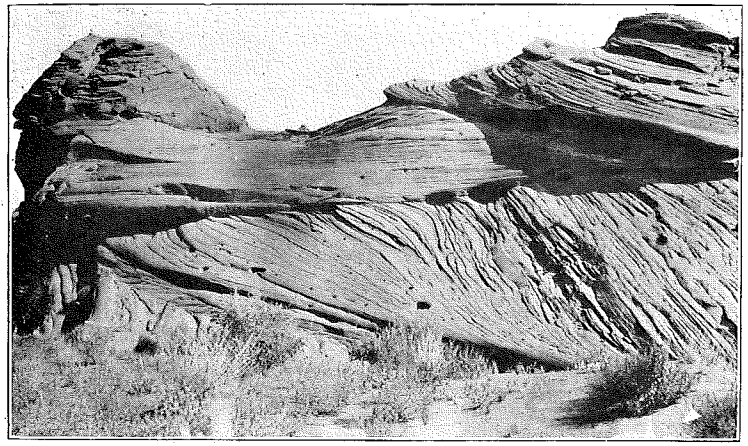


Plate 17b. Coconino sandstone, head of Gypsum Creek 12 miles north-northeast of Kayenta; shows characteristic cross-bedding. Photo by Gregory.

on Virgin River is regarded as Redwall, but Reeside and Bassler[1] reported a Pennsylvanian fauna, including *Marginifera* aff. *M. splendens*, 650 to 700 feet below the top, and *Chaetetes milleporaceus* about 1000 feet below the top, in the Beaverdam Mountains just north of the stream.

At Nelson, Arizona, Lee[2] collected fossils from the Redwall limestone which were determined by G. H. Girty as follows: *Menophyllum excavatum*, *Schuchertella inaequalis*, *Spirifer centronatus*, *S. striatus* var. *madisonensis*, and *Straparollus* sp., an earlier Mississippian fauna. In the upper beds near Yampai, Lee found a Pennsylvanian fauna. See page 71.

Sampson[3] found abundant lower Mississippian fossils in the Salt River region in the central part of Gila County on Salt River Draw, on Cibique Creek, and in Salt River Canyon 3 miles below the mouth of Carrizo Creek. The following species were determined by G. H. Girty:

Triplophyllum sp.,	Camarotoechia n. sp.,
Cladochonus sp.,	Camarotoechia aff. C. metallica,
Orophocrinus sp.,	Productus sp.,
Actinocrinus sp.,	Eumetria verneuiliana,
Platycrinus n. sp.,	Martinia sp.,
Fenestella sp.,	Phillipsia sp.
Schizophoria sp.,	

Escabrosa limestone.—The limestone overlying the Martin (Devonian) limestone in the Bisbee region is defined as the Escabrosa limestone. It is classed as early Mississippian, probably representing the Kinderhook, Osage, and (in part) Meramec groups. The formation consists of rather thick-bedded, nearly white to dark-gray, granular limestones, mostly of great purity. Near the base the beds are generally 10 to 15 feet thick,

[1] *Loc. cit.*, Prof. Paper 129, p. 66.
[2] Lee, W. T., *op. cit.*, Bull. 352, p. 16.
[3] Personal communication.

but they are thinner in the upper part of the formation. The total thickness is between 600 and 800 feet. Fragments of crinoid stems are very abundant and remains of corals and shells occur at various horizons. The formation was noted by Ransome[1] at Tombstone, and I found that it is present in most of the other mountains in southeastern Arizona, as far west as the Vekol Range and north through the Santa Catalina and Turnbull mountains. In the Ray, Globe, and Roosevelt Dam regions Ransome has included in the Tornado limestone, the limestones of Pennsylvanian and lower Mississippian age, the latter represented by the Redwall or Escabrosa strata.

The following species were determined by G. H. Girty from material collected by Ransome in the Bisbee region:

Menophyllum excavatum,	Brachythyris cf. B. peculiaris,
Syringopora aculeata,	Reticularia pseudolineata,
Rhipidomella thiemei,	Syringothyris carteri,
Rhipidomella michelini,	Athyris lamellosa,
Leptæna analoga,	Eumetria marcvi,
Schuchertella inæqualis,	Pernopecten shumardanus,
Chonetes loganensis,	Myalina keokuk,
Productus ovatus,	Phanerotinus paradoxus,
Productus semireticulatus var.,	Euomaphalus luxus,
Spirifer centronatus,	Platyceras sp.,
Spirifer mysticensis,	Phillipsia peroccidens,

They probably represent the earlier half of Mississippian time, including the Kinderhook and Osage divisions.

Mississippian-Pennsylvanian unconformity.—As the Redwall limestone is of lower Mississippian age and the overlying limestones are of Pennsylvanian age, there is a hiatus between them. The limestones are conformable in attitude, although this hiatus comprises all later Mississippian and possibly some of the earliest Pennsylvanian time. The same condition exists at some undetermined plane in the Tornado limestone, also between the Modoc and Tule Spring limestones, and between the Escabrosa and Naco limestones, in all of which the Mississippian representative is of lower Mississippian age. Although various geologists have had the question before them in the field very few data have been obtained as to relations and in most places unfortunately the two series have been mapped together. Noble[2] has described the relations of the Mississippian-Pennsylvanian contact in the Grand Canyon from Bass Canyon to Red Canyon.

MISSISSIPPIAN AND PENNSYLVANIAN SERIES

Tule Spring and Modoc limestones.—In the region about Morenci and Clifton the Carboniferous is represented by two limestones—the Modoc[3]

[1]Ransome, F. L., *op. cit.*, pp. 42-44.
[2]Noble, L. F., *op. cit.*, Prof. Paper 131, pp. 58-59.
[3]Lindgren, *loc cit.*, U. S. Geol. Surv., Prof. Paper 43, and U. S. Geol. Surv. Geol. Atlas, Clifton Folio (No. 129), p. 5, 1905.

of lower Mississippian age and the Tule Spring of Mississippian and Pennsylvanian age. The Modoc consists of about 170 feet of blue to gray limestone, with subordinate beds of quartzite and dolomite. One notable exposure is in slopes south of Modoc Mountain toward Chase Creek, and another extends westward from the first railroad loop below Morenci Smelter. At the base are about 10 feet of gray limestone known as the Coralliferous member; next above are 15 to 20 feet of light-colored

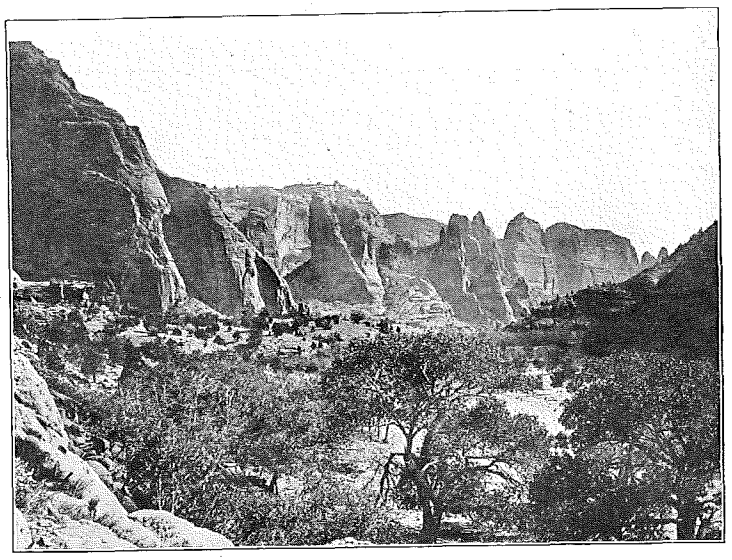


Plate 18a. Coconino sandstone in walls of Canyon de Chelly.

quartzite and then steep slopes and cliffs of gray limestone. There are some local variations. Most of the limestones are exceptionally pure but a lower 60-foot member near Morenci is a dolomite.

The Tule Spring limestone outcrops along a narrow zone crossing the northern part of the Clifton quadrangle. The beds comprise about 500 feet of heavy-bedded, bluish-gray limestone, of which the lower 200 feet are thought to be Modoc and the upper 300 feet to be of Pennsylvanian age. The three principal exposures are at the head of Tule Creek, at the headwaters of Whitewater Creek and about Granville, and in the bluff on lower Sardine Creek. The rocks contain considerable chert. The Pennsylvanian member was recognized by its fossils just north of the bend of Whitewater Creek and near Corral Spring, but was not separated from the Mississippian portion.

The Modoc limestone in the Morenci region has yielded fossils from

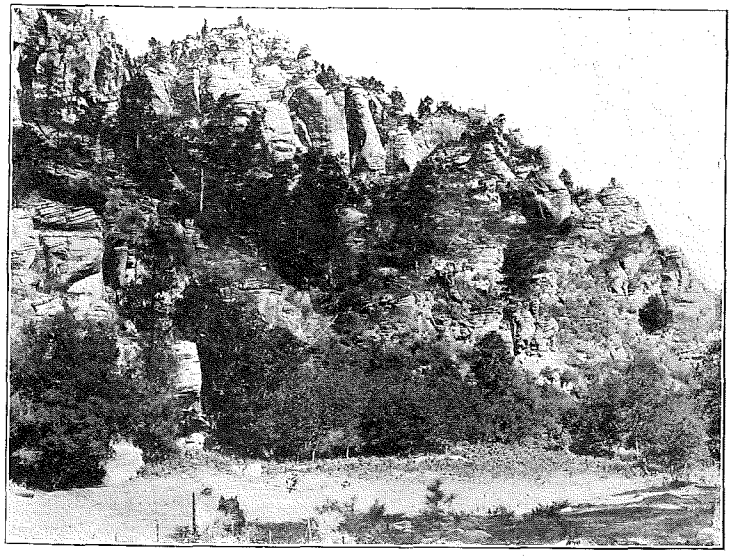


Plate 18b. Coconino sandstone in canyon of Oak Creek 20 miles south of Flagstaff, Arizona.

top, basal, and intermediate members. The following are the principal Mississippian forms identified by G. H. Girty:

Rhipidomella michelini;	Spirifer centronatus,
Schuchertella inæqualis?,	Spirifer near S. keokuk,
Leptæna analoga	Composita humilis,
Chonetes loganensis,	Athyris lamellosa,
Camarotoechia metallica,	

and various crinoids, corals, and bryozoans not determinable. Dr. Girty assigns this fauna to the lower Mississippian.

Fossils in the Pennsylvanian member of the Tule Spring formation north of Clifton include the following:

Chætetes milleporaceus,	Orthotetes robusta, ?
Schizophoria resupinoides,	Pseudomonotis kansasensis,
Productus cora,	Myalina apachesi,
Productus aff. P. coloradensis,	Schizodus wheeleri, ?
Pustula nebraskensis,	Pinna peracuta, ?
Marginifera wabashensis,	Bellerophon cf. crassus,
Composita subtilita,	Bulimorphia chrysalis,
Dielasma hastatum,	Phillipsia major.
Squamaluria perplexa, ?	

Tornado Limestone.—This name was proposed by Ransome[1] for lime-

[1]Ransome, F. L., *op. cit.*, Prof. Paper 98-k, p. 142, 1916.

stones in the Ray and Globe regions which correspond to the Escabrosa (Mississippian) and the Pennsylvanian part at least of the Naco. The thickness near Ray is about 1000 feet, the base lying on Martin limestone; the eroded top is capped by Gila conglomerate and volcanic rocks of Cretaceous age. The basal member, about 75 feet thick, is a thinly banded limestone. It is surmounted by a very massive bed, about 100 feet thick, of light tint, the two forming a conspicuous cliff above the slope of soft strata of the Martin limestone. (See Pl. 71a.) The fossils found in the upper portion of the formation but some distance below its top, are, according to G. H. Girty, early Pennsylvanian; the lower beds yield an early Mississippian fauna. The following fossils are listed by Ransome:

Pennsylvanian fauna

Fusulina sp.,	Spirifer cameratus,
Derbya crassa,	Spirifer boonensis,
Productus semireticulatus,	Composita subtilita?,
Productus cora,	Myalina subquadrata,
Pustula semipunctata,	

Mississippian fauna

Syringopora aculeata?,	Camarotœchia metallica,
Menophyllum sp.,	Dielasma burlingtonense,
Amplexus ?sp.,	Spirifer centronatus,
Rhipidomella aff. R. owenI,	Brachythyris peculiaris,
Rhipidomella dubia?,	Spiriferina solidirostris,
Leptæna analoga,	Syringothyris sp.,
Schuchertella inflata,	Composita humilis,
Chonetes sp.,	Cliothyridina sp.
Avonia arcuata?,	

In the upper part of the Tornado limestone series in the Salt River region in central part of Gila County, Sampson[1] obtained the following Pennsylvanian fossils, determined by G. H. Girty. One locality was on Cibique Creek and the other in Salt River Canyon 3 miles below the mouth of Carrizo Creek:

Campophyllum torquinum,	Pustula semipunctata,
Lophophyllum profundum,	Marginifera muricata,
Derbya crassa,	Spirifer rockymontanus,
Productus semireticulatus,	Spirifer triplicatus,
Productus n. sp.,	Squamularia perplexa,
Productus coloradoensis,	Composita subtilita,
Productus cora,	Cliothyridina orbicularis

I found the Pennsylvanian part of the formation about 250 feet thick on Canyon Creek below Ramer (Wallace) Ranch.

[1]Personal communication.

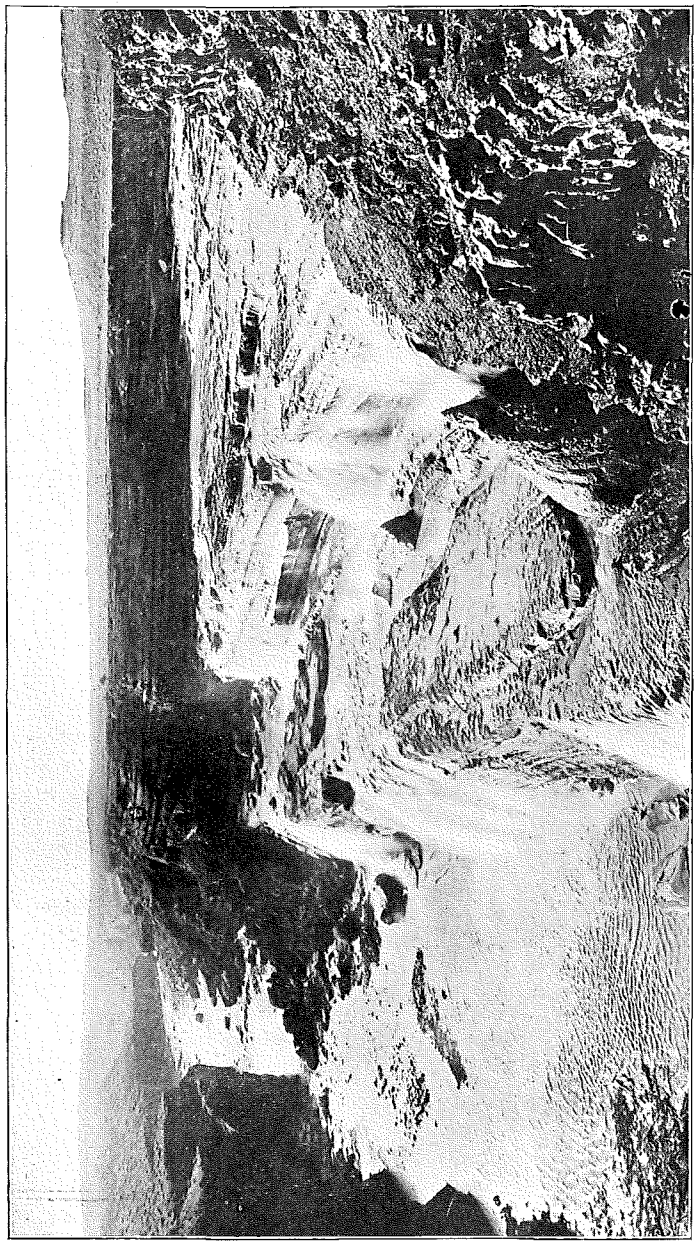


Plate 19. Top of Kaibab limestone at Grand Falls of Little Colorado River, 18 miles northwest of Leupp. Looking north. Lava to left, Moenkopi beds to right. Photo by Mendenhall.

From Mescal Mountains near the canyon of Gila River I collected the following:

Chonetes granulifer,
Productus coloradensis,
Marginifera splendens,
Spirifer triplicatus,
Spirifer rockymontaus,
Edmondia sp.,
Deltopecten occidentalis.

These are Pennsylvanian forms. From lower beds a small variety of Mississippian species were collected.

On White River, where it is crossed by the road from Fort Apache to Rice, I collected many fossils of Pennsylvanian age comprising *Productus coloradoensis*, *Spirifer cameratus*, and *Composita subtilita*.

At Yampai, in beds near the top of the great "Redwall" limestone succession, Lee[1] found the following:

Derbya sp.,
Composita aff. C. subtilita,
Aviculipecten sp.,
Myalina sp. aff. M. meliniformis and M. congeneris,
Edmondia sp.

PENNSYLVANIAN AND PERMIAN (?) SERIES

Naco limestone.—The name Naco limestone was applied by Ransome[2] to the limestone overlying the Escabrosa (early Mississippian) limestone in the Bisbee region. The two limestones are conformable in attitude, but the overlying Cretaceous strata lie on an eroded surface. The thickness of Naco beds exposed between these limits is stated to be at least 1500 feet and probably as much as 3000 feet. The rocks are similar to those of the underlying limestone but some of the bedding is thinner and the texture generally is finer-grained. Some beds also have a pinkish hue. Chert is common, occurring in irregular bunches and nodules and also in thin layers. According to G. H. Girty[3] the fossils from the lower part represent the early Pennsylvanian and the fauna in the higher strata presents features suggesting the upper Hueco of the Hueco Mountains in western Texas, which I have found is a southern extension of the Manzano of New Mexico, now classed as Permian.

Ransome found several hundred feet of Naco limestone at Tombstone, and I observed the formation in the Dragoon, Little Dragoon, Whetstone, and other ranges in southeastern Arizona. I obtained a few fossils from high in the Naco beds 5 miles south of Tombstone, which are as follows: *Meekella pyramidalis?*, *Productus leei?*, *P. invesi* and *Marginifera* sp. They were determined by G. H. Girty, who regards them as Manzano (Permian) in age.

Strata of the same character as the Naco and apparently of the same age occur in the central part of the State, where part of

[1]Lee, W. T., *op. cit.*, pp. 15-16.
[2]Ransome, F. L., *op. cit.*, Prof. Paper 21, pp. 44-46.
[3]Ransome, F. L., Some Paleozoic Sections in Arizona: U. S. Geol. Surv., Prof. Paper 98-k, p. 149.

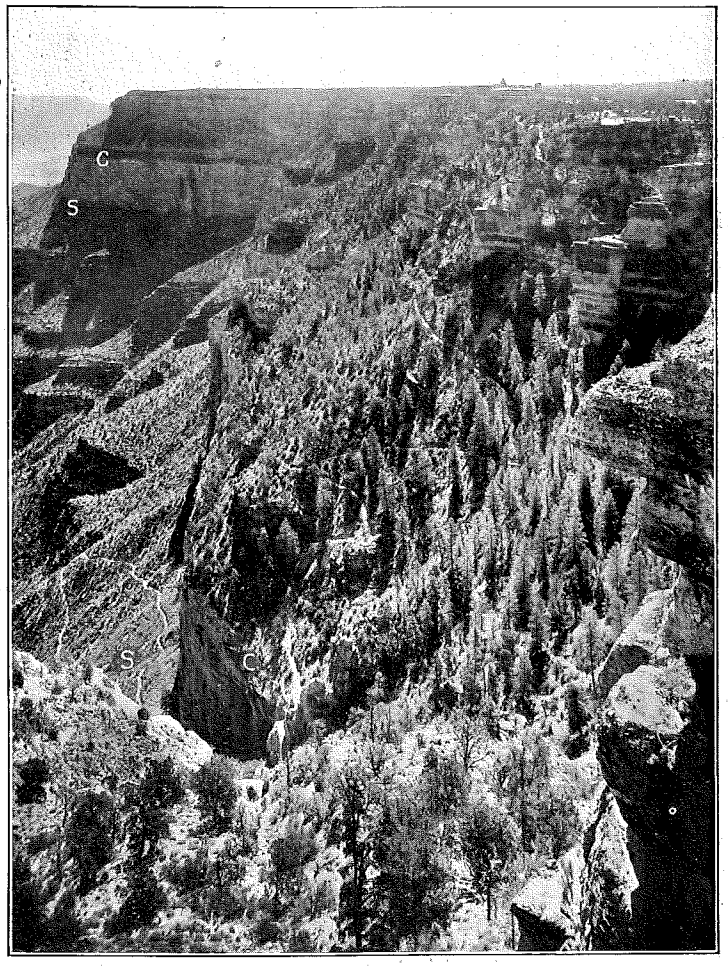


Plate 20. South rim of Grand Canyon. Bright Angel Trail looking east at El Tovar. Shows plateau of Kaibab limestone underlain by C, Coconino sandstone, and S, Supai red beds.

them at least are included in the Tornado limestone, and in the Grand Canyon region where they are now included in the Supai formation. I believe, however, that careful study of these strata and their fossils will afford a basis for separating the rocks of the Pennsylvanian series as a separate unit or formation, which is eminently desirable. Because of the hiatus at its base such a formation would be equivalent to all or a part

of the wide-spread Magdalena limestone of New Mexico and the use of this name might well be extended westward into Arizona.

Unclassified later Carboniferous rocks.—Limestones of later Carboniferous age occur in various localities in the mountains of south-central Arizona, of which the stratigraphic limits and range are not yet ascertained. Such limestones in the Empire, Santa Rita, and Patagonia mountains and the Canelo Hills, have been mapped by Schrader.[1] Their thickness may be as much as 2000 feet, and while the fossils so far obtained are all Pennsylvanian or Permian in age, representatives of earlier Carboniferous may also be present. The rocks are nearly all gray and vary from massive to thin-bedded; some sandy members occur.

Fossils collected by Schrader from near the Mowry Mine, 8 miles south of Patagonia, comprised the following:

Echinocrinus cratis,
Echinocrinus trudifer,
Echinocrinus gracillis aff. E. aculeatus,
Fistulipora sp.,
Tabulipora sp.,
Productus semireticulatus,
Productus ivesi,
Productus occidentalis,
Productus aff. mexicanus,
Pugnax aff. osagensis,
Spirifer rockymontanus,
Composita subtilita,
Composita mexicana,
Bellerophon crassus?,
Murchisonia aff. copei.
Schizostoma aff. catilloides,
Orthonema sp.,
Euomphalus n. sp.,

Some fossils of this same fauna were collected 2 miles east of Helvetia. These were determined by G. H. Girty, who regarded them as a Naco fauna, representing both the Pennsylvanian and the Manzano. From a slightly lower horizon in the same vicinity were collected *Productus cora*, *Spirifer rockymontanus*, and *Spirifer cameratus*, which may be slightly earlier Pennsylvanian than the others.

From ledges south of McDonald's ranch 20 miles east of Douglas, I collected the following: *Fusulina* sev. sp., *Composita* sp., *Cliothyridina orbicularis*, *Bellerophon* sp., *Schizostoma catalliodes?*.

Limestones of Carboniferous age have been observed by Tolman[2] at the north end of the Tucson Mountains and at Silver Bell,[3] and by Bryan[4] at Snyder's Hill 10 miles southwest of Tucson and in and near the Vekol Mountains. The fossils collected by Bryan at Snyder's Hill comprised the following:

Zaphrentis? sp.,
Pustula aff. P. porrecta,
Pustula aff. P. subhorridus,
Rhyncopora n. sp.,
Squamularia perplexa,
Composita mexicana.

[1]Schrader, F. C., *loc. cit.*, Bull. 582.

[2]Tolman, C. F., The Geology of the Vicinity of the Tumamoc Hills: Carn. Inst., Pub. 113, p. 76, Wash., 1909.

[3]Tolman, C. F., Copper Deposits of Silver Bell, Ariz.: Min. & Sci. Press, vol. 99, pp. 710-712, 1909.

[4]Bryan, K., *loc. cit.*, pp. 22-23.

They were determined by G. H. Girty, who regards them as Pennsylvanian or "perhaps even Permian."

From limestone on the south slope of the mountain at Vekol Mine Bryan collected the following forms:

Cladochonus sp.,
Campophyllum torquium,
Rhombopora lepidodendroides,
Schizophoria? sp.,
Chonetes verneuilianus,
Productus semireticulatus,
Marginifera splendens,
Spirifer cameratus,
Spirifer rockymontanus,
Composita subtilita.

These were determined by G. H. Girty, who regarded them as lower Pennsylvanian or corresponding to the lower part of the Naco limestone of the Bisbee district.

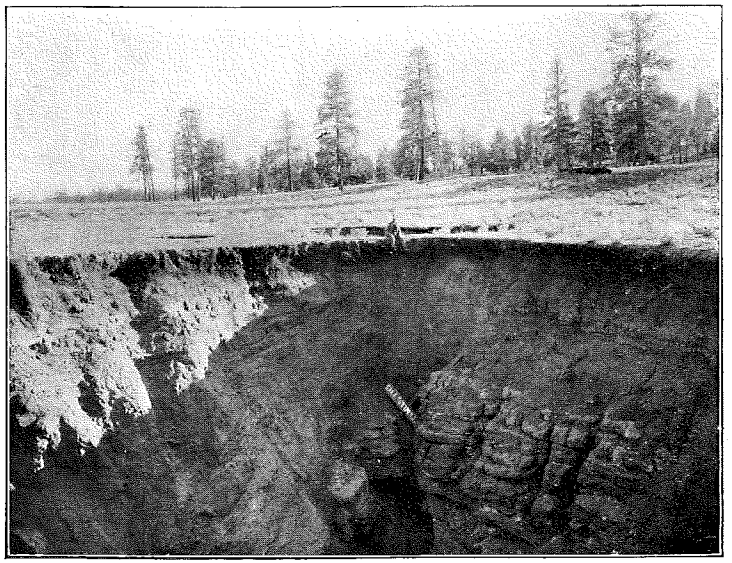


Plate 21a. Kaibab limestone showing characteristic sink hole known as Bottomless Pits, 4 miles east of Flagstaff, Arizona.

Bryan also noted limestone and quartzite in Growler Pass and at the Black Prince Mine at the east foot of Sierra Blanca, where detached masses of blue limestone are imbedded in intrusive rocks, but obtained no evidence as to their age. Limestone, mostly highly altered, occurs at Twin Buttes, 20 miles southwest of Tucson.

I found limestones, presumably Carboniferous, on the western slope of the Sierra Blanca, and west and northwest of Dripping Springs at the northwestern end of Puerto Blanco Mountains 21 miles south by west of Ajo, where abundant crinoid fragments were collected.

I discovered Carboniferous fossils in limestones in many localities in the southwestern part of Arizona. In the Vekol Mountains Pennsylvanian and Mississippian faunas were collected, the latter being represented by *Triplophyllum* sp., *Rhipidomella* aff. *R. thiemi* and *Spirifer* sp., as determined by G. H. Girty. These fossils were from a ridge about 1 mile north of the Reward Mine. From nearby ledges was collected a large fauna of minute forms comprising molluscs, pelecypods, scaphopods and gastropods, about 25 species in all, many of them new and regarded by Dr. Girty as Kaibab or Manzano (Permian) in age. Fossils of this same age from the Waterman Mountains were identified by Girty as

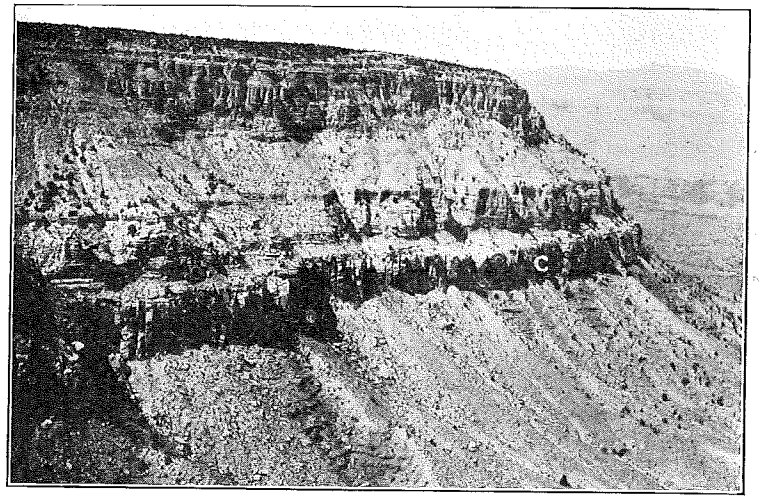


Plate 21b. Wall of high plateau on north side of Mohawk Canyon 60 miles north of Seligman, Arizona. Looking north across canyon of Colorado River. C, Coconino sandstone on Hermit shale, and overlain by Kaibab limestone. Shows soft medial member of latter.

Triplophyllum? sp., *Batostomella?* sp., *Phyllopora?*, *Productus occidentails*, *Squamularia* aff. *S. perplexa*, *Composita* aff. *C. mexicana*, and *Phymatifer* sp. A spirifer from another outcrop appeared to be a Mississippian form. In Slate Mountain many Pennsylvanian fossils were obtained and the Mississippian may also be present.

Fossils were also discovered in several of the partially metamorphosed limestones in Yuma County, notably south of the Bonanza Mine, near the Billy Mack Mine, near the Socorro Mine, and in a conglomerate 8 miles southeast of the latter mine. This conglomerate, which rises in an isolated butte, may be considerably younger than Carboniferous, but its boulders of light gray limestone have been derived from nearby ledges such as occur at intervals along the southern foot of the Harquahala Mountains.

It is not at all unlikely that some Devonian and Carboniferous sediments were deposited over all of southwestern Arizona, but apparently they have been removed by Mesozoic and later erosion in the region west of longitude 113°, at least from ridges now rising above the desert basin. There are no suggestions of ancient shores or significant overlaps in this general region.

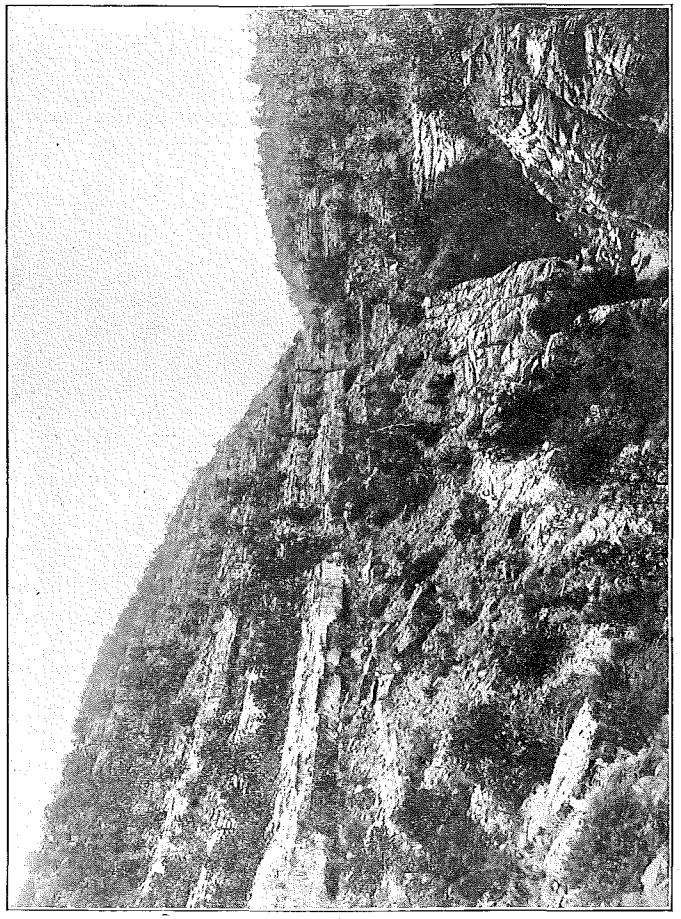


Plate 22. Coconino sandstone overlain by Kaibab limestone at Cliff Dwellings on Walnut Creek southeast of Flagstaff, Arizona. Looking east. Contact is at C.

Metamorphosed limestones and shales.—In the central part of Yuma County and the western part of Maricopa County there are many areas of schists, parts of which, associated with subordinate amounts of limestone and quartzite, appear to be of Carboniferous to Cambrian age.

They are classed as pre-Cambrian by Bancroft,[1] but Ross[2] has recently suggested that they are Paleozoic. Moreover, as stated in a preceding paragraph, I discovered Carboniferous fossils in some of the less altered limestones, and the stratigraphic relations suggest the presence of a regular

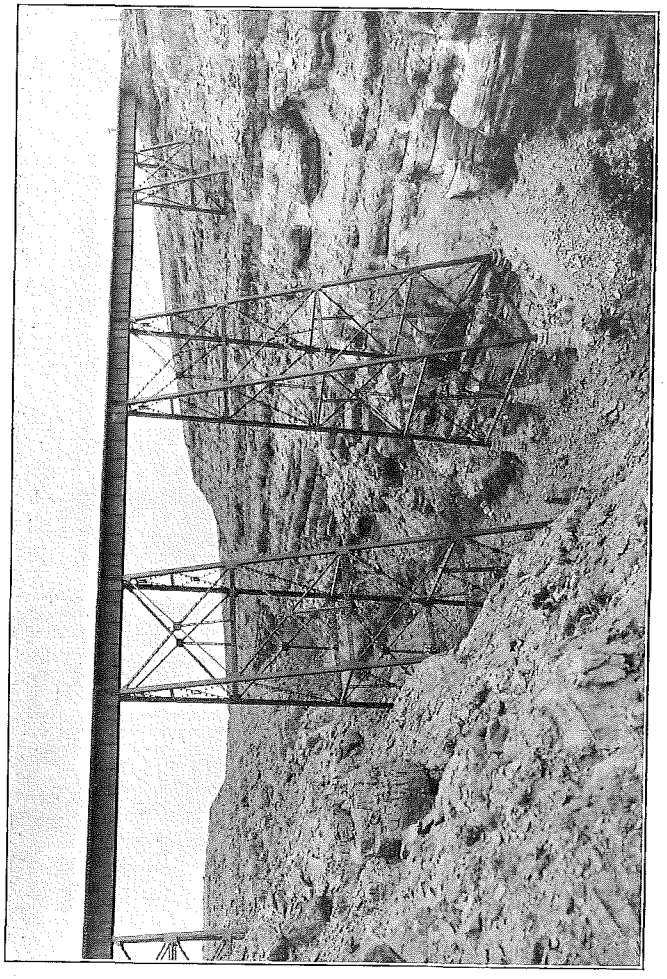


Plate 23a. Kaibab limestone in walls of Canyon Diablo at crossing of Santa Fe Railroad. Looking north.

succession of Paleozoic rocks, at least at most localities. There are also some very thick successions of schists which appear to be older than the others and resemble the Pinal and Yavapai schists.

[1]Bancroft, H., *op. cit.*

[2]Ross, C. R., *op. cit.*, pp. 183-186

Metamorphosed sedimentary rocks occurring in a number of detached areas in the western part of the Buckskin Mountains in northern Yuma County, have been described by Blanchard,[1] who regarded them as pre-Cambrian. The rocks are schists, quartzites, and limestones, nearly everywhere considerably altered, the limestone mostly in the form of marble. The limestone occurs about Planet, on Brown Mountain, and in the vicinity of the Billy Mack Mine near the Colorado River, 15 miles northeast of Parker. At the latter places I found part of the limestone only slightly altered and presenting all the aspects of the Carboniferous limestone of the Plateau region and carrying unmistakable crinoid stems. Blanchard describes a thin section of limestone at one of the mines, presumably near Planet, in which crinoid stems appear to be well exhibited.

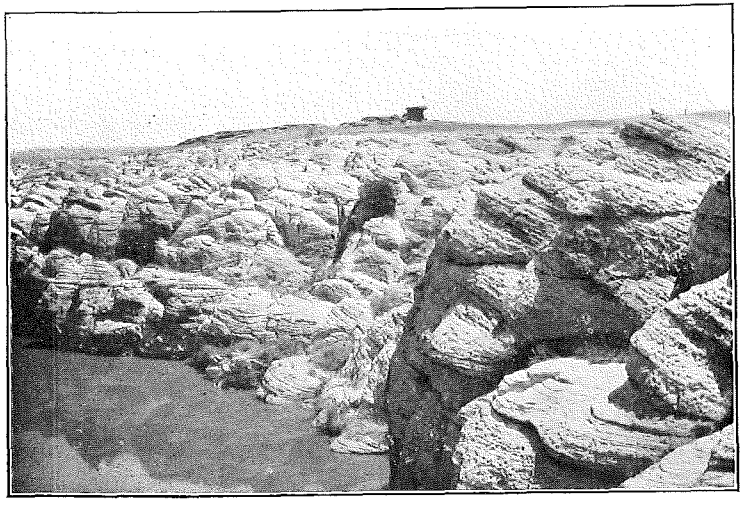


Plate 23b. Coconino sandstone and base of Moenkopi formation. Spring Creek east of Winslow, Arizona. The thin edge of sandy bed representing the Kaibab limestone outcrops on shelf between these two formations.

I found Carboniferous fossils in the less altered portions of some of these limestones at various points in Yuma County, which will be described on succeeding pages.

Supai formation.—In its type locality,[2] in Havasu (Cataract) Canyon (see Pls. 11a) and contiguous portions of the Grand Canyon, the Supai formation consists of 1100 to 1200 feet of red sandstones and shales. An upper member, consisting of 200 feet or more of red shale, was originally included, but this has since been separated as the Hermit

[1]Blanchard, R. C., *op. cit.*

[2]Darton, N. H., A Reconnaissance of Parts of Southwestern New Mexico and Northern Arizona: U. S. Geol. Surv. Bull. 435, p. 25, 1910.

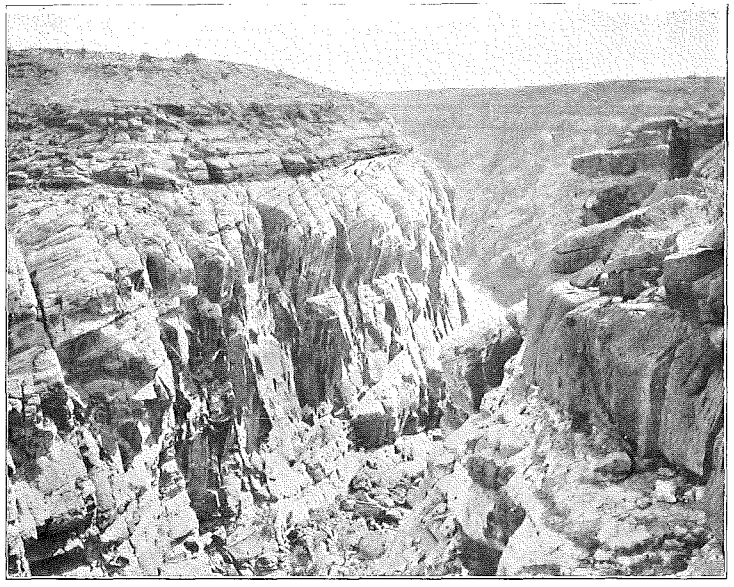


Plate 24a. Kaibab limestone on Coconino sandstone. Spring Creek southeast of Winslow.

shale. This shale is conspicuous in the Grand Canyon, but is absent in the southern part of the plateau region, where perhaps it gives place to sandstone. Recently Noble,[1] with concurrence of the United States Geological Survey, has redefined the Supai formation so as to include in its lower portion the alternation of slabby limestones formerly regarded as part of the Redwall and containing fossils of Pennsylvanian age. This member, however, as stated above, should be separated as soon as suitable field work is done to define it.

These alternating red shales and sandstones of the Supai are a conspicuous feature in the middle slopes of the Grand Canyon, constituting a long succession of steplike terraces from the top of the Redwall Cliff to the base of the Coconino Cliff. Near the mouth of Havasu or Cataract Creek the medial beds of the formation become increasingly sandy and develop into a very massive sandstone member, which in the region westward, constitutes a wide bench halfway down the canyon sides known as the Esplanade. In general the cliff at the edge of this member becomes coincident with that of the Redwall, so that the profile of the canyon changes from the type shown in Plates 10, 44, 45, and 49, to the type shown in Plates 50 and 51. Some change in the texture of the Tonto rocks and thickening of the Hermit shale are also important factors in this change.

[1]Noble, L. F., A Section of the Paleozoic Formations of the Grand Canyon at the Bass Trail: U. S. Geol. Surv., Prof. Paper 131, p. 59.

At most localities there appears to be a pronounced stratigraphic break between the Pennsylvanian or lower member of the Supai formation and the massive limestone of the Redwall. Noble[1] mentions the abrupt change from red shale at the base of the Supai formation to massive limestone at the top of the Redwall limestone. In Bass Canyon and near the Hermit Trail the surface of the limestone presents jagged knobs projecting 25 feet or more into the reddish, sandy shale at the base of the Supai, and these shales contain thin layers of conglomerate with chert

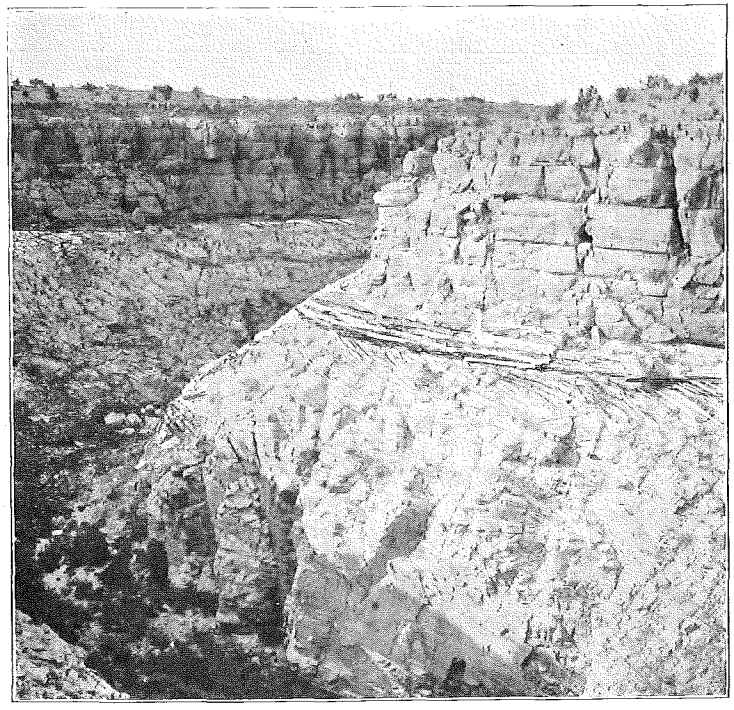


Plate 24b. Kaibab limestone on Coconino sandstone. Chevlon Canyon southeast of Winslow.

fragments which were doubtless derived from the underlying limestone. At Red Canyon, east of Grand View, there is a limestone-chert conglomerate up to 20 feet thick at the base of the Pennsylvanian member of the Supai, which appears to have derived its pebbles from the Redwall limestone. The matrix is red shale and the rock appears to lie in hollows on an old limestone surface. Walcott[2] noted a break or nonconformity pre-

[1]Noble, L. F., *op. cit.*, p. 58.

[2]Unpublished notes quoted by Noble, *op. cit.*, p. 162.

sumably at this horizon on Kanab Creek. Ransome[1] noted a limestone conglomerate 2 to 3 feet thick at the base of the Supai formation in the Verde Breaks 58 miles north of Jerome.

The thickness of the Supai formation is nearly uniform in a wide area in northern Arizona. At El Tovar, under 210 feet of red shale (Hermit) are 900 feet of red sandstone and shale with only a small thickness of alternations of red shale and limestone at the base. In the canyon of Kanab Creek, according to Gilbert,[2] there are 980 feet of red beds with a 2-foot limestone member near the middle. They lie on 200 feet of "purple and white, heavy-bedded arenaceous limestone with pink chert in one bed, passing into cross-bedded sandstone." In a section at the mouth of Grand Canyon (near old Pierce Ferry) Gilbert describes

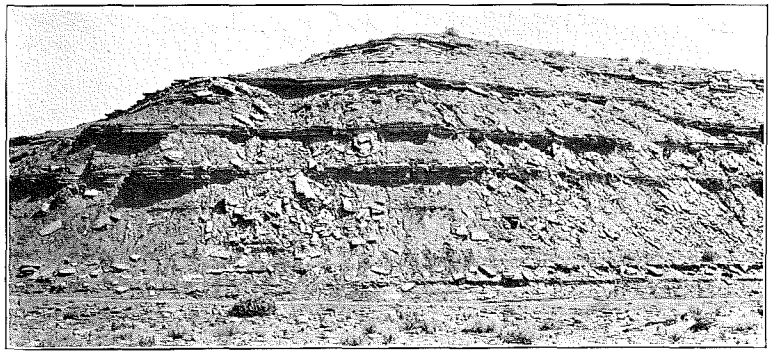


Plate 25a. Moenkopi in valley of Little Colorado River near Leupp. Photo by Gregory.

strata below the Coconino sandstones as friable, red sandstone 800 feet, limestone 120 feet, white sandstone 35 feet, limestone 40 feet, and red and purple, cross-bedded sandstone 315 feet (on Redwall limestone)—1310 feet in all. A boring at Seligman penetrated 677 feet of middle and lower beds of the Supai formation.

Noble has described many details of the Supai formation near Bass Trail on the south rim of the Grand Canyon, where the thickness is 953 feet. Three members are recognized, as follows:

A. Three hundred and six feet thick, of alternating beds of reddish, soft, platey sandstone and buff, massive, cross-bedded sandstone, passing down into heavy beds of reddish, purplish, and buff, massive, cross-bedded sandstone, with partings of red sandy shale; makes the "Esplanade" in region westward.

B. Four hundred and thirty-nine feet thick, of which the upper part is red, friable sandstone and massive, cross-bedded sandstone, with a few

[1]Ransome, F. L., *op. cit.*, p. 162.

[2]Report U. S. Geol. Surv. West 100th mer., vol. 3, Geology, 1875, pp. 161-162.

thin beds of limestone conglomerate, and lower part of heavy beds of reddish and buff, cross-bedded, calcareous sandstone with thin beds of limestone or red shale.

C. Two hundred and eight feet thick, of red, sandy shale, purplish and gray limestone, with red chert and reddish to buff, calcareous sandstone.

These subdivisions may possibly be separated by unconformities, but no evidence on this point was obtained. One bed of limestone conglomerate in division B, 28 feet thick, near Bass trail, has been recognized by Noble at various other points 18 to 32 miles east, and also in Aubrey Cliff west of Seligman and on Kanab Creek[1] near the mouth of Hacks Canyon. It appears to mark an unconformity. A similar bed 12 feet thick was noted by Ransome[2] in the Jerome district, about 450 feet above the base of the red beds of the Supai formation.

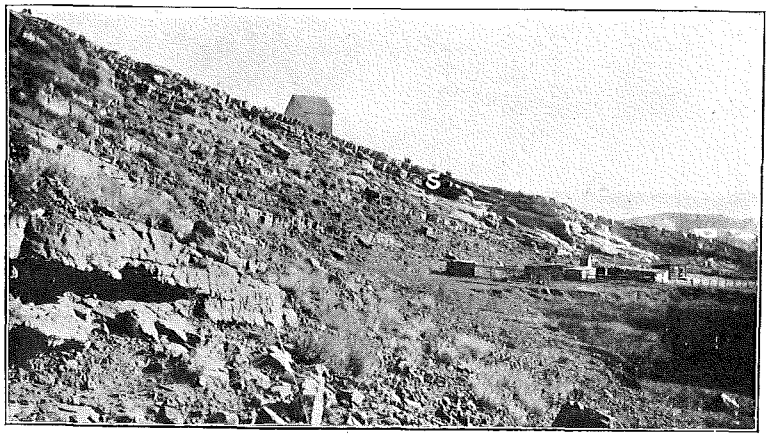


Plate 25b. Moenkopi and Shinarump formations in gap just west of Fort Defiance. Looking east. S, Shinarump conglomerate.

The Supai strata in the southern part of T. 27 N., R. 9 W., about 16 miles northeast of Peach Springs, have a lower member consisting of about 300 feet of alternating limestones and gray to brown sandstones with a conspicuous body of maroon shale near its base not far above the massive limestone of the Redwall. Next above is the massive sandstone member which forms the widespread "esplanade." In the lower part of the latter was found a bed of limestone which yielded fossils near Blue Mountain Tank in section 23, T. 26 N., R. 9 W., but the organic material obtained was too fragmentary to be determined. An 8-foot bed of limestone was found at about the same horizon as the above, in exposures southwest of Ash Fork, and two thin limestones were observed

[1]Gregory, H. E., and Noble, L. F., *op. cit.*, p. 234.
[2]Ransome, F. L., *op. cit.*, p. 160.

not far below the top of the formation in the buttes north of Sedona. At the latter locality and generally along the Verde Breaks there is no Hermit shale and the sandstone at the top of the formation is so coarse that the Supai-Coconino contact is not well marked at all points.

The exposures of Supai formation extend almost continuously along the Aubrey Cliffs, Black Mesa, and Verde Breaks or south front of the Arizona (Mogollon) Plateau, from the Grand Canyon to White River, a distance of about 250 miles. They constitute long, red slopes and step-like cliffs, notably in the canyons of Oak and Sycamore creeks. (See Pl. 13.) In the Apache Indian Reservation, where dips are low, the outcrop of the formation broadens greatly, with notable exposures along the valleys of Cibique, Carrizo, and Cedar creeks, and the North Fork of White River. To the south in the Natanes Plateau and to the east in the White

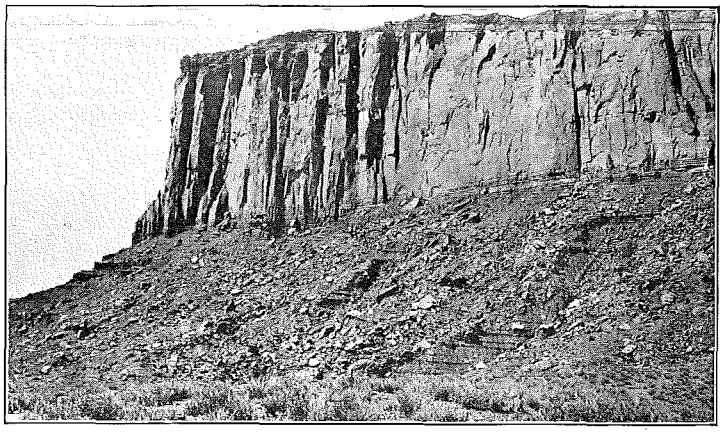


Plate 25c. Local sandstone member (Oljeto) underlain by red shale; Moenkopi formation near Meridian Butte, 20 miles northeast of Kayenta. Photo by Gregory.

Mountains the formation is buried under thick bodies of lava. Notable outliers occur under the lava cap of Jerome Mountain. Throughout this district the red strata lie on limestones (Redwall-Tornado) and are overlain by a very thick development of Coconino sandstone, the intervening Hermit shale being absent. The formations present precise or very close conformity in attitude, but at most places they are clearly separated.

The Supai rocks are uniformly red to buff sandstone and red, sandy shale, with local coarser members, in part gray. The disappearance of the top red shale (Hermit) of the Grand Canyon region to the southeastward appears to be due to thinning out, but the stratigraphic relations have not been studied. In the region south of Seligman and in the canyons of Sycamore and Oak creeks the uppermost beds are moderately coarse, red to buff sandstone. However, red, sandy shales appear at intervals in the

upper part of the formation farther eastward. The lowest beds throughout are alternations of red shales and limestones, but the thickness of this succession varies, and to the southward in the Cibique-White River district the basal limestones (Pennsylvanian) are much more of a separable unit than in the Grand Canyon region. Further south, in the Salt River basin and near Globe, and southward, corresponding beds are included with limestones of Mississippian age in the Tornado limestone.

In the northern and northwestern parts of the Fort Apache Reservation limestone members become prominent at various horizons in the Supai formation, there being one thick bed about 150 feet below the top, and other beds at lower horizons. Some of these limestones are shown in Plate 14. They contain Manzano fossils which indicate that most, if not all, of the red strata are of Permian age. A section on Carrizo Creek near the Navajo-Gila County line shows the following succession, which, in general, is typical for many miles east and west:

SECTION OF SUPAI FORMATION ON CARRIZO CREEK, FORT APACHE INDIAN RESERVATION

	Feet
Sandy red shale (capped abruptly by Coconino sandstone)	60
Red shale, with 6-inch bed of limestone and 2 to 3 feet of gypsum in middle	45
Limestone	8
Shale, red	12
Limestone, sandy	6
Red sandy shale	34
Limestone	10
Red sandy shale	25
Limestone ("upper limestone")	75
Red shale, with thin limestone and 4 feet of gypsum in its medial part	70
Limestone	10
Massive sandstone, hard, mostly brown-red	50
Red sandy shale	80
Limestone and calcareous shale	30
Red sandy shale	50
Limestones and red shales interbedded, lying on massive limestone	150
Total	715

The "upper limestone" member is also a conspicuous feature in the head of Canyon Creek, on Cibicue Creek, Cedar Creek (Pl. 146b), and on both main branches of White River (Pl. 14a). To the westward it may be represented by a 6-foot bed of limestone in Oak Creek Canyon, above Sedona, and there is a similar but thinner bed in the buttes northwest of Peach Springs, notably at Blue Mountain Tank. An 8 to 10-foot limestone member also occurs in the Supai formation in the canyon of Black Creek, 15 miles south of St. Michaels. The member of hard, brown-red sandstone, from 80 to 100 feet lower than the "upper limestone" member in the Carrizo Creek section, was traced far to the west and may be represented in the western part of the Grand Canyon. The

limestones not far below this massive sandstone were traced only 20 or 30 miles on either side of Carrizo Creek. The lowest member, of alternating limestones and red shales, is of universal occurrence, but possibly its upper limit at least, is not everywhere at precisely the same horizon.

The Supai beds are well exposed in the southern slope of Mogollon Plateau near Ramer's Ranch (now Wallace) near the head of Canyon Creek. They lie on about 250 feet of "Redwall" limestone with Pennsylvania fauna at the ranch and are about 800 feet thick. About 200 feet below the top is a 40-foot limestone member containing many fossils of the Manzano (Chupadera) type which is Permian in age. The other Supai rocks are the characteristic red, sandy shale and red-brown sandstone. They are capped by Coconino sandstone.

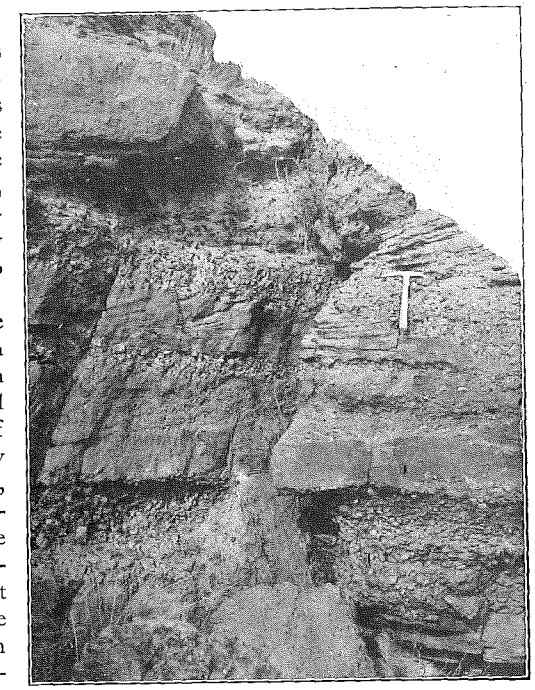


Plate 26a. Shinarump conglomerate near Fort Defiance Shows irregular distribution of coarse and fine materials. Photo by Gregory.

The Supai beds are extensively exposed in White River Canyon above the Indian School and in the vicinity of Fort Apache. They consist of the usual red, sandy shales and sandstones, and also the thick member of limestone about 100 feet below the top of the formation, as shown in Plate 14a. This limestone appears to attain its maximum development in this part of the area for it is more than 100 feet thick, including some alternations of red shale and limestone at the top. It carries Manzano fossils.

The contact of the Supai formation with the pre-Cambrian quartzite on Quartzite Creek, 3 miles northwest of Fort Defiance, shows some interesting features. There is a strong unconformity, with depressions and knobs of the old rock surface, some of them 50 feet or more in depth or height. In most places the red, sandy shale lies directly on or against the quartzite, but local masses of conglomerate were observed, consisting of angular masses of quartzite and a few boulders of limestone

in a red, sandy matrix. The Supai formation is about 550 feet thick in this uplift and is overlain by a thick mass of Coconino sandstone.

The red beds of Permian age have similar relations in the Zuni uplift not far to the southeastward in New Mexico where they are classed as the Abo formation. They are extensively exposed, lying directly on pre-Cambrian granite and including a limestone member near the base containing many Manzano fossils.

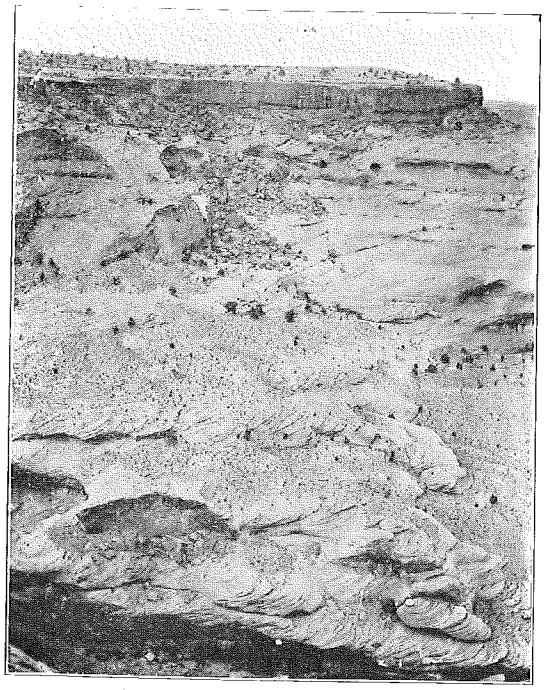


Plate 26b. Coconino sandstone capped by Shinarump conglomerate (at S-S), south side Canyon de Chelly, 3 miles southeast of Chinle. Looking northwest.

Two diamond drill borings recently made by Wilson, Cranmer & Co. for oil in the Defiance uplift afford important data as to the relations of the Supai formation. One hole about 6 miles northwest of Fort Defiance entered granite at 114 feet, and another hole 1½ miles east of Nazlini Store, or about 18 miles southeast of Chinle, entered granite at 806 feet. In both holes typical pre-Cambrian, red granite was brought up in long cores, and there could be no mistake as to its identity. The hole northwest of Fort Defiance began low in the Supai beds, while the hole near Nazlini began at the foot of a 200-foot cliff of Coconino sandstone and penetrated the following beds:

APPROXIMATE RECORD OF BORING IN NAZLINI CANYON, 18 MILES SOUTHEAST OF CHINLE, ARIZ.

	Feet
Sandstone, cross-bedded in greater part	210
Shale red	20
Sandstone, coarse, brown, cross-bedded	35
Sandy shale, brown-red, few gray layers	120
Sandstone, coarse brown-red, cross-bedded	20

Sandy shale, red	35
Sandy shale, brown-red, thin gray layers	185
Shale, red, soft	40
Sandy shale, red and gray alternations	55
Shale, brown-red and gray	30
Shale, red, soft	11
Sandy shale, red and gray mottled	45
Granite	20+

This log was made up from an examination of cores lying on the ground. The upper 210 feet or more of beds are lower Coconino and the red strata below are characteristic Supai rocks.

Red strata extend from 460 to 2800 feet or deeper in borings on Holbrook anticline. From the big bed of limestone in the Supai formation on Cedar Creek and Carrizo Creek there were obtained the following fossils:

Deltopecten coryanus,
Phanerotrema sp.,
Echinocrinus cratis,
Bellerophon sp.,
Productus leei,
Plagioglypta canna?
Bucanopsis n. sp.,
Phymatifer cornudanus,
Orthonema sp.,
Euomphalus sp.,
Pleurotomaria alamillana,
Cyclonema sp.,
Hemizyga? sp.,
Nautilus sp.
and sponge spicules.

The upper limestone on the head of Canyon Creek, above Ramer's Ranch, yielded *Echinocrinus* sp., *Schizodus?*, *Plagioglypa* n. s.?, *Bellerophon*, and several *Euomphalus* sp.

From the "lower limestone" member of the Supai formation on Carrizo Creek were collected the following:

Rhombopora lepidodendroides,
Pustula nebraskensis?,
Spirifer triplicatus,
Composita subtilita,
Hustedia mormoni,
Deltopecten occidentalis,
Pugnoides utah,
Allerisma capax,
Edmondia sp.,
Parallelodon sp.,
Myalina subquadrata,
Myalina perattenuata?,
Pinna peracuta,
Monopteria marian,
Pleurophorus sp.,
Bellerophon sp.,
Pleurotomaria sp.,
Goniospira sp.

On Cedar Creek this horizon yielded *Productus cora* and *Composita subtilita*. These were determined by G. H. Girty, who regards the fauna as more closely allied to the Manzano (Permian) than to the Magdalena fauna, but having the character of the lower rather than of the upper Manzano fauna.

The lower limestone in the red beds (Abo formation) in the Zuni mountains, 1 mile west of Sawyer, New Mexico, yielded the following Manzano forms:

Productus sp.,
Composita subtilita,
Myalina aff. permiana,
Schizodus? sp.,
Pleurophorus? sp.,
Bellerophon? sp.,
Goniospira? sp.,
Naticopsis? sp.,
Bulimorphia aff. chrysalis?.

In 1913 E. C. Chase and W. B. Emery obtained plants from medial members of the red beds which I am now classing as Supai, 3 miles west of Fort Defiance. They were identified by David White as follows:[1]

"One of the fossils . . . . is a *Walchia*, which though badly

Plate 27. Badlands in Chinle formation 8 miles northwest of Holbrook, Arizona. Looking north to Montezuma's Chair and other igneous buttes.

smeared with mud appears to be identified with *Walchia piniformis*. The larger specimen, with closely placed lateral twigs, belongs to another *Walchia* resembling *Walchia hypnoides*. It is perhaps identical with that described by Dawson as *Walchia gracilis*. One or two small fragments in

[1]Gregory, H. E., Geology of the Navajo Country: U. S. Geol. Surv., Prof. Paper 93, p. 31.

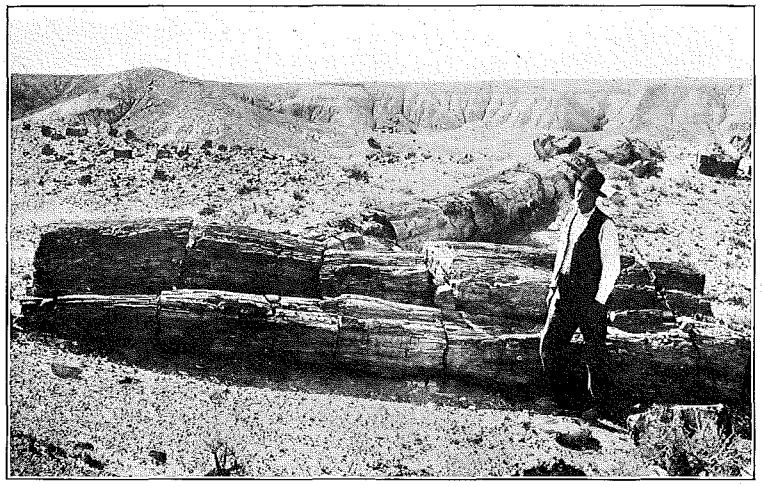


Plate 28a. Petrified logs from Shinarump sandstone, Petrified Forest, southeast of Holbrook, Arizona. Chinle formation in background.

one of the loose rock pieces agree still more closely with *Walchia gracilis*. These forms of *Walchia* are characteristic of the Permian and are present in Oklahoma and in the Wichita formation of Texas."

A few impressions of coniferous twigs and leaves found in the medial beds of the Supai formation just north of the automobile road about 5 miles west of Cibecue were examined by David White. He informs me that they are "almost certainly *Walchia gracilis*, a tree characteristic of the Permian." The horizon was about 60 feet above the "lower limestone member."

The evidence of these various fossils shows that the Supai formation as originally defined is all of Permian age.

PERMIAN SERIES

Hermit shale.—The formation which Noble[1] has separated as the Hermit shale is the upper red shale member of the Supai formation as originally defined. At Hermit Basin, the type locality, the rocks are described as deep brick-red, sandy shales and fine-grained, friable sandstones, 267 to 317 feet thick, the variation being due to the uneven surface on which the formation lies. It is everywhere overlain by the Coconino sandstone, with a very abrupt change of material, possibly indicating hiatus. The uneven basal contact of the Hermit shale is strikingly exhibited in Hermit Basin, and less distinctly at other places eastward in the south rim of the Grand Canyon, details of which have been described by Noble. As the Hermit shale is Permian, and most of the Supai formation is also of Permian age, it is likely that this unconformity represents only a very short time hiatus.

[1]Noble, L. F., *op. cit.*, Prof. Paper 131, p. 64.

The Hermit material is predominantly fine-grained and soft, but some beds are more compact than others and some are slightly coarser. Sun cracks, rain prints, and ripple marks occur. It is similar to many bodies of red, sandy shale included in the Supai formation. In the eastern part of the Grand Canyon outcrop it thins to 75 feet or less, but at Bass Canyon it is 332 feet and further west it increases to 500 feet. Noble records 80 feet of supposed Hermit shale west of Seligman. The formation disappears to the eastward in southeastern Coconino County, apparently by thinning out, and is absent in the southern part of the plateau area about Jerome, in the canyons of Sycamore and Oak creeks, and on the Verde River.

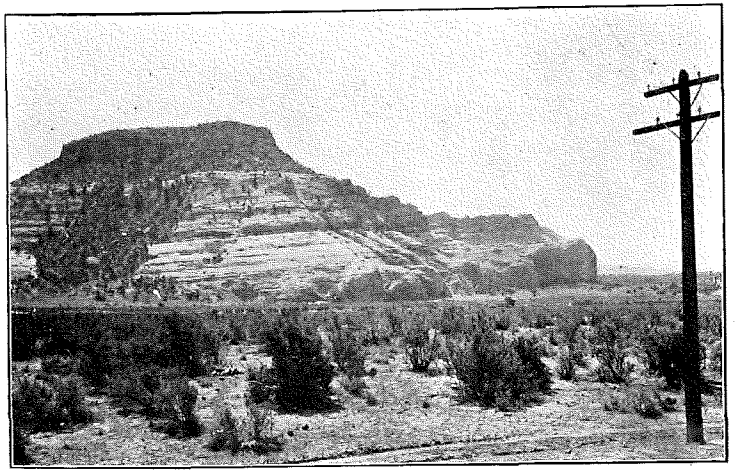


Plate 28b. Cliff of Wingate sandstone at Arizona-New Mexico State Line, looking south from A., T. & S. F. R. R., near Lupton Station. Navajo and McElmo? sandstones to the left.

Fossils found by Noble[1] and Schuchert[2] in the Hermit shale comprised a few foot tracks of queried genera of little value for correlation, and obscure plant remains. The latter were determined by David White as *Callipteris* sp. cf. *C. conferta*, *Walchia* cf. *W. gracilis*, *Gigantopteris*, cf. *sphenophyllum*, *Alethopteris?*, and *Pecopteris?*, which are regarded as Permian.

Coconino sandstone.—The light-colored, cross-bedded Coconino sandstone underlies all of the plateau region of northern Arizona, and also a portion of southern Utah. It is a prominent feature in the cliffs bordering the Grand Canyon and constituting the Grand Wash, Verde Breaks, and Mogollon escarpments. In the latter it extends eastward to the southwestern part of Apache County where it passes under the heavy

[1]Noble, L. F., *op. cit.*, pp. 353-354.

[2]Schuchert, Charles, *op. cit.*, pp. 65-66.

mantle of igneous rock of the White Mountains. It reappears again extensively in New Mexico as part of the Chupadera formation. The location of its original southern and southwestern margin can only be surmised. It extends far south in Arizona if the formation is represented by limestones or sandy and shaly beds in the Naco limestone, the upper part of which appears to be of Manzano (Permian) age. The outcrops on the sides of the canyon of the Colorado River are continuous for about 160 miles, the formation passing under the Kaibab limestone in the river bed a short distance below Lees Ferry. The outcrop extends some distance up the canyons of the Little Colorado River, Kanab and

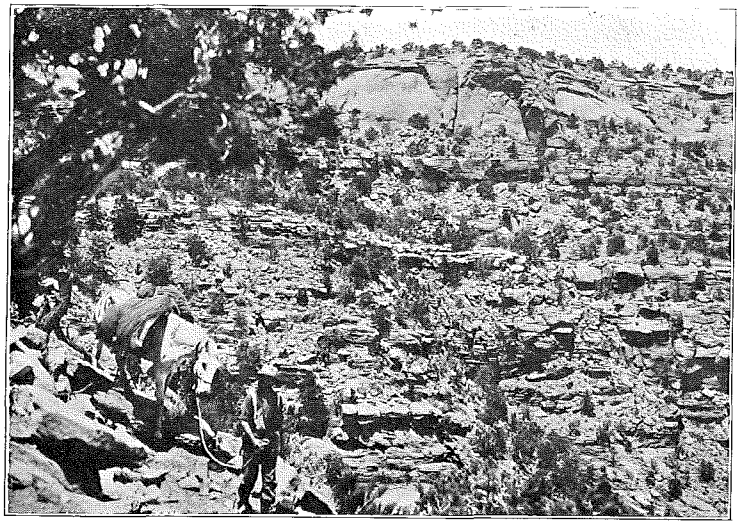


Plate 29a. "Todilto" formation in Piute Canyon near upper crossing, 25 miles northwest of Kayenta. Cliffs of overlying sandstone in background. Photo by Gregory.

Cataract creeks, and northward along the Grand Wash Cliffs north of the Colorado River, and southward along the face of Aubrey Cliff. The sandstone is uplifted and exposed over a considerable area extending from near Winslow to Holbrook and in the Defiance uplift in the central and northern part of Apache County where there cannot be the slightest doubt as to its identity.

The formation in the Defiance uplift has been called De Chelly sandstone by Gregory, and the substitution of Coconino for De Chelly, as here proposed, has not thus far been considered and passed upon by the United States Geological Survey.

The formation consists of sand, mostly in small grains of uniform size and light color, cemented to a rock of considerable hardness. Most of it

is cross-bedded, often on a large scale, and a large part at least has been wind blown. Some characteristic cross-bedding is shown in Plates 15, 17b, and 18b. In general, especially to the eastward, the rock presents a characteristic fawn or pale brownish color on weathering. A few thin beds of limestone are present in the formation in the east-central part of Arizona but they are minor features. To the eastward, however, in New Mexico, there is a thick alternation of sandstones and limestones constituting the Chupadera formation which comprises the Coconino and Kaibab sediments.

For many miles along the walls of the central part of the Grand Canyon, as shown in Plates 2, 9a, 10, and 15b, the Coconino sandstone is a conspicuous feature. It averages about 300 feet thick and the amount was

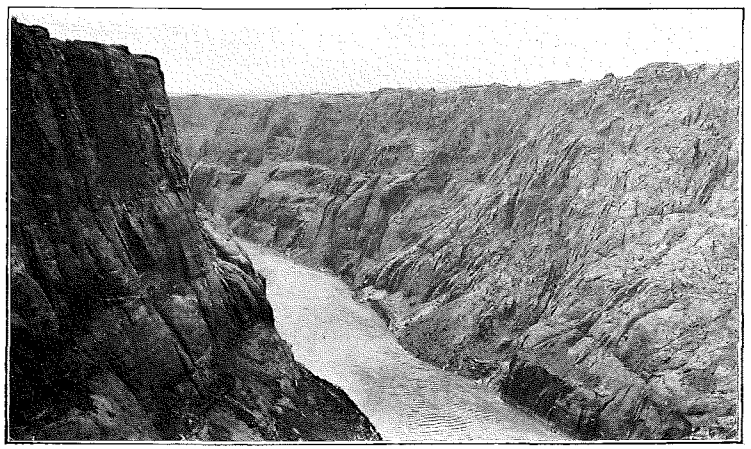


Plate 29b. Wingate sandstone? at Lees Ferry dam site in Glen Canyon on Colorado River. Photo by La Rue.

found to be about the same as this in Cataract (Havasu) Canyon, but it diminishes rapidly to the northward and northwestward. It is only about 30 feet thick on Kanab Creek and less than 50 feet in the Virgin Mountain region. It thins out entirely in southern Nevada and part of southern Utah. It thickens to the eastward to about 600 feet near Grand View and the mouth of the Little Colorado, and this amount is present in the region near Holbrook and the Defiance uplift. The formation reaches its maximum thickness in the Verde Breaks near Pine, where the amount appears to be nearly 1,000 feet and there are very notable exposures of it in the deep canyons of Oak and Sycamore creeks, as shown in Plate 18b. A thick development of the typical Coconino sandstone is revealed in the Canyon de Chelly, Canyon del Muerto (see Pls. 16, 18, and 63a), Nazlini, and Black Creek canyons in Apache County, and deep borings for oil south of Holbrook penetrated it for 620 feet to the underlying

red beds of the Supai formation. A boring at Winslow penetrated the sandstone from 100 to 965 feet and one at Coconino Siding near El Tovar penetrated it from 500 to 895 feet.

Noble[1] has given details regarding structure and petrography of the Coconino sandstone in the region near Bass Trail and eastward along the southern rim of the Grand Canyon.

No molluscan fossils have been obtained in the Coconino sandstone, but from the fact that it is included between strata of Permian age it is referred to that epoch. On the Hermit Trail Noble[1] and Schuchert found footprints of small amphibians, which have been classed as *Laoporus schucherti* and *L. noblei* by Lull,[2] both new species.

Kaibab limestone.—The Kaibab limestone constitutes the capping of

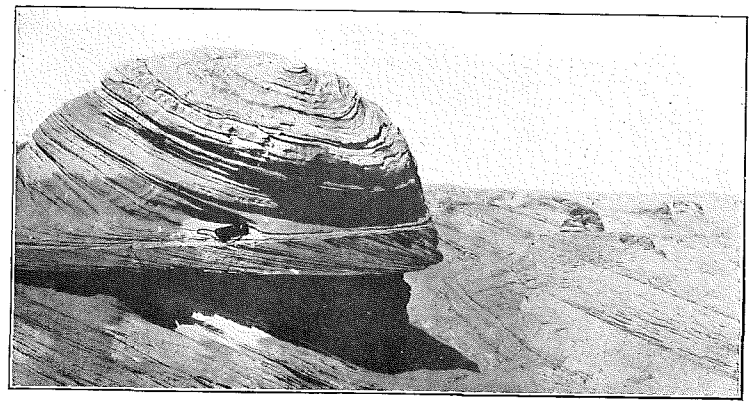


Plate 30a. Navajo sandstone showing characteristic cross-bedding, Kaibito Plateau north of Tuba. Photo by Gregory.

the greater part of the high plateau of northern central Arizona, of which various parts are known as the Kaibab, Arizona, Coconino, and Mogollon plateaus. To the west it is cut off by the Grand Wash fault, west of which it occurs in several detached blocks; to the southwest it ends in the Aubrey Cliffs, and to the south in the Verde Breaks. To the eastward it passes under the Moenkopi and overlying formations in the Painted Desert region, and finally thins out so that it is not present in the Defiance Uplift-Canyon de Chelly region. In the Flagstaff Mountain to Mt. Floyd volcanic region it is overlain by a great mass of igneous material and to some extent by Moenkopi formation, although locally it appears in several small uplifts and deep canyons. Apparently the formation is represented in the upper part of the Naco limestone of southeastern Arizona and other late Carboniferous successions in the south-

[1]Noble, L. F., *op. cit.*, Prof. Paper 131, pp. 66-68.
[2]Lull, R. S., *op. cit.*, pp. 338-341.

western part of the State; as stated above, fossils of Kaibab age were found at several places in the southwestern counties.

The formation is about 600 feet thick at El Tovar, which is the average for a wide area in the Grand Canyon region where in most places the surface has been eroded to an unknown extent. There appears, however, to be but few additional beds between El Tovar and Red Butte, where the limestone is capped by Moenkopi formation. Noble[1] found 562 feet at Bass Trail and 600 feet at Point Sublime, Dutton's Point, and some other places in the Shinumo region. In the cliffs near the Grand Canyon in the plateau west of Cataract Creek, and in the vicinity of Grand Wash, and near Marble Canyon, about 500 feet of the limestone remain. Reeside found 830 feet near the mouth of Hack's Canyon, 775

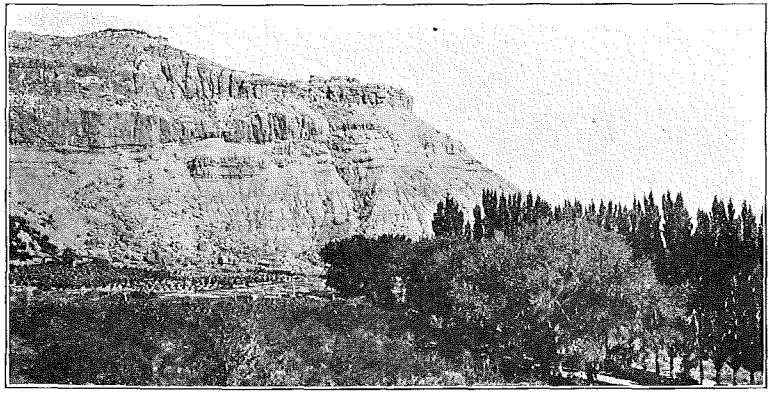


Plate 30b. La Plata sandstones at Moa Ave; shows soft lower members. Photo by Gregory.

feet on Toroweap, and about 950 feet on Virgin River and along the Hurricane Fault. On Cataract Canyon west of Anita there are about 425 feet. A recent measurement by Gregory and Noble of a complete section 12 miles southwest of Paria, Utah, gave 695 feet. In the plateau about Flagstaff and southward the limestone is from 200 to 300 feet thick. To the eastward it thins materially but in much of the plateau its surface is eroded. Near Mule Spring only 50 feet appear under the boulder cap of the Mogollan Plateau. West of Lakewood the amount is the same, the Cretaceous strata lying on its eroded surface. Near Heber in Navajo County, the thickness is less than 200 feet, and at the mouth of Pierce Wash into Black Canyon it is 150 feet. The amount diminishes to the northward in Navajo County, the formation thinning out a short distance south of Holbrook. It appears again to the north on Moonlight Creek in southern Utah, 20 miles north of Kayenta, where it is 4 feet thick.

[1]Noble, L. F., *op. cit.*, Prof. Paper 131, p. 70.

The Kaibab limestone consists almost entirely of limestone, with some portions dolomitic, and much of it is cherty. There are local sandstone members and gypsum, features which become prominent to the northwest and to the east. In the Grand Canyon region west of longitude 112° there is a very pronounced tripartite constitution, the upper member, 250 to 350 feet thick, consisting of light-colored, massive to slabby limestone with some chert; the middle member, 100 to 140 feet, of friable sandstone in which some gypsum appears to the west; and a lower member, 100 to 130 feet thick, of massive limestone above, passing down into alternations of sandstone and limestone. The medial member forms a pronounced slope between the cliffs of massive limestone. Walcott[1] found

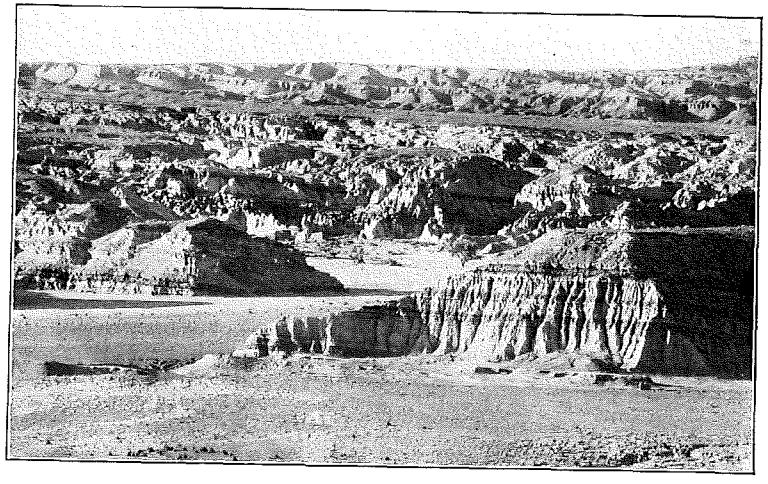


Plate 31a. McElmo? formation and overlying Cretaceous, Blue Canyon, 25 miles east of Tuba. Photo by Mendenhall.

this member well developed on Kanab Creek where it includes 125 feet of alternating layers of gypsum and soft sandstone. In Cataract Creek west of Anita it is represented by about 110 feet of yellow to brownish, sandy shale, the base of which is about 75 feet above the top of the Coconino sandstone. This medial member is shown in Plates 14c and 21b.

In the uplift at Crater Mound the Kaibab limestone is somewhat more than 150 feet thick, with Moenkopi above and Coconino sandstone below. In an arroyo east of Crater Mound, crossed by the automobile road about 11 miles west of Winslow, a 10-foot sandstone bed is exposed in the upper part of the Kaibab limestone. It is overlain by about 20 feet of limestone, but the arroyo is only deep enough to expose 10 feet of limestone below the sandstone. Doubtless the total thickness of the latter here is at least 100 feet.

[1]Walcott, C. D., *op. cit.*, Am. Jour. Sci., 3rd ser., vol. 20, pp. 221-225.

In examining the long slopes of the Arizona Plateau south of Holbrook and Winslow, it was found that the Kaibab limestone thinned rapidly to the northwestward, so that it finally thins out near Holbrook, where the red beds of the Moenkopi formation lie directly on the Coconino sandstone. In this region this characteristic sandstone is extensively exposed in the deep canyons of Chevlon, Clear, and Silver creeks and the Little Colorado River, and penetrated by deep borings to underlying Supai red beds, so that there could be no question as to the stratigraphic relations. In the next dome to the northeast, that of the Defiance uplift, the Kaibab limestone is absent, but in the Zuni uplift in New Mexico it appears again as a component of the Chupadera formation.

The thinning of the Kaibab limestone to the north and east in Navajo County is well exhibited in several deep canyons southeast of Winslow and west and south of Snowflake. Some features of the stratigraphy are shown in Fig. 1. Near Heber the limestone is about 200 feet thick and presents high cliffs, in most places with an outcrop of Coconino sandstone

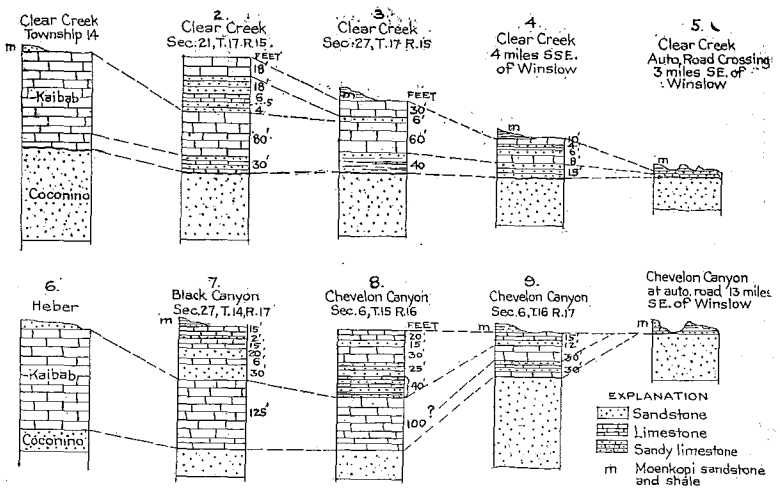


Fig. 1—Columnar sections of Kaibab limestone southwest of Holbrook.

at their base, while on the adjoining divides the limestone is capped by a thin but persistent member of hard sandstone of wide extent in this region. These limestone cliffs continue to the north down Black Canyon for several miles, and in Section 27, T. 14 N., R. 17 E., where the formation is somewhat more than 100 feet thick, it comprises the succession shown in section 7 in Fig. 1. A similar alternation of limestones and sandstones was observed in the wall of the canyon of Phoenix Park Wash in the southwestern part of T. 13 N., R. 18 E., which does not, however, reveal the underlying Coconino sandstone. Farther east, on Stinson Wash in Section 18, T. 11, R. 19, and also on Cottonwood Creek in the center

of T. 12, R. 19, a 15-foot bed of slabby sandstone is included in the Kaibab limestone. On Mortensen Wash, in the southern part of T. 11 N., R. 19 E., limestone members, parted by 6 feet of white sandstone, lie on a 50-foot bed of slabby to cross-bedded sandstone, presumably Kaibab, which lies on buff, cross-bedded sandstone closely resembling Coconino sandstone.

Black Canyon is shallow just below Lake Richards, in the southwest corner of T. 16 N., R. 17 E., and shows only 20 feet of the upper part of the Kaibab formation which includes two beds of gray, cross-bedded sandstone. The upper one of these is capped by 1 foot of limestone, above which is a massive red sandstone, the characteristic basal member of the Moenkopi formation. Six miles west of this point Chevlon Canyon, about 200 feet deep, reveals the lower beds, as shown in section 8 in Fig. 1.

At Sawyer's Ranch in Section 25, T. 15 N., R. 15 E., Chevlon Canyon is about 250 feet deep and cuts about 120 feet into the Coconino sandstone. The Kaibab beds comprise the following members:

SECTION IN CHEVLON CANYON AT SAWYER RANCH 25 MILES SOUTH OF WINSLOW

	Feet
Limestone of plateau (eroded somewhat)	10
Sandstone, white	5
Limestone	20
Sandstone	1
Limestone	8
Sandstone, white	8
Limestone, massive	80
Sandstone, platy	8
Limestone, thin-bedded	5
Coconino sandstone	

A view near this place is given in Plate 24b.

Eight miles farther down this canyon (northeast), or at a point 6 miles north of Lake Richards, the thickness of Kaibab beds has diminished to 87 feet, but the formation comprises the same alternation of sandstone and limestone members as in the region farther south. The section at this place is given in section 9, Fig. 1. Still farther north these beds all thin out, the lowest member, which consists of an alternation of sandstones and slabby limestones, continuing farther north than the overlying massive limestone member. At the automobile road bridge in Section 23, T. 18 N., the Moenkopi lies directly on the Coconino, which is finely exposed in and near Chevlon Canyon. Along Clear Creek the northward thinning of the Kaibab limestone is well exposed, as shown by sections 1 to 5 in Fig. 1. In township 14 there is nearly 100 feet of typical massive Kaibab limestone between the Moenkopi and Coconino sandstones, and at the place where Clear Creek is crossed by the automobile road, 3 miles southeast of Winslow, the formation is represented by a few feet of

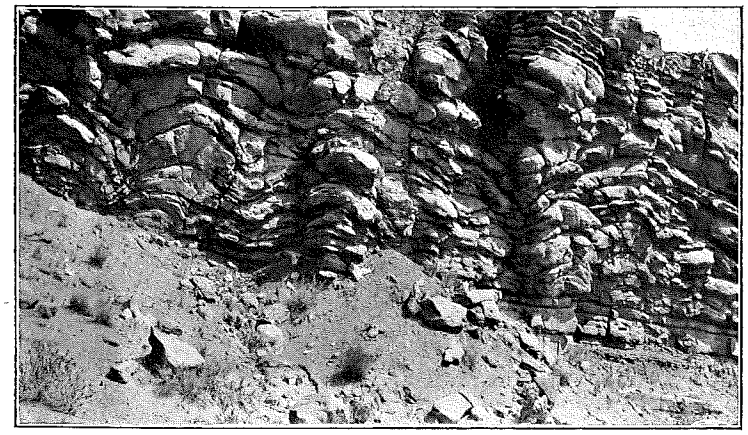


Plate 31b. McElmo? formation showing peculiar stratification, Garnet Ridge, 30 miles northeast of Kayenta, Arizona. Photo by Gregory.

buff, limy, slabby sandstone overlain by the massive basal sandstone of the Moenkopi, as shown in Plate 23b, which also shows the appearance of the extensive exposure of characteristic, cross-bedded Coconino sandstone near the road. A view farther south up Clear Creek Canyon is given in Plate 24a. At this place the Kaibab consists of an alternation of limestone and sandstone—here, as at all other localities, sharply separated from the underlying Coconino sandstone. By following the canyon north the thinning and disappearance of the limestone can be traced, bed by bed.

On most of the northern and eastern slope of the Holbrook dome the Kaibab limestone is absent. On the southwestern side of the dome the limestone appears, and west of the small fault in Section 28, T. 15 N., R. 18 E. its thickness is about 30 feet, including a 10-foot bed of slabby sandstone at the base, a feature which is also present in Black Canyon below Richards Lake, and in Potato Field Draw still farther west.

The Kaibab limestone is a prominent feature in slopes and cliffs south of the syncline of Dry Lake Valley. On the north side of that valley or on the south flank of the Holbrook anticline considerable limestone must be present, as shown by the extensive sinks which extend along the north side of Township 14 in Ranges 19 and 20 E.

A view of the rim of one of these sinks is shown in Plate 60b. The limestone is about 10 feet thick and overlain by Moenkopi beds; the underlying sandstone, 25 or 30 feet exposed, is so like the typical Coconino sandstone in cross-bedding and color that it would easily pass for that formation. However, although not exposed, the formation under the sink must clearly be limestone because there is no likelihood of salt or gypsum at the top of the Coconino sandstone, and moreover, the upper part of the Kaibab exposures in the region west and south consists of

alternations of limestones and sandstones, although most of the latter are slabby and not like typical Coconino. Moreover, the records of the deep borings, not far north, show alternations of sandstones and limestones near the top. However, a few miles farther north on the crest and northeast slope of the dome, the Kaibab beds thin out entirely. While it is possible that the sandstone is a top member of the Coconino, underlain locally by a limestone member, it is more likely a top member of the Kaibab as in the region south and west of Dry Lake Valley.

Very extensive exposures of Coconino sandstone, with all its typical features, occur along the Little Colorado River near and southeast of Holbrook, and extending up Silver Creek nearly to Snowflake without any overlying Kaibab beds. Near the latter place there appears to be a thin representative of the Kaibab limestone between the Moenkopi and the Coconino sandstone, consisting mostly of a buff, chalky rock in slabby beds 3 to 6 feet thick in all, extensively exposed on ridges north of Snowflake on the southeastern slope of the Holbrook dome. A mile southeast of Taylor, a small dome brings up this same chalky bed and reveals the underlying sandstone. This sandstone strongly resembles Coconino but may possibly be an extension of the sandstone member exposed at the Sinks and apparently belonging in the top part of the Kaibab limestone.

In the northwestern part of Arizona the Kaibab limestone includes several members not developed farther south. The stratigraphy in the northern part of this region has been described in detail by Reeside and Bassler[1] and I have verified most of their Kaibab sections. The thickness of the formation is between 900 and 1000 feet in most of the area which they examined. Five members were found as follows:

	Feet
1. Limestone, gypsum, and shale, with local cherty masses or fragments; local "Bellerophon limestone" at top	0–280
2. Limestone, very massive, much cherty limestone breccia at base in places	185–455
3. Gypsum, gray and yellow shale, some sandstone and thin limestone	80–285
4. Limestone, massive, cross-bedded, dark chert	150–230
5. Gypsum, gray and yellow shale, soft gray sandstone and thin dark limestone	0–100

These divisions are not present everywhere and they vary in thickness and character. No. 1, named the Harrisburg gypsiferous member, is absent in places, but it is highly characteristic and generally clearly separated from the overlying Moenkopi formation. Several sections constructed from lists of beds given by Reeside and Bassler are shown in Fig. 2.

[1]Reeside, John B., Jr., and Bassler, Harvey, Stratigraphic Sections in Southwestern Utah and Northwestern Arizona: U. S. Geol. Surv., Prof. Paper 129.

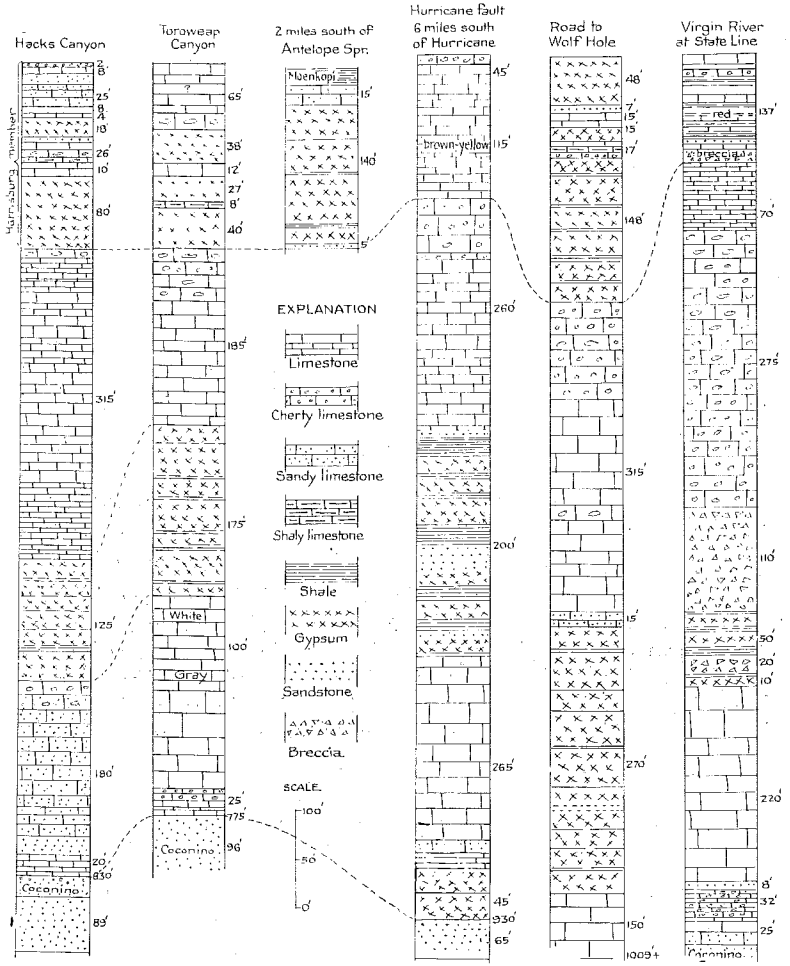


Fig. 2—Columnar Sections of Kaibab Limestone in Northwestern Arizona. (Reeside and Bassler)

In exposures along the Hurricane fault scarp the Kaibab limestone presents about the same succession of massive and softer limestones and gypsum as in the sections given above. Reeside and Bassler give the following sections. The first is in Black Rock Canyon close to the fault scarp, 18 miles south of Hurricane.

SECTION OF KAIBAB LIMESTONE 18 MILES SOUTH OF HURRICANE

	Feet
Limestone, gray, cherty, massive	high cliff
Gypsum, shale and some limestone	225

Limestone, thin-bedded	22
Limestone, massive, light gray, weathers brown, in part cherty	168
Sandstone, gray, fine, weathers brown	5
Gypsum	15
Limestone, thin-bedded, gray	60
Gypsum	20
Limestone, thin-bedded, gray	7
Gypsum, (on Coconino sandstone)	45

Three miles farther north, where the Rock Canyon conglomeratic member of the Moenkopi formation is seen lying unconformably on the massive limestone of the Kaibab, the following section is exposed:

SECTION OF KAIBAB LIMESTONE AT MOUTH OF ROCK CANYON, 15 MILES SOUTH OF HURRICANE

	Feet
Limestone, massive, gray, much dark chert	400
Gypsum, impure	55
Limestone, white, thin-bedded, cherty	20
Gypsum, impure	150
Limestone, upper part over the lower part gray, not much chert, not hard	40
Limestone, gray, cherty, massive	175
Gypsum, earthy, gray, impure, some limestone and sand (on Coconino sandstone)	108
	948

A section given by Reeside and Bassler near Black Rock Spring in Arizona, 25 miles south of St. George, Utah, shows the red shales, lime-

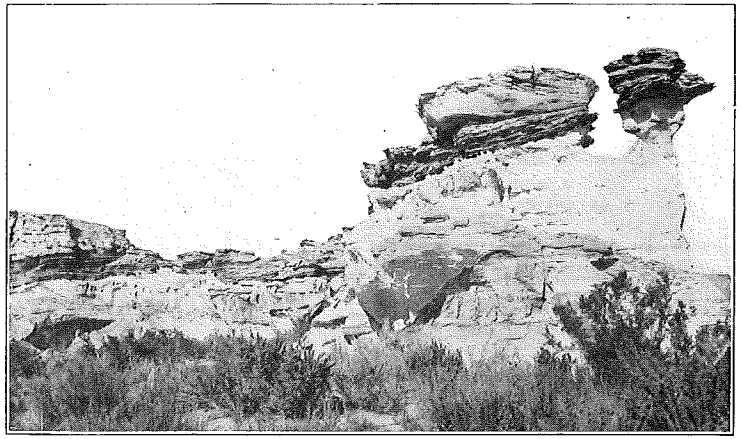


Plate 32a. Dakota sandstone on supposed McElmo formation. Blue Canyon line between Coconino and Navajo counties. Photo by Gregory.

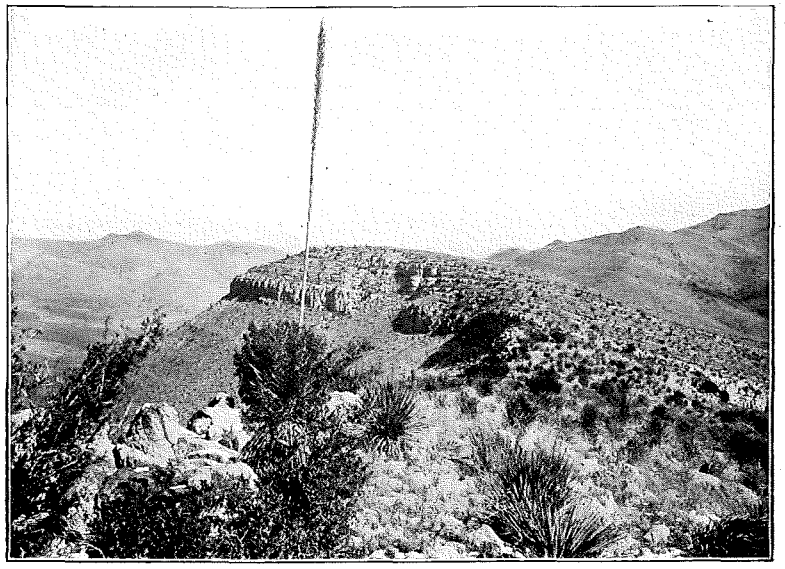


Plate 32b. Comanche series east of Bisbee. Mural limestone in middle, overlying Cintura formation to right. Photo by Ransome.

stone, and gypsum of the Moenkopi, underlain by the Harrisburg gypsiferous member of the Kaibab limestone about 110 feet thick, lying on the massive limestone, of which 250 feet are exposed. The gypsiferous member here presents the following section:

SECTION OF HARRISBURG GYPSIFEROUS MEMBER OF KAIBAB LIMESTONE, NEAR BLACK ROCK SPRING, 25 MILES SOUTH OF ST. GEORGE, UTAH.

	Feet
Limestone filled with nodules of white chert	25
Concealed	10
Limestone, granular, weathers white, fossils	7
Limestone, soft, weathers yellowish, many chert nodules	8
Gypsum, in part pinkish	43
Limestone, dark	4
Concealed, probably gypsum	8
Limestone, gray with much chert	4
Concealed, to cliff of massive Kaibab limestone	1

The fossils collected from the Kaibab limestone in the Grand Canyon region are as follows:[1]

[1]Noble, L. F., *op. cit.*, Bull. 549, p. 71; and Prof. Paper 131, pp. 70-71.

Sponges,
Lophophyllum n. sp.,
Crinoid stems,
Fistulipora sp.,
Meekopora sp.,
Stenopora sp.,
Septopora sp.,
Polypora sp.,
Lingulidiscina convexa,
Derbya sp.,
Meekella pyramidalis,
Chonetes aff. C. hillianus,
Productus occidentalis,
Productus ivesii,
Pustula aff. P. irginae,
Pustula subhorrida var. rugatula,
Pugnax osagensis var.,
Heterelasma n. sp.,
Squamularia guadalupensis,
Spirifer campestris,
Composita subtilita,
Aviculipecten, 2 sp.,
Acanthopecten occidentalis,
Pseudomonotis aff. P. hawni,
Anisopyge perannulata?

These were determined by G. H. Girty, who correlates the fauna with the Manzano group of New Mexico; it contains several species which are very similar to or identical with species which occur in the Guadalupian fauna.

Fossils were collected by Reeside and Bassler[1] from various horizons in the Kaibab limestone and determined by G. H. Girty. The highest or "Bellerophon limestone" of the Harrisburg member yielded the following:

Phyllopora? sp.,
Dielasma sp.,
Nucula levatiformis,
Leda obesa,
Aviculipecten? sp.,
Pteria (Bakewellia)? sp.,
Pseudomonotis? sp.,
Myalina sp.,
Schizodus wheeleri,
Pleurophorus mexicanus,
Plagioglypta canna,
Bellerophon majusculus,
Bucanopsis aff. B. bella,
Euphemus sp.,
Pleurotomaria sp.,
Goniospira sp.,
Naticopsis? sp.,
Euomphalus sp.,
Metacoceras sp.,
Platyceras sp.,
Nautilus sp.

Collections from the lower strata of the Harrisburg member included the following, all of Permian age.

Batostomella n. sp.,
Polypora sp.,
Derbya? sp.,
Chonetes hillanus,
Pugnax osagensis var.,
Spirifer sp.,
Spiriferina sp.,
Squamularia guadalupensis,
Composita subtilita,
Composita n. sp.,
Myalina aff. M. deltoidea.

The massive limestones of the Kaibab in northwestern Arizona yielded the following typical Kaibab (Permian) forms:

Echinocrinus sp.,
Spirorbis sp.,
Batostomella n. sp.,
Lioclema sp.,
Stenopora n. sp.,
Fenestella sp.,
Polypora sp.,
Derbya aff. D. nasuta,
Orthotetes sp.,
Meekella pyramidalis,
Chonetes hillanus,
Pustula aff. P. irginae,
Marginifera aff. M. splendens,
Dielasma sp.,
Squamularia guadalupensis,
Spiriferina sp.,
Composita mexicana?,
Composita subtilita,
Pseudomonotis? sp.

[1]Reeside, J. B., and Bassler, H., *op. cit.*, p. 66.

Gregory[1] collected fossils on the rim of the canyon of the Little Colorado 5 miles above its mouth, from a horizon clearly below the Moenkopi. They were determined by G. H. Girty as follows: "*Bakewellia* or *Pteria*, resembling *B. parva* and one or possibly two species of *Schizodus?*, an *Allerisma?*, *Pleurophorus?*, and *Euphemus*."

I collected fossils from the Kaibab limestone in the Aubrey Cliffs northwest of Seligman, which were determined by G. H. Girty as follows:

Fistulipora sp.,
Septopora sp.,
Meekella pyramidalis?
Orthotetes? sp.,
Productus ivesi?
Productus occidentalis,
Pustula subhorrida,
Pustula aff. montpelierensis,
Pugnoides n. sp.?,
Spiriferina campestris,
Squamularia guadalupensis?,
Composita subtilita.

From Kaibab limestone, 3 miles east of Pinedale, the following forms were collected. They were determined by G. H. Girty.

Echinocrinus sp.,
Edmondia sp.?,
Cardiomorphia? sp.,
Nucula levatiformis,
Schizodus wheeleri?,
Pleurophorus sp.,
Plagioglypta canna,
Euphemus sp.,
Goniospira? sp.,
Foordiceras? sp.

At the White River Cattle Company Ranch, on Corduroy Creek, fossils were collected from ledges at the base of the Kaibab limestone. The forms recognized by G. H. Girty were *Euomphalus cornudanus?* and *Schizodus* sp., a Manzano fauna.

PERMIAN-TRIASSIC UNCONFORMITY

Many observers have noted the unconformity between the Moenkopi red beds and the Kaibab limestone in northern Arizona. There is no notable difference in attitude of the strata but locally there is considerable channelling. In some places upper members of the Kaibab are absent, doubtless because of removal by erosion, and the basal bed of the Moenkopi is conglomeratic. Gregory[2] described a notable locality near the Little Colorado River, about 1½ miles south of Tolchaco, where the upper irregular surface of the cherty Kaibab limestone is overlain by a conglomerate of angular masses of limestone and angular and subangular pebbles of quartz in a matrix of lime and sand. This material lies in the hollows of the limestone. It was deposited in overlapping lenses all exhibiting cross-bedding. Various other instances in the valley of the Little Colorado are described by Gregory.

EARLY MESOZOIC INTRUSIVE ROCKS

There are many large bodies of granites and granitic rocks intruded in the Paleozoic rocks of southern, southeastern, and western Arizona, especially

[1]Gregory, H. E., *op. cit.*, p. 22.
[2]Gregory, H. E., *loc. cit.*, p. 21.

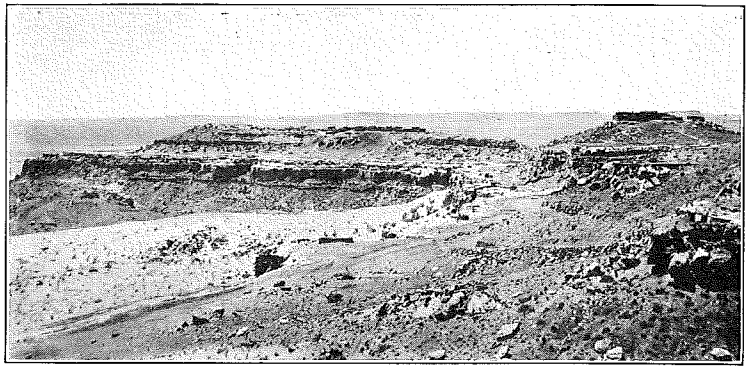


Plate 33a. Mesaverde sandstone in the mesas at Shipauluvi and Mishougnovi, Hopi Indian Reservation, 15 miles west of Keam's Canyon. Photo by Mendenhall.

in the latter region, which are believed to be considerably older than the Cretaceous-Tertiary intrusives. Owing to their similarity in general appearance to the pre-Cambrian granites, and to lack of evidence as to local relations, it has not been possible to differentiate them in all places.

Schrader[1] has mapped and described large masses of granite in the Santa Rita Mountains and a smaller mass in the northern part of the Empire Mountains. Some of this granite cuts the Cambrian, Devonian, and Carboniferous rocks, but granite of pre-Cambrian age is also revealed by erosion of the overlying Paleozoic rocks.

Bryan[2] found granitic rocks, monzonite, and rhyolite at various places in the Papago region, notably in the Palo Verde Mountains, the Little Ajo Mountains, the ridges in the pass north of Table Top Mountains, the Maricopa Mountains near Estrella, the O'Neills Hills, the Tule

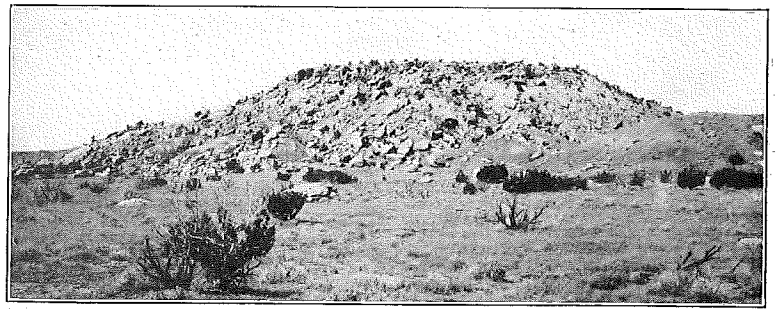


Plate 33b. Dakota (?) sandstone on Chinle formation 16 miles east of St. Johns, Arizona. Looking north.

[1]Schrader, F. C., *op. cit.*, Bull. 582, pp. 57-59.
[2]Bryan, K., *op. cit.*, pp. 26-26.

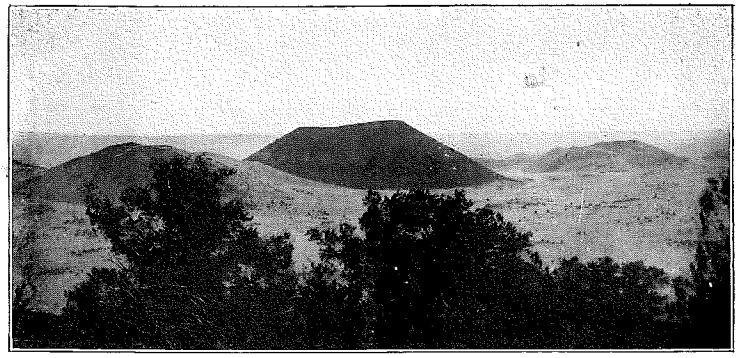


Plate 33c. Recent cinder cone and lava flow on east side San Franciscan volcanic field. Photo by Gilbert.

Mountains, and in the Tinajas Altas Mountains. He also noted fractured and altered porphyritic felsite of "pre-Tertiary" age in the Papago Saguaro National Monument north of Tempe, and in Growler Pass.

On the west side of Dome Rock Mountains west of Quartzsite and in some of the ridges next north in the Colorado River Indian Reservation, Jones[1] found granites penetrating schists and quartz diorites believed to be pre-Cambrian in age. He regarded this granite as post-Paleozoic.

Bancroft[2] and Ross[3] found granites and granitic rocks of probable post-Paleozoic age in central Yuma County and western Maricopa County. These granites are difficult to distinguish from the pre-Cambrian granites, especially in areas where contact relations are not exposed. Ross mentions fresh gray granite without gneissic structure in the southern part of the Buckskin Mountains north of Bouse, which he regards as probably Mesozoic. Similar rocks were recognized by Bancroft in Harcuvar Mountain and Granite Wash Hills northwest of Wendon, and by Jones near Kofa and Polaris and in the Dome Rock Mountains and ridges north. Ross has mapped two large areas of younger granite in the Sierra Estrella, on the authority of Schrader.

In the Planet region in the northwestern part of Yuma County there are intrusions of rhyolite porphyry which have been described by Blanchard.[4] He regards the rock as pre-Cambrian in age because it is considerably metamorphosed, but some of the masses, at least, appear to cut Carboniferous limestone.

In various parts of northern Mohave County Schrader[5] found granitic

[1]Jones, E. L., Jr., Gold Deposits near Quartzsite, Arizona: U. S. Geol. Surv. Bull. 620 (c), pp. 47-48, 1915.

[2]Bancroft, H., *op. cit.*

[3]Ross, C. R., *op. cit.*, pp. 183-186.

[4]Blanchard, R. C., *op. cit.*, pp. 20-22.

[5]Schrader, F. C., *op. cit.*, Bull. 397.

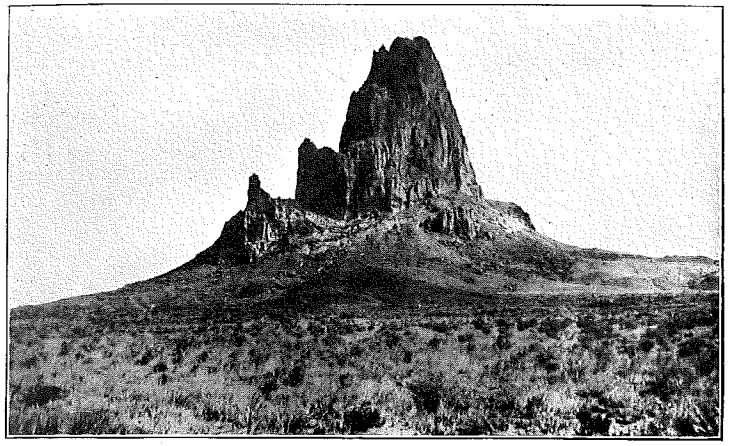


Plate 34a. Agathla, a volcanic neck, 1,225 feet high, northeast of Kayenta. Photo by Gregory.

rocks of post-Paleozoic age cutting the pre-Cambrian complex. The principal rocks in this category are granites and granite porphyries of various types, and dark lampophyric dikes such as minette or vogesite, and possibly some diabase. In places the younger granites

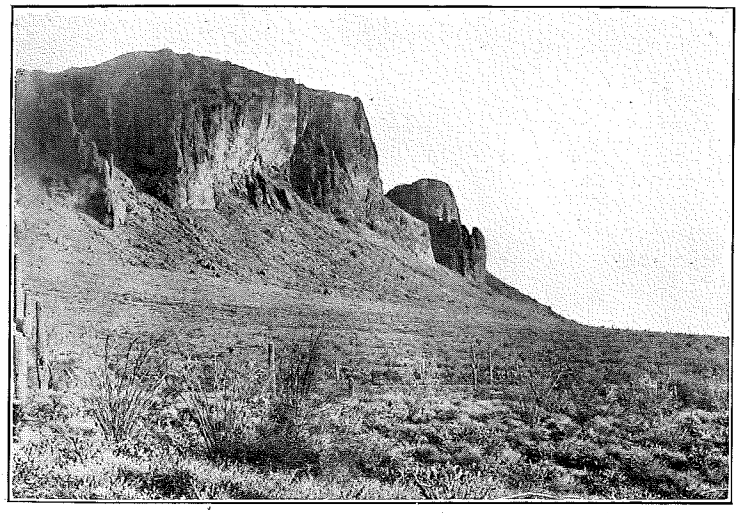


Plate 34b. Tertiary volcanic rocks in west face of Superstition Mountain 30 miles east of Phoenix, Arizona. Photo by W. T. Lee.

are difficult to distinguish from the pre-Cambrian rocks, especially where there is much close jointing simulating schistosity. Granite porphyry was found mainly in the Cerbat Mountains where it extends from Stockton Hill to Chloride with a few interruptions. An allied rock occurs in Black Mountains, in the Hardy Mountains, and 4 miles northwest of the latter range. Quartz monzonite and hornblende granites occur in the Music Mountain district, but they are not seen in contact with the Paleozoic rocks.

Supposed early Mesozoic intrusive rocks are described by Ransome[1] in the Globe and Ray mining districts.

TRIASSIC SYSTEM

General relations.—Much of the high plateau region in northeastern Arizona is underlain by red shales and sandstones of Triassic age, and outlying areas extend south nearly to the edge of the Mogollon Plateau near longitude 110°, and westward to beyond longitude113°. They also occupy a downfaulted block along the east side of the Virgin Mountains. Triassic rocks appear to be absent, however, in the southern and west-central parts of the State. In the southeastern counties, where Lower Cretaceous strata lie directly on Carboniferous limestones, Triassic sediments may never have been deposited, or if deposited, they were removed by erosion in the long interval of latest Triassic, or Jurassic time.

Moenkopi formation.—The Moenkopi is a conspicuous formation in the plateau region of northern Arizona, especially in the valley of the Little Colorado River, in the uplift in the northern part of Navajo County, in the slopes at the foot of Echo and Vermilion Cliffs, under some of the lava flows on the Coconino, Unikaret, and Shiwits plateaus, and also west of Hurricane fault; a small area was found on the east side of the Virgin Mountains. To the east and south of Echo Cliffs the formation consists of a rather monotonous succession of red sandstones and shales, from 300 to 400 feet thick; it thins out entirely in the central and northern parts of the Defiance uplift.

The Moenkopi formation is extensively exposed along the valley of the Little Colorado River from Holbrook to its mouth, an area which has been described in considerable detail by Gregory. One complete section about 5 miles below Tanner Crossing[2] shows 389 feet of beds consisting of alternations of shales and sandstone mostly red brown to chocolate colored, the sandstones largely in members 2 to 5 feet thick and the shale in bodies 15 to 25 feet thick. In the middle there is a 40-foot member of shale, chocolate colored to red, with gray and lavender lenses and some sandy and sandstone layers. Next below are 52 feet of fine-grained sandstone, chocolate red with streaks of maroon and purple. There is

[1]Ransome, F. L., *op. cit.*, Prof. Paper 115.

[2]Gregory, H. C., *op. cit.*, Prof. Paper 93, p. 24. Given in modified form in Am. Jour. Sci., 4th ser., vol. 38, pp. 497-498, 1914.

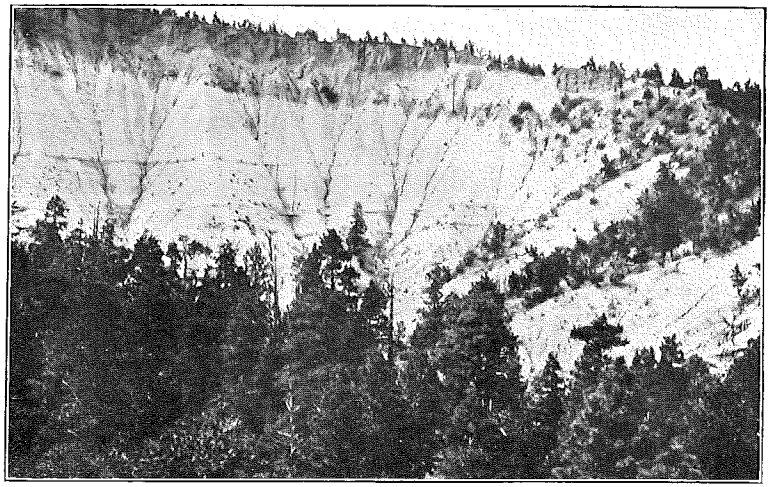


Plate 35a. Tertiary tuff and ash deposits at New Mexico line 12 miles southeast of Springerville, Arizona, looking east.

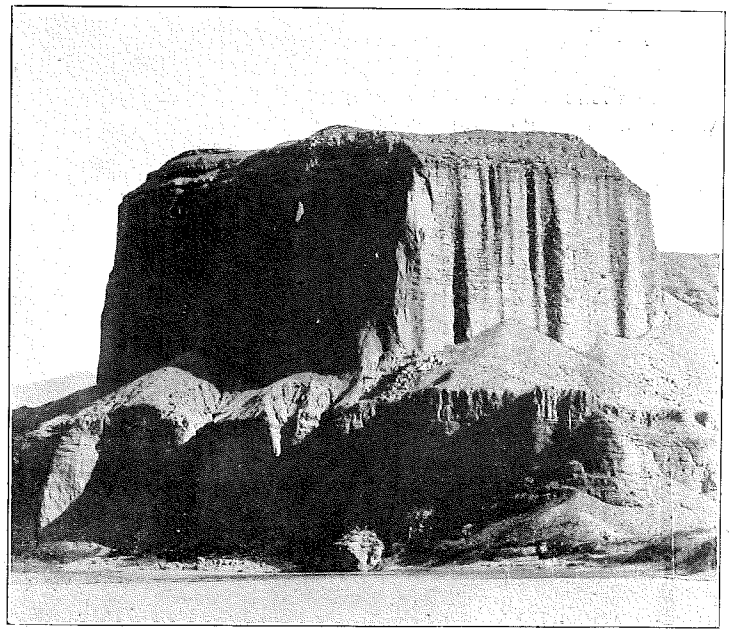


Plate 35b. Temple Bar conglomerate at Temple Bar on the Colorado River. Photo by U. S. Reclamation Service.

some cross-bedding and a few conglomeratic streaks. This member forms a cliff and is separated from the Kaibab limestone by 100 feet of shale of chocolate color with white bands. There are, however, so many variations in the stratigraphy that no two sections are closely alike. A typical exposure is shown in Plate 25a. North and east of Box Springs there are beds of massive shale which weather into badlands of ash gray, maroon, black, and light red colors. Mud cracks and ripple marks are frequent on the surface of the beds. Some notable features of this kind were observed in the lower part of the valley of Canyon Diablo.

Gregory reports a section 2 miles east of Holbrook in which about 124 feet of beds appear, consisting of alternations of sandstone and shale, mostly of red or chocolate color, mainly in bodies 3 to 27 feet thick, but varying considerably from place to place.

In much of the region near Winslow and Holbrook a bed of gypsum, generally 2 to 3 feet thick, occurs about 60 feet above the base of the formation, probably the same as the one mentioned by Gregory, between Aztec and Winslow and between Grand Falls and Black Falls. From near Canyon Diablo eastward, there is a distinct basal member of massive sandstone mostly red and fine-grained. It is quarried at Sunshine and an outlier of it has been quarried extensively just east of Flagstaff.

The Moenkopi formation is brought to the surface in the southern part of the Defiance uplift, but its thickness is greatly diminished, and it thins out and disappears to the north, where the Shinarump conglomerate lies directly on the Coconino sandstone, as shown in Plate 26b. Outcrops were found at intervals along the east side of the Defiance uplift from the Santa Fe Railroad to a point a few miles north of Fort Defiance, where the formation thins out.

In the vicinity of Black Canyon and St. Michaels, all that remains of the Moenkopi is about 40 feet of red and gray sandstones with interbedded red shales. Between these two points, however, the formation is cut out by the fault shown in Plate 61. In the gorge just west of Fort Defiance the formation is well exposed, lying on typical Coconino sandstone and overlain by typical Shinarump conglomerate, as shown in Plate 25b. The Moenkopi beds are alternations of red shales and sandstone, the latter mostly gray, with a 30-foot member of red sandstone at the top which, however, may possibly be a lower member of the Shinarump. The thinning and absence of the Moenkopi on the Defiance uplift may be due either to limitation in the original deposition, or to erosion due to local uplift prior to Shinarump deposition.

The Moenkopi formation is extensively exposed in Monument Basin west of Comb Ridge, and also in the valley of Moonlight Creek, where its thickness is 300 feet or more. The rocks are red, sandy shales, having the character of the formation near the Little Colorado, but there is included near the middle of it a member of massive, light-gray sandstone, which is conspicuous in some of the monuments and cliffs of the region. (See Pl. 61a.) This sandstone is in a succession which in southeastern

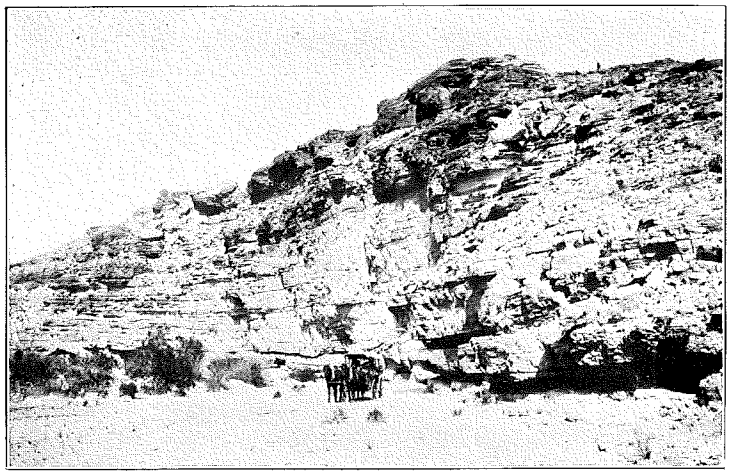


Plate 36a. Limestone of Tertiary or early Quaternary age in lower part of Hualpai Arroyo. Photo by W. T. Lee.

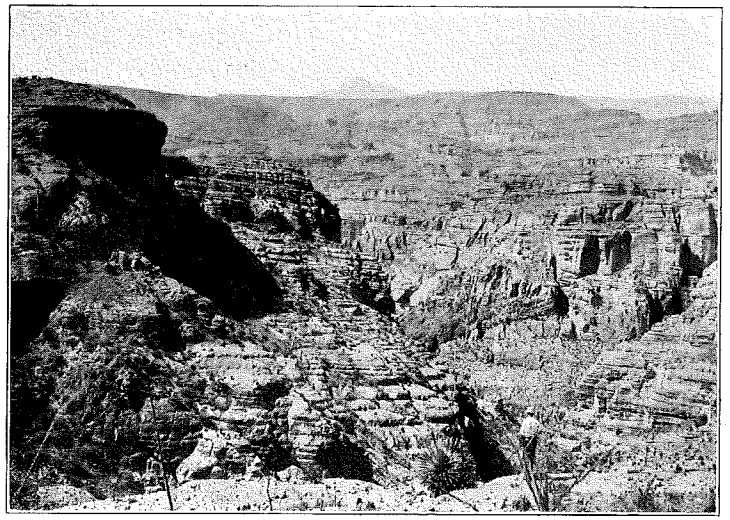


Plate 36b. Gila conglomerate and Tertiary volcanic rocks in Canyon del Oro, on road from Phoenix to Roosevelt Dam. Photo by U. S. Reclamation Service.

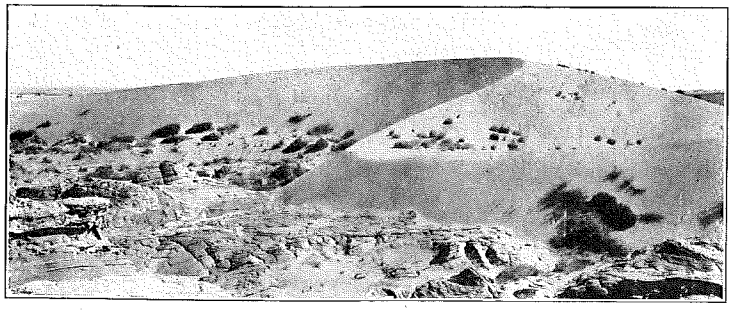


Plate 37c. Gila conglomerate in slopes north of Pinal Mountains near Globe, Arizona. Looking east. Photo by Ransome.

base a limestone and shale member 198 feet thick and a shale and sandstone member above extending to the base of Shinarump. The limestone in the lower division carries a fauna now known to be Lower Triassic.

A section of the Rock Canyon conglomeratic member of the Moenkopi, in the typical locality at the head of Rock Canyon 5 miles north of Antelope Spring, Arizona, is as follows:

SECTION OF MOENKOPI AT THE HEAD OF ROCK CANYON

	Feet
Limestone, pale red, some gray	30
Limestone, gray	15
Conglomerate of rounded and subangular fragments of quartz and chert, white to dark gray up to 12 inches, but mostly less than 5 inches	55
Conglomerate, coarse, with large nodules of blue chert 1 inch to 1 foot	15
Limestone, gray to white, some chert	4
Conglomerate of large blue limestone cobbles in white granular matrix	2
Limestone, coarse, granular; base irregular	10
Sandstone, soft, and limestone and limestone breccia, cherty in part	25
Limestone, light yellow, filled with white, platy chert	6
Sandstone, yellowish gray, grading laterally into sandy limestone	6
	185

At the mouth of Rock Canyon, which is at the Hurricane fault, 15 miles south of Hurricane, Utah, the member consists of 25 feet of black, thin-bedded limestone, 70 feet of dense, gray limestone, and 100 feet of gypsum and red shale, 195 feet in all, lying unconformably on massive Kaibab limestone, of which, however, the upper (Harrisburg) gypsiferous member is absent.

Near Black Rock Spring, Arizona, 25 miles south of St. George, Reeside and Bassler report the following section of the lower members of the Moenkopi:

SECTION OF THREE LOWER MEMBERS OF MOENKOPI FORMATION NEAR BLACK ROCK SPRINGS, IN ARIZONA, 25 MILES SOUTH OF ST. GEORGE, UTAH

	Feet
Virgin limestone member (100 feet) of the following beds:	
Limestone, earthy yellow	9
Shale, red	36
Limestone, earthy yellow	5
Shale, red	26
Limestone, earthy yellow (fossils)	24
Shale, red, with beds of gypsum in lower part	153
Gypsum, reddish above, yellowish brown below	27
Lies unconformably on Harrisburg gypsiferous member of Kaibab.	

Reeside and Bassler[1] obtained much new fossil evidence as to the Lower Triassic age of the Moenkopi formation in southwestern Utah and the adjoining portion of Arizona.

The Rock Canyon conglomeratic member yielded the following:

Spirorbis sp.,	Pseudomonotis n. sp.,
Discina sp.,	Naticopsis sp.,
Terebratula sp.,	Pleurophorus sp.,
Bakewellia n. sp.,	Pseudomelania? sp.,
Myalina sp.,	Turritella, several n. sp.,
Myophoria? sp.,	Meekoceras aff. M. mushbachanum.

From the Virgin limestone member were obtained the following:

Isocrinus sp.,	Myalina n. sp.,
Spirorbis sp.,	Aviculipecten, 4 sp.,
Pugnax n. sp.,	Myophoria? sp.,
Terebratula? n. sp.,	Pleurophorus, n. sp.,
Pinna? sp.,	Pleurotomaria, 2 sp.,
Bakewellia n. sp.,	Naticopsis sp.,
Pseudomonotis n. sp.,	Ammonite?.
Monotis? sp.,	

These fossils were determined by G. H. Girty, who regards them as Lower Triassic, and they have been placed in this system by the United States Geological Survey. The fauna correlates closely with that of the well established Lower Triassic of Idaho and the Wasatch Mountains.

The statement of Dr. Girty[2] in this connection is as follows:

"As regards the evidence furnished by the Moenkopi beds themselves, I have identified *Meekoceras*, one of the distinctive ammonites of the Idaho faunas, both in the present collections and in Mr. Walcott's, and there are a few other characteristic Triassic types, though less important ones. I may also point out that there is an almost complete faunal change from the Kaibab to the Moenkopi. Both faunas are fairly extensive, but I know of no species that they contain in common. Furthermore, all the characteristic Paleozoic genera of brachiopods become extinct with the Kaibab—*Productus*, *Chonetes*, *Derbya*, *Meekella*, *Spirifer*, *Composita*, and

[1]Reeside, J. B., and Bassler, H., Prof. Paper 129, p. 67.
[2]U. S. Geol. Surv., Prof. Paper 129, p. 68.

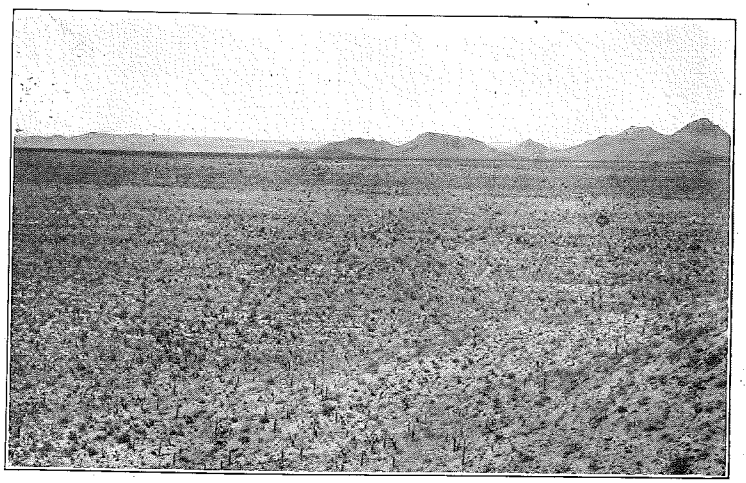


Plate 38a. Typical desert of western Arizona. Detrital—Sacramento Valley looking northwest from the south end of Hualpai Mountains, Arizona. Photo by W. T. Lee.

a score of others—not to mention the numerous bryozoan types—*Fenestella, Septopora, Rhombopora, Stenopora,* and many more. These types appear neither in the typical Moenkopi nor elsewhere in the Lower Triassic of this region. Furthermore, the Kaibab, which is correlated with

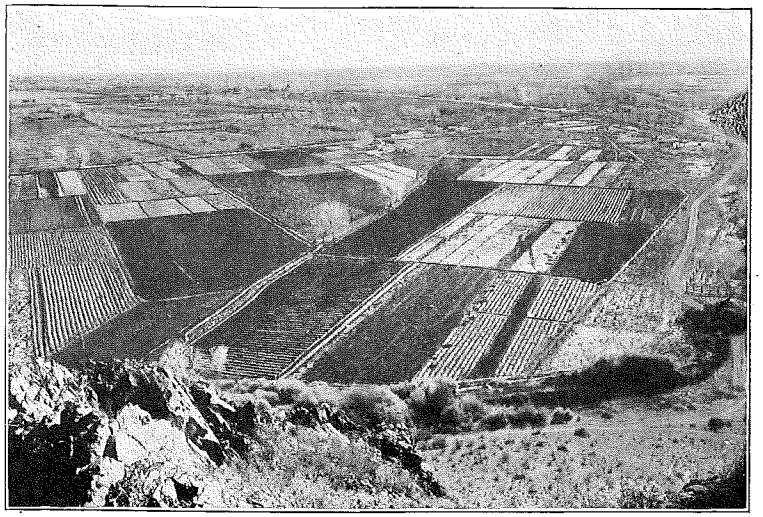


Plate 38b. Alluvial plain, Salt River Valley. Looking east from Tempe Butte. Photo by W. T. Lee.

part of the Manzano group of New Mexico, is itself Permian. . . . . "I think that we have here an almost perfect example of a boundary between two geologic systems, the formations being separated by a profound erosional unconformity and by an almost complete change of fauna, the upper formation containing many diagnostic fossils of the latter system and the lower formation containing many diagnostic fossils of the earlier system."

A few fossils were found by Veatch[1] in strata below the Cretaceous coal measures north of Pinedale, doubtless in Moenkopi beds, which were reported by Dr. Girty as probably *Schizodus* cf. *S. ovatus* or *affinis* and *S. symmetricus*, *Petria* or *Bakewellia?*, and a possible *Schizostoma*.

In the Moenkopi formation at Tucker Springs, E. C. Case collected a bone fragment believed to be *Metoposaurus*, closely allied to *Metoposaurus frassi*, a distinctly Triassic species.[2]

Shinarump conglomerate.—The thick succession of fine-grained, red beds representing the Triassic system in northern Arizona is generally separated into two formations by a thin deposit of coarse sandstone and conglomerate known as the Shinarump conglomerate. This formation is thin but persistent, and on account of its hardness makes a prominent bench in most parts of its outcrop.

The Shinarump rocks vary greatly in character from place to place, but coarse sand, irregularly conglomeratic, is a nearly constant feature. Some extensive layers of coarse pebble conglomerate occur and locally constitute the entire mass of the formation. Much of the coarse material is in channels or lens-shaped masses. (See Pl. 26a.) Ordinarily the rock is hard, but in places it is loosely cemented or cemented by carbonate of lime and rapidly crumbles into gravel or sand. The predominant color is gray. Scattered boulders occur, and there are included beds of shale or fine sandstone, mostly of red tint. In the Defiance uplift the lower part of the formation is a slabby red sandstone. The coarser materials generally present cross-bedding. The components are predominantly quartz and quartzite but pebbles and boulders of chert and limestone occur locally. A large amount of petrified wood occurs in the formation throughout its extent.[3]

The outcrop of Shinarump conglomerate rims the eastern, southern, and western margins of the Black Mesa structural basin in northeastern Arizona, with almost continuous outcrop from Holbrook to Lees Ferry on the one hand, and from Holbrook northeastward around the Fort Defiance uplift to beyond lat. 36° 30′. It also appears extensively in the uplift north of Kayenta, where it caps various mesas and "monuments." In the central and northern part of the Defiance uplift it lies directly on the Coconino sandstone as shown in Plate 26b.

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[1]Veatch, A. C., *op. cit.*, p. 241 (Bull. 431).

[2]Gregory, H. E., *op. cit.*, p. 35.

[3]Gregory, H. E., The Shinarump Conglomerate: Am. Jour. Sci., vol, 35, pp. 424-438, 1913.

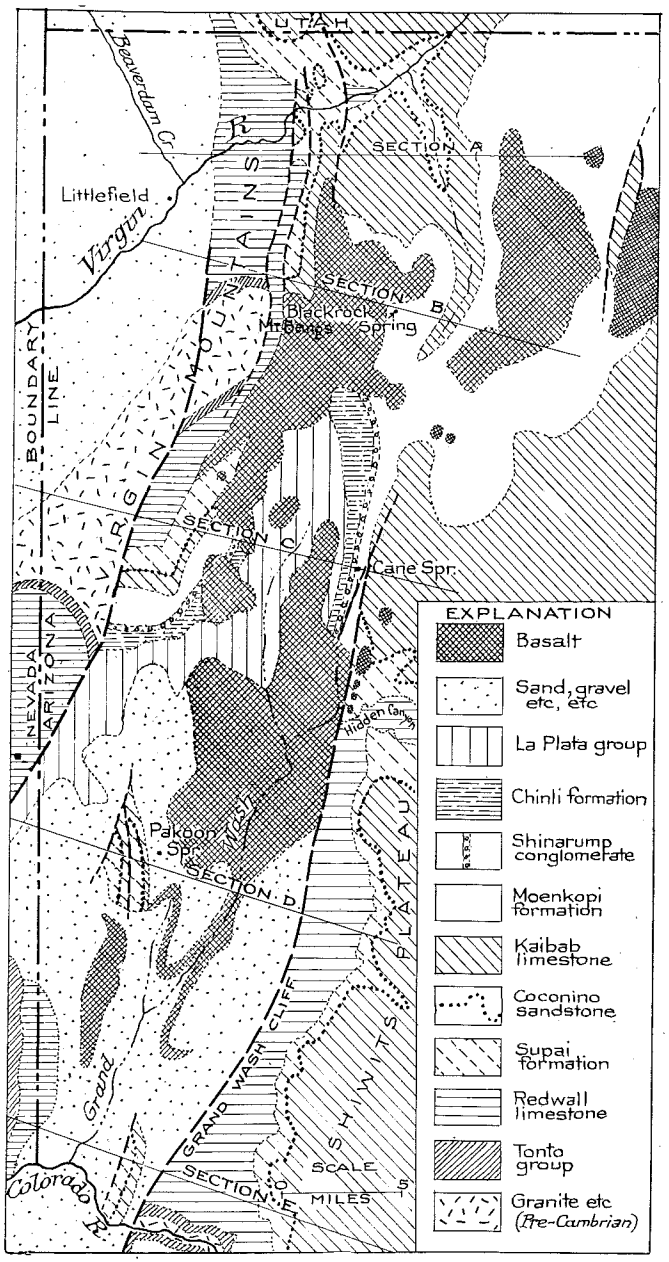


Plate 39. Reconnaissance geologic map of Virgin Mountains, by N. H. Darton. Heavy dash lines are faults.

Gregory[1] gives the following thicknesses for the Shinarump conglomerate: Lees Ferry, 45 feet; Willow Springs, 50 feet; mouth of Moenkopi Wash, 30 to 60 feet; 4 miles southeast of Black Falls, 30 feet; north of Tolchaco, 30 feet; Tucker Springs, 40 to 50 feet; Hardy, 30 feet; Querino, 25 feet; Fort Defiance, 20 to 40 feet; Buell Park, 80 feet; Chinle, 20 to 60 feet; Sehili, 40 to 60 feet; Oljeto Ranch, 45 feet.

I have observed the Shinarump conglomerate in a wide area in northern Arizona, and found no evidence of any notable unconformity or time break between it and the Moenkopi, except that in part of the Defiance uplift the latter may have been removed by pre-Shinarump erosion. In geologic successions generally, there is at most places a sharp break between coarse sediments lying on finer grained ones, caused by strong currents which transported the coarse materials. This feature is locally exhibited at the Shinarump-Moenkopi contact, and while there is some local erosion and channelling, apparently it represents no more than the result of an abrupt change of conditions from slack water overflow or weak currents of Moenkopi time, to strong currents which deposited the Shinarump.

The Shinarump conglomerate appears at several localities in the northern part of Mohave County. It forms a wide bench along the south foot of the Vermilion Cliff west and southwest of Fredonia, and at the western end of these cliffs it caps several high mesas of considerable extent. Its thickness is less than 100 feet at most places, and it consists in part of conglomeritic sandstone much harder than the adjoining red shale. The formation constitutes some rocky knobs and ridges at the foot of the Hurricane ledge on Rock and Pierce creeks at the Utah State line.

The Shinarump conglomerate extends along the eastern foot of the Virgin Mountains, one outcrop passing through Cane Spring and the other lying 6 to 10 miles west of that spring.

Chinle formation.—This name, applied to the shale above the Shinarump conglomerate, was introduced by Gregory,[2] who mapped the formation in a wide area in the Navajo country in northern Arizona. Four principal divisions were described, as follows:

SUBDIVISION OF CHINLE FORMATION IN NORTHERN ARIZONA

A. (At the top.) Shales and shaly sandstones of red, brown, and pink color, rarely gray, with a few thin beds of limestone and limestone conglomerate.

B. Cherty limestone, gray, pink, and purple, and red shale in alternatnating beds, the limestones 1 to 6 feet and shales thin; conspicuous west of Chinle and on Leroux Wash.

C. Shale with rare calcareous sandstone, all lenticular and variable, variegated tones of pink, red, ash, and purple. Includes some limestone conglomerate, gypsum, and much petrified wood. Weathers into badlands as in Cottonwood Wash, Black Creek Valley, Beautiful Valley, and Round Rock fossil forest.

[1]Gregory, H. E., *op. cit.*, Prof. Paper 93, pp. 37-42.

[2]Gregory, H. E., *op. cit.*, Prof. Paper 93, p. 42.

D. Shales (70 per cent), shaly sandstones (30 per cent), dark red, light red, chocolate, and rarely gray, some lenses of conglomerate, of lime and clay pebbles, gypsum, and petrified wood, rough topography. Lies on Shinarump conglomerate.

A typical section in the Chinle region and northeastward is given by Gregory as follows:

SECTION OF CHINLE FORMATION IN CHINLE REGION, ARIZONA

	Feet
Wingate sandstone, light red, massive, cross-bedded.	
1. Sandstone in beds 3 inches to 4 feet thick and arenaceous shales; light red to yellow-red, mottled with green-white spots; very fine white or rarely red quartz; cement calcite stained with iron; weathers into miniature flat-topped mesas. Thickness, average of three sections	315
2. Limestone, gray-green to pink, massive; abundant chert fragments 1 to 2 inches in diameter; very hard; forms mesa cap over large areas	4
3. Shale, light red, arenaceous, calcareous	6
4. Limestone, green-gray to pink, massive, cherty	3
5. Shale, light red, calcareous	17
6. Limestone, pink, massive, conglomeratic	3
7. Shale, dark red, calcareous	7
8. Limestone, pink, massive, cherty	2
9. Shale, red, highly calcareous	27
10. Limestone, gray-pink, massive; much chert; prominent cliff maker	3
11. Shale, light red mottled, calcareous, with lenses of limestone conglomerate 2 to 4 inches thick	45
12. Limestone, pink, cherty; bone fragments	1
13. Shale, light red mottled, calcareous	11
14. Limestone, red mottled, massive	2
15. Shale, light red mottled	10
16. Limestone, pink, with limestone and chert nodules in two bands	6
17. Shale, yellow-red, calcareous	30
18. Limestone, pink, cherty	5
19. Shale, light red, calcareous	28
20. Limestone, mottled, cliff maker; includes teeth and bones of *Metoposaurus*	4
21. Shales and shaly limestone, variegated, irregular foliation; include concretionary pebbles of limestone, mud pellets, and a little gypsum	30
22. Shales and "marls," brightly colored red, purple, gray, rarely yellow and blue; structure and composition widely and abruptly variant; series of short overlapping lenses of calcareous shale, arenaceous limestone, limestone conglomerate, fine and coarse sandstone, and amorphous clays; contain concretions of limestone, mud lumps, clay pellets, and balls of coarse sand; gypsum common in veins and disseminated fragments; petrified wood in chunks and trees abundant, especially near top; all beds calcareous and friable; forms badland topography	420
23. Sandstone, gray, friable, lenticular, with chunks of mud shale and petrified wood	6
24. Sandstone, light green, evenly thin-bedded	14
25. Brown, fine grained sandstone and gray-brown conglomerate in overlapping lenses; conglomerate of gray limestone pebbles 1/16 inch to 3 inches and quartz 1/16 to ¼ inch in diameter; gypsum and abundant plant fragments	23
26. Shale, dark red, arenaceous	20
27. Brown, fine grained, thin-bedded sandstone and arenaceous shale; lenticular; ripple marked; gypsiferous; contain many thin lenses of sandy mud flakes and conglomerate of concretionary limestone pellets; petrified wood, teeth, and bones in small amounts; estimated thickness	140
Shinarump conglomerate.	
	1182

The badlands developed in the soft clays of the Chinle formation, as shown in Plates 27 and 28b, are characteristic features, those in some beds being gray and others red. There are extensive exposures in the Petrified Forest, as shown in Plate 28b.

A section of divisions B and C of the Chinle formation, in the Painted Desert east and southeast of Cameron, is given by Gregory as follows:

	Feet
1. Limestone conglomerate, green-gray, with chert; resistant, bone fragments and gastropods in loose blocks; form top or plateau	5
2. Shale, pink, light and dark chocolate red, and ash-gray, argillaceous, paper-thin, highly calcareous, gypsiferous; contains short lenses of limestone conglomerate and of sandstone; forms slope with knife-edge spurs	195
3. Sandstone, brown, calcareous cement; at top is 2-inch sheet of gray and yellow limestone pebbles	2
4. Shale, red and ash-gray, calcareous, argillaceous, and arenaceous	6
5. Sandstone, brown; calcareous cement; black, red, and white, angular quartz; fine; gritty; some gypsum	2
6. Shale, pink, red, and ash-colored, splotched with white and green-gray calcareous, argillaceous, paper-thin	12
7. Limestone, green-gray and purple; a knobby, rough bed; irregular concretionary masses of limestone containing other limestone concretions; set in pink and pink-purple shales or marls, which are spotted with greenish white blotches; few tiny subangular grains of quartz and fragments of dark-red shale distributed throughout; all highly calcareous; erodes in grotesque forms	15
8. Shale like No. 12	33
9. Limestone conglomerate of concretions half an inch or less in diameter; contains thin beds of sandstone	3
10. Shale like No. 12; forms slope	15
11. Conglomerate of light green and purple-red shale fragments, limestone and a few tiny grains of quartz; forms bench; is a lens	4
12. Sandstone and argillaceous shale or "marl"; very thin-bedded, friable, flaky, cross-bedded, highly lenticular, gypsiferous; includes limestone concretions	60
13. Conglomerate of limestone concretions, red and white quartz, biotite, gypsum, and muscovite; contains bones and teeth and specimens of *Unios* converted into gypsum; calcareous and gypsiferous cement; strongly cross-bedded	1
14. Shale and sandstone in irregular beds; sandstone gray, fine grained, of white and red quartz, biotite, and lenses, thin beds,	

and single lines of limestone pebbles; shale dark red, purple, and ash-colored, markedly cross-bedded, in laminae of paper thickness; cement calcareous; irregular limestone concretions common; in places dark purple-red clay shales predominate and develop as lenses 30 to 80 feet long and 3 to 10 feet thick; gypsum in seams and scattered specks; petrified wood common; weathers into badland knobs, rounded divides, and box canyon heads	50
	403

A section of the upper part of the formation (divisions A and B and upper part of C) a few miles northwest of Kayenta, as described by Gregory, comprises at the top, dark red sandstone and sandy shale, 190 feet; limestone of light color, in large part conglomeratic or concretionary, 22 feet; shale, red and green, with alternations of nodular limestone strata in its lower half, 125 feet; limestone conglomerate, 5 feet, and calcareous, sandy shale with irregular, calcareous and impure limestone layers and lenses of limestone conglomerate, brilliantly colored in bands and patches, red, brown, pink, purple, lavender, ash and green, 250 feet. Near Fort Defiance the formation is about 1,000 feet thick, and presents its typical character but is more sandy and has fewer limestone layers. The peculiar limestone conglomerates are present everywhere and generally in many beds.

The Chinle formation occurs extensively at the foot of the Vermilion Cliffs west of Fredonia, and there are other areas at the foot of Hurricane Ledge at the Utah State line, and in the ridges at and west of Cane Spring. The formation presents about the same character as in areas to the east and south. Shale of red, brown, and gray tints predominates with some beds of sandstone, red, gray, or purple, with thin members of limestone and limestone conglomerate. A typical section in southern Utah given by Reeside and Bassler is as follows:

SECTION OF CHINLE FORMATION IN SOUTHWESTERN UTAH

	Feet
Shale and sandstone, brick red to deep red	200
Sandstone, massive, medium grained, cross-bedded, mauve	90
Sandstone and shale, brick red	420
Sandstone, cross-bedded, arkosic, banded gray, white, and mauve, with fossil wood: "Silver Reef sandstone"	25
Clay, shale, variegated, bluish-gray, greenish-gray, mauve, red	265
	1000

The fossiliferous horizon reported by Walcott[1] in Kanab Valley "about 900 feet above the Shinarump conglomerate" may be in the Chinle, but more likely it belongs to the overlying Jurassic beds. The fossils were fish and reptilian teeth, *Estheria*, and a fragment of an ammonite, suggesting Jurassic rather than Triassic age.

[1]Discussed by Cross and Howe, "Redbeds of Southwestern Colorado and Their Correlation: Geol. Soc. Am. Bull., vol. 16, pp. 486-487, 1905.

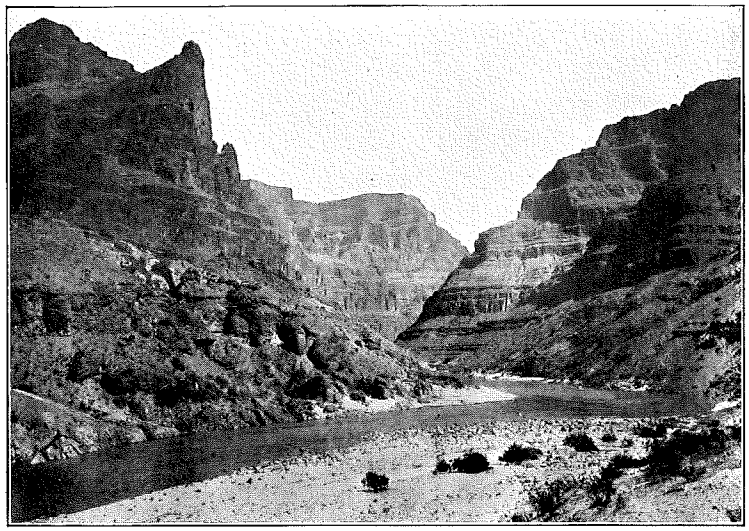


Plate 40a. West end of Grand Canyon of the Colorado River east of old Pierce Ferry, 80 miles north of Kingman, Arizona. Looking east. High cliffs, Redwall limestone; lower cliffs, Tonto group. Photo by W. T. Lee.

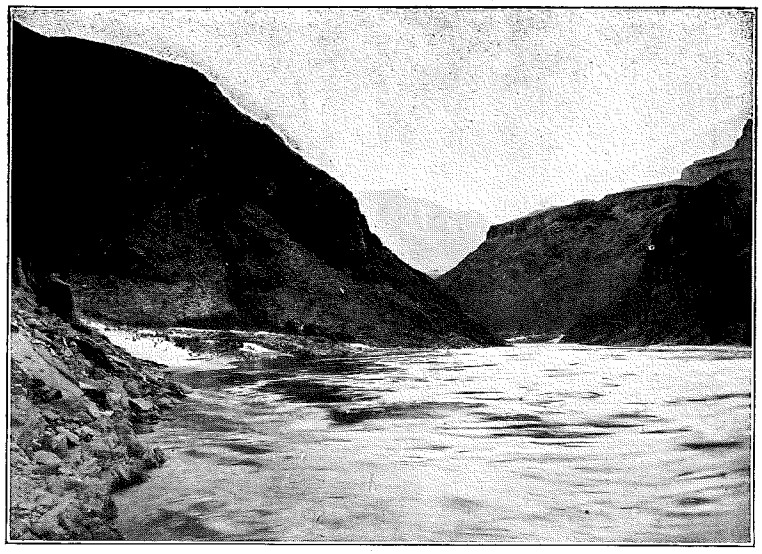


Plate 40b. Colorado River in granite gorge below mouth of Diamond Creek. Looking west. Shelf of Tapeats sandstone on either side. Redwall limestone of Hualpai Plateau in distance.

Triassic fossils have long been known in the Chinle formation. Lucas[1] has described bones of the following: *Episcoposarus* sp.?, *Heterodontosuchus ganei*, *Metoposaurus frassi*, *Placerias hesternus*, and *Palaeoctonus* sp.?, which are classed as Upper Triassic. Large numbers of *Unio cristonensis* have been collected in the badlands of Seven Springs basin 25 miles south of Navajo station. This mollusc is regarded as Triassic. A large amount of fossil wood occurs in the lower Chinle beds, as well as in the Shinarump below. In the Navajo country it is notably abundant north of Adamana on Lithodendron Creek, near Nazlini store, in Beautiful Valley, at Round Rock north of Chinle, in Moonlight Valley, near Willow Springs, northwest of Tuba, and near Lees Ferry. At these places there are many large logs and a vast amount of broken material. The petrified wood occurs at various horizons at Willow Springs, Lees Ferry, and Petrified Forest National Monument, and in division C in Beautiful Valley and Round Rock. The forests north of Adamana are in the horizon of limestone conglomerate of C or the lower part of horizon B. All the material appears to have been driftwood, even the stumps, similar to driftwood now accumulating on river flats. The trees are of several species of which Knowlton has recognized *Araucarioxylon arizonicum* and *Woodworthia arizonica*.[2]

TRIASSIC-JURASSIC UNCONFORMITY

In nearly all exposures of the base of the Wingate sandstone there is an abrupt change of material which suggests unconformity. Gregory[3] has described the relations in the Navajo country, and while no channelling was observed, several contacts present evidence believed to indicate an erosion interval. He refers to a locality east of Tanner Crossing at which Mr. Heald found at the contact, a 2-foot bed of conglomerate with "well rounded pebbles of quartz with rare limestone, gray shale, and red quartzite fragments arranged as stringers, cross-bedded, and with ripple-marked and mud-cracked surfaces. A slight difference in direction of strike and dip are also noted." Six miles southwest of Tuba a similar stratum was observed by Gregory. Other localities showing marked breaks in the sedimentation are in Laguna Canyon, at Azansoesi Mesa, at the east base of Carrizo Mountain, and in Piute and Copper canyons. Gilbert and Dutton found evidences of unconformity and while no proof of a long hiatus has been obtained, there is a possibility of one that represents either a part of late Triassic or of early Jurassic time or both. In most places in Arizona there is but little evidence of unconformity between Navajo and Wingate sandstones when the Todilto is absent.

[1]Lucas, F. A., Vertebrates from the Trias of Arizona: Science, N. S., vol. 14, p. 376, 1901; A New Batrachian and a New Reptile from the Trias of Arizona: U. S. Nat. Mus. Proc., vol. 27, pp. 193-195, 1904.
[2]Knowlton, F. H., The Fossil Forests of Arizona: Am. For., vol. 9, p. 214, 1913.
[3]Gregory, H. E., *op. cit.*, p. 415.

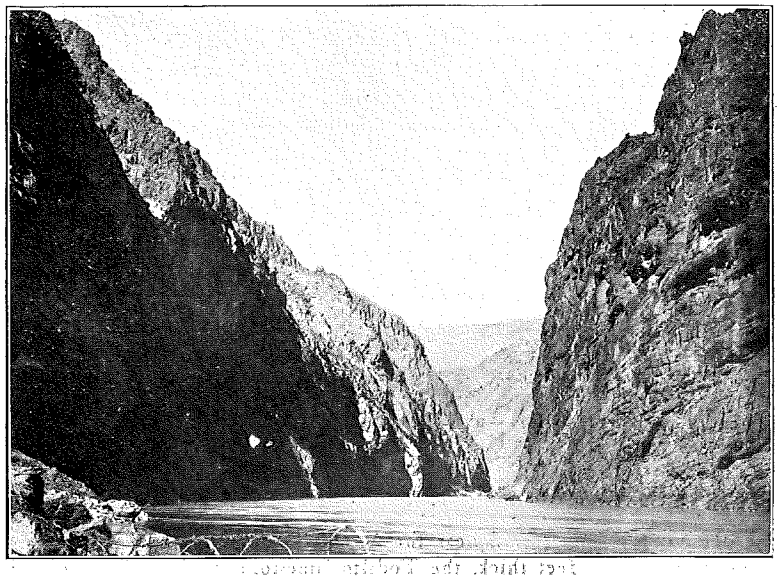


Plate 41a. North end of Black Canyon of the Colorado River at north end of the Black Mountains, Mohave County, Arizona. Photo by W. T. Lee.

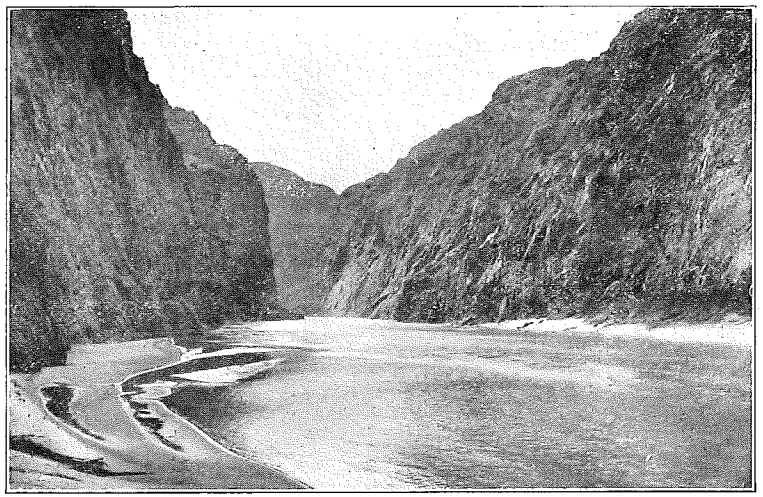


Plate 41b. Granite walls of Boulder Canyon, Arizona. Photo by Ransome.

JURASSIC SYSTEM

The Wingate and Navajo sandstones outcrop along the east side of the Defiance uplift from Lupton northward near the New Mexico State line, and extend across the northern part of the State in a wide zone to and along the Echo Cliffs. The Colorado River cuts them deeply in Glen Canyon, west of which they constitute the Paria Plateau and the Vermilion Cliffs. I have found another outcrop zone extending along the eastern side of the Virgin Mountains.

In the eastern part of the State these sandstones are separated by the Todilto limestone but to the westward, where this medial formation loses its limestone character or possibly thins out, the sandstones have not been differentiated. Some overlying sandstones also appear to come in from the northwestward.

In most parts of the region the sandstones are red and very massive, outcropping mostly in great cliffs of brilliant color. (See Pl. 28a.) In the Moenkopi region, however, there are alternations of harder and softer beds, and as shown in Plate 30b, the cliffs are less steep. The total thickness varies from 800 to 1,000 feet, with local exceptions. In the outcrop zone along and near the New Mexico line the Navajo sandstone is about 500 feet thick, the Todilto limestone, with its interbedded sandstone and shale, 25 feet, and the Wingate sandstone 300 feet. Near Kayenta 800 to 900 feet is the average thickness of the sandstones and the amount is somewhat less in the region west.

The Wingate sandstone is a very conspicuous formation in the Defiance uplift, where it presents high cliffs (see Pl. 28a), in places sculptured into towers, alcoves, and buttresses, all of bright red color. To the northward there is considerable banding, a part of which is gray. Gregory presents numerous details regarding its outcrop, character, and thickness. Southwest of Chinle it is a single bed of light red rock, intricately cross-bedded, 375 feet thick; northwest of Kayenta the thickness is 275 to 300 feet. In Echo Cliffs the thickness appears to be much less. The rock is nearly all very fine grained, but much of it is cross-bedded. The Todilto formation has its type locality in the southwestern corner of McKinley County, New Mexico, not far from the Arizona line. It there caps a cliff of "Wingate sandstone and consists of 10 feet of resistant, compact, blue-gray limestone, separated into two parts by a few inches of sandy, lumpy shale containing flattened calcareous mud pebbles." Some quartz and cherty pebbles occur in the top. In the Lukachukai Mountains the Todilto limestone is 3 feet thick; at Round Rock it was not observed, and west of Chinle only thin detached limestone lenses were noted. Near Hogansaani Spring, west of Mount Carrizo, the formation is 3 feet thick with very sandy members at top and bottom. In the canyon 10 miles northwest of Kayenta the formation is 28 feet thick, consisting of limestone conglomerate at top and bottom, separated by 18 feet of calcareous sandstone and shale, as shown in Plate 28b.

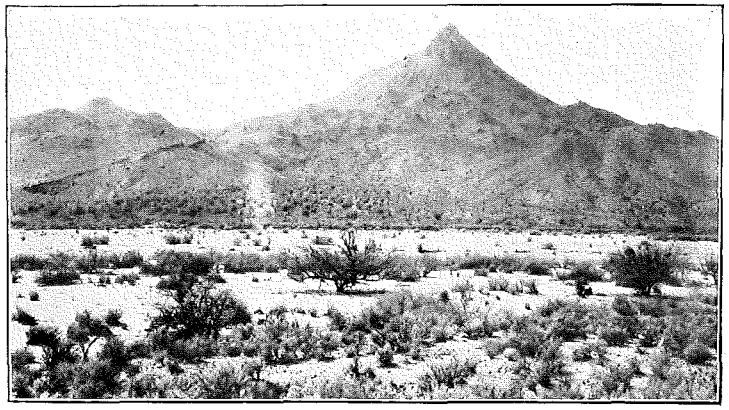


Plate 42a. Artillery Peak near Alamo on Williams River. Photo by W. T. Lee.

Footprints of dinosaurs were described by Gregory in supposed Todilto formation in Navajo Canyon and Willow Springs, but probably they throw no light on the age.

The Navajo sandstone underlies a wide area in northeastern Arizona and outcrops in numerous large mesas. The rock is nearly all sandstone and of considerable hardness, but some of it is less coherent than most of the Wingate sandstone, so that it presents more rounded forms. Nearly all of it is cross-bedded (see Pl. 30a), in many cases on a grand scale. In the base of Tyende Mesa northwest of Chinle, a 3-foot bed of limestone

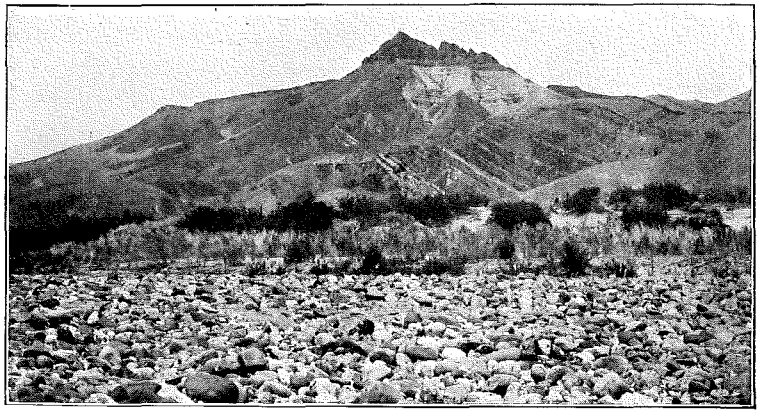


Plate 42b. Tilted limestone overlain by gravel capped by basalt, near mouth of Grand Wash, Colorado River. Photo by W. T. Lee.

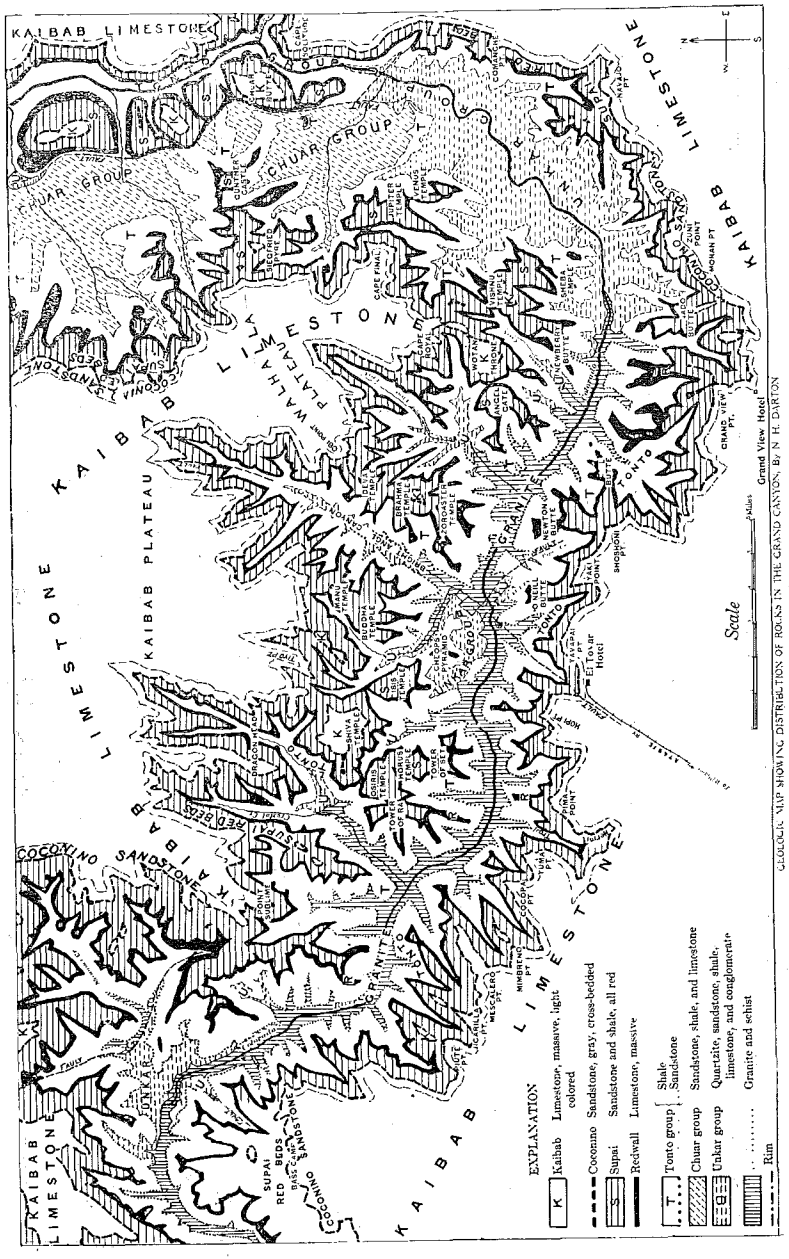


Plate 43. Geologic map of part of the Grand Canyon.
By N. H. Darton.

occurs 115 feet below the top of the formation and a 2-foot bed occurs 12 feet lower down,[1] and similar occurrences of limestone are reported at other places to the west. At Willow Springs, northwest of Tuba, "where 365 feet of fine-grained, cross-bedded calcareous sandstone is exposed, a band of cherty blue limestone 1 foot thick was found 165 feet above the base." Many of the limestone deposits are lenticular.

In connection with work on the geological map of the State, Messrs. Lausen and Wilson have traced the sandstones from Pueblo Colorado Valley westward to the vicinity of Moenkopi, but the Wingate and Navajo sandstones have not been separated.

These sandstones, possibly overlaid in part by higher beds (see Pl. 29), constitute the Vermilion Cliffs (see Pl. 56a) in the northern part of Mohave County, and it was found that they appear again in a zone of outcrop which extends along the east side of the Virgin Mountains. The rock is massive, cross-bedded, and the total thickness is about 2000 feet. The lower portion and top beds are red and most of the upper half is white or light gray, but the distribution of color is somewhat variable. The most notable exposures are in the Virgin Valley, especially in Zion National Park in Utah, not far north of the Arizona line.

Recent observations by Paige[2] and others in southeastern Utah appear to indicate that Wingate sandstone is not part of the La Plata Group (Jurassic) of Cross as classed by Gregory in 1917,[3] but is probably the upper member of the Dolores formation of southwestern Colorado of supposed Triassic age as suggested by Newberry, Gilbert,[4] Howell, Darton[5], and others.

CRETACEOUS (?) ROCKS

McELMO FORMATION

Gregory traced the McElmo formation of Cross, of Cretaceous (?) age, from its type locality in southwestern Colorado southward across the San Juan Valley, and found that it was apparently included in the upper part of the "Zuni sandstone" of Dutton, the lower part of which Gregory named the Navajo sandstone. In studying the geology of western New Mexico I found that the upper part of the "Zuni sandstone" of Dutton was a sandy western extension of the Morrison formation, at most places easily separated from the underlying Navajo sandstone. This stratigraphic relation is evidence that the McElmo and Morrison are equivalent. Owing to the predominance of sandstone in the McElmo formation Gregory found difficulty in locating the McElmo-Navajo contact at many places. The formation is exposed in a wide belt encircling the Black Mesa and the

[1] Gregory, H. E., *op. cit.*, pp. 53, 57.
[2] Communication to Section E, Am. Assoc. Adv. Science, Dec. 1924.
[3] Loc. cit. Prof. Paper 93, p. 52.
[4] Loc. cit. vol. 3, pp. 551-553.
[5] Loc. cit. Bull. 435, pp. 43-48, 1910.

White Mesa and in a narrow outcrop zone along the east side of the Defiance uplift. Notable exposures occur at Blue Canyon, Lohali Butte southwest of Chinle, Yale Point northwest of Chinle, Square Butte, and in the high walls of White Mesa. It is probable that some of the sandstones immediately overlying the Navajo sandstone in northern central Arizona are older than McElmo.

The three following sections given by Gregory[1] show the character of the formation at representative localities:

SECTION OF McELMO FORMATION AT TODOKOZH, ON EAST FACE OF BLACK MESA, BETWEEN LOHALI AND YALE POINTS, ARIZONA

	Feet
Unconformity at base of Dakota sandstone.	
1. Thin-bedded sandstone and green-white and yellow shale; top very white, powdery, as if exposed to weathering before the Cretaceous sandstone was deposited; very fine-grained, calcareous and slightly gypsiferous	17
2. Shales, yellow-gray, argillaceous and calcareous	6
3. Sandstones, yellow-gray, thin-bedded, cross-bedded, with streaks of gravel consisting of pebbles the size of B shot	8
4. Shales, alternating green, white, and yellow-gray, friable; at bottom is 6 feet of soft, thin-bedded, dark green, coarse sandstone interleaved with lenses of dark red shales	18
5. Sandstone, white to yellow-green, massive, cross-bedded, fine-grained except for thin lenses of coarse sand; consists of clear quartz cemented by lime, with disseminated grains of gypsum	66
6. Shale, banded white and yellow-green, with streaks of dark red; argillaceous and highly gypsiferous; consists of series of thin lenses	4
7. Sandstone, green-gray streaked with pink and yellow, massive, cross-bedded, lenticular; mostly fine-grained but contains lenses of subangular quartz and green clay pellets as large as buckshot; includes flakes of gypsum and pancake concretions of brown sandstone	60
8. Shales, dark red, with green-white bands and one 2-foot bed of fine-grained sandstone; argillaceous and calcareous; contains many flat flakes of gypsum	14
9. Sandstone, gray-green, soft, massive, in irregular beds and overlapping lenses; mostly very fine-grained but includes short thin lenses consisting of white and pink rounded and subangular grains of quartz the size of birdshot	18
10. Shales, dark red, with broken pinched-out lenses of green-white shale and a 4-inch bed of dark green and red mottled sandstone; arenaceous and gypsiferous	3
11. Sandstone, light green, soft, massive, cross-bedded; consists of very fine, well-rounded quartz grains; near the top are two 3-inch bands of resistant dark green sandstone	40
12. Shale, banded dark red and green, gypsiferous, irregularly-bedded, nodular, includes broken fragments of No. 13	5
13. Sandstone, white to green-gray, in places yellow or red, soft, semi-massive, cross-bedded; extremely irregular in deposition; includes thin lenses of green and red shale; prevailingly fine-grained but lenses of conglomerate consisting of red mud lumps and rounded grains of quartz the size of buckshot are present; gypsiferous, noncalcareous	36
14. Shale, light green at top, dark red at base; nodular within a distance of 100 feet; ranges in thickness from 4 inches to 3 feet; arenaceous, gypsiferous	2
15. Sandstone, green-gray, friable, massive, cross-bedded with pronounced vertical jointing, poorly exposed	
16. Interval not exposed; estimated	200
Navajo sandstone.	
	497

[1]Gregory, H. E., *op. cit.*, pp. 61-62.

SECTION OF McELMO FORMATION AT BLUE CANYON, ARIZONA

(Measured by J. E. Pogue)

	Feet
Unconformity at base of Cretaceous sandstone	
1. Sandstone, pale greenish white, massive, cross-bedded, very fine-grained, dense, tough, probably argillaceous	100
2. Sandstone, white, pure, fine-grained, mostly friable and cross-bedded	110
3. Sandstone, dark red, massive, fine-grained, argillaceous; weathers to remarkable irregularly spherical forms; contains streaks of white sandstone	50
4. Alternating red shales and white sandstones; could not be measured very accurately; begins third cliff	150
5. Sandstone, white, fine, argillaceous in places; seams of grayish white shales	20
6. Shales, dark red, arenaceous	10
7. Sandstones, white, fine, in places somewhat calcareous; contain thin bands of red shales	15
8. Shales, dark red, arenaceous; 2-foot band of purple shale; contains seams and bands of white sandstone	10
9. Sandstone, white, fine; some bands somewhat calcareous	10
10. Shales, red, with sandstone seams and bands	10
11. Sandstone, white, fine-grained, slightly calcareous in places; contains few thin seams of gray shales	25
12. Shales, dark red, arenaceous, thin-bedded; seams of white friable sandstone and white calcareous sandstone; begins second cliff	25
13. Sandstone, white, fine, calcareous	1
14. Sandstone, white, very friable, pure, fine-grained; some seams appear to be slightly calcareous; composed almost exclusively of clear, well-rounded small grains of quartz	12
15. Shales, dark red, arenaceous	10
16. Sandstone, white, fine, calcareous, in resistant band; weathers to dirty color	5
17. Shales, dark red, arenaceous, in fairly thin beds; contains some thin bands of red and white sandstone	32
Navajo sandstone	
	595

SECTION OF McELMO FORMATION ON NORTH FACE OF WHITE MESA, ARIZONA

(Measured by J. E. Pogue)

	Feet
Unconformity at base of Cretaceous sandstone	
1. Sandstone like No. 2 but massive	20
2. Sandstone, light yellow to white, fine-grained; clear, well-rounded quartz grains; thin-bedded and cross-bedded, speckled or mottled appearance	65
3. Sandstone, light yellow, thin-bedded, cross-bedded, fine-grained, lower 50 feet layers of red sandstone; remainder contains lenses and narrow bands of light green sandstone and sandy shale with a few bands of dark green sandstone; forms great mesa wall which appears at a distance to be greenish white	240
4. Sandstone, white, more resistant than other members	5
5. Sandstone like No. 7 but with bands of white sandstone; Nos. 5, 6, and 7 form badland topography	40
6. Sandstone, white, fairly coarse-grained, bedding oblique to that of No. 7	5
7. Sandstone, red, fine-grained, thin-bedded, cross-bedded, with seams and bands of white sandstone	75
8. Sandstone, gray, resistant	15
9. Sandstone, gray, like No. 10 but more resistant	75
10. Sandstone like No. 11 but with fewer resistant bands; forms gentle slope between steeper slopes of Nos. 9 and 11	40
11. Sandstone, light yellow to grayish white, pure, fine-grained, friable, occasionally reddish on exterior; weathers to a slope; contains several more resistant bands (6 inches) and at the top a 4-foot layer of rather coarse calcareous grayish white sandstone	40
Interval not exposed, estimated	50
Navajo sandstone	
	670

East of the Haystacks at St. Michaels the McElmo beds are not readily separable from the underlying sandstone. At this point the McElmo formation consists of greenish-yellow sandstone with bands of green and dark red shales and lenses of fine conglomerate in its upper portion. Lenses of red and green shale are included even in its massive cross-bedded sandstone. In the cliffs at Red Lake Store on the Kaibito Plateau, 65 feet of thin-bedded, cross-bedded sandstone includes numerous short, thick lenses of green sandstone and shale, below which is 75 feet of sandstone, white at the top but grading through a banded yellow, white, and red series to a lower part that is red, banded with green-white. Lying on the surface near this locality the centrum of a carnivorous dinosaur like that of *Creosaurus* was found. Two miles south of Red Lake Mr. Pogue found massive cross-bedded McElmo sandstone, greenish yellow in tone, displayed as a cliff 600 feet in height, below which was 40 feet of mottled and banded thin-bedded sandstone. On the edge of Black Mesa, 6 miles west of Ganado, there is 200 feet of red fine-grained sandstone in beds 2 to 10 feet in thickness, banded with layers of white 6 inches to 2 feet thick. The white strata increase in number and thickness upward, and near the top the cliff wall is composed entirely of greenish-white sandstone. Along the upper part of Pueblo Colorado Wash the typical Navajo is not present and the sections display features somewhat unlike the McElmo of other localities. The region has not been carefully studied, and the strata of the following section are assigned to the McElmo with hesitation; the lower beds may represent equivalents of part of the Navajo sandstone.

SECTION OF McELMO FORMATION (?) 2 MILES WEST OF CORNFIELD SCHOOL, IN PUEBLO COLORADO VALLEY, ARIZONA

	Feet
1. Sandstone, yellow-green, firm, cross-bedded; forms top of mesa wall	50
2. Sandstone, greenish-white, well stratified, poorly cemented, crossed by three red bands in lower 40 feet; the upper band composed of several irregular red lenses	200
3. Sandstone, red to dark brown, banded at base by six to eight white layers about 2 inches in thickness; erodes along joints into picturesque remnants, of which "Neubert's Organ" is an example	200
4. Shales, brown and blue-white	30
5. Sandstone, white, of clean quartz pebbles marked by black spots and dendritic figures	2
6. Shales, yellow-red, white, green-white, and light blue, arenaceous; include three beds 1, 4, and 5 feet thick, which weather with honeycomb structure along ancient sun-cracked surfaces	150
7. Sandstone, white, cross-bedded	3
8. Sandstone, yellow-brown, much cross-bedded, friable, marked near top by eight bands of green-white and red-brown shale ½ inch to 3 inches thick	50
9. Shales, arenaceous; yellow-brown 10 feet, dark red and purple 5 feet, brown 10 feet, white and red 5 feet, brown 30 feet	60
10. Sandstone, red, massive, friable, terminated above and below by white bands	20
	765

Along the Tusayan Washes the McElmo is represented by greenish-white friable sandstone with subordinate amounts of arenaceous shale. At Burro Spring 300 feet of intricately cross-bedded, green-white sandstone is capped by a 4-foot bed of cherty limestone, fragments of which are widely spread over the floor of Oraibi Wash. Near Flat Rock Mr. Pogue found the following strata:

SECTION OF McELMO FORMATION (?) ON THE EAST SIDE OF ORAIBI WASH, 5 MILES SOUTH OF BIG BURRO SPRINGS, ARIZONA

	Feet
1. Sandstone, green-white, wholly quartzose, cross-bedded, friable	85
2. Shales and sandstone, banded red and gray	25

3. Sandstone, gray-white, fine-grained; forms vertical wall	50
4. Shale, horizontally banded, interstratified with thin beds of white and red calcareous sandstone	100
	260

Gregory[1] mentions an extension of supposed McElmo beds southeastward from Kayenta to Garnet Ridge where his map shows only an outlier of the formation, with east dips. The strata are poorly consolidated, somewhat resembling Tertiary deposits.

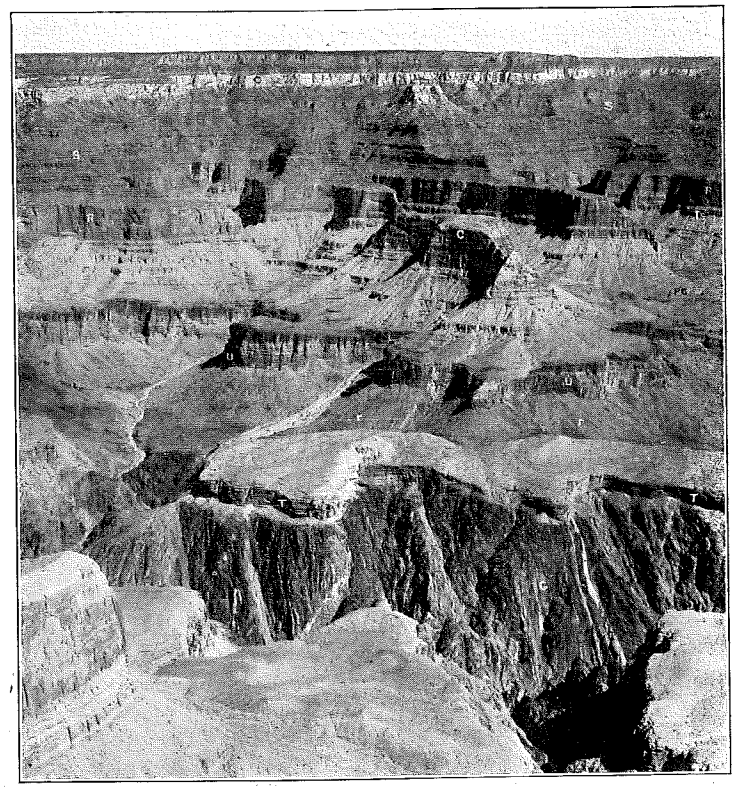


Plate 44. North wall of Grand Canyon opposite El Tovar. At top is Kaibab Plateau capped by Kaibab limestone. B, Buddha Temple (Kaibab cap); C, Coconino sandstone; S, red beds of Supai formation and Hermit shale; R, Redwall limestone (capping Cheops Temple at C); T S , Muav limestone and Bright Angel shale; T, Tapeats sandstone; U, dark quartzite of Unkar group (Shinumo); r, red shale of Unkar group; G, granite; B A, Bright Angel Canyon. Colorado River is 1,000 feet below the cliffs T-T.

[1]Gregory, H. E., *op. cit.*, p. 64.

Supposed McElmo beds were traced through the district of the Hopi Buttes and Tusayan Washes by Messrs. Lausen and Wilson of the Bureau of Mines, but no special study was made of the stratigraphy.

EARLY CRETACEOUS UNCONFORMITY

The rocks of Comanche age in southern Arizona lie unconformably on various formations from pre-Cambrian granite and schist to late Carboniferous limestone, not only on irregularly channelled surfaces, but generally with considerable difference in attitute of the strata. Ransome[1] has described the relations in the Bisbee region, where the Glance conglomerate lies in part on a plane bevelled across the upturned Carboniferous strata, and in part in old valleys cut in various older rocks down to the Pinal schist. If the McElmo formation of northern Arizona is a western extension of the Morrison formation of New Mexico its age is probably Lower Cretaceous. Its contact relations with the Navajo sandstone, as described by Gregory,[2] probably indicate unconformity, although in places there is apparent gradation of sediments. At certain localities there are conglomerate and coarse sandstone members and local channelling at the base of the McElmo, which may indicate a hiatus of unknown duration. It would, however, be quite natural to find late Jurassic merging into earliest Cretaceous sediments at some places.

COMANCHE SERIES

(LOWER CRETACEOUS)

The Lower Cretaceous (Comanche series) of the Bisbee region has been divided by Ransome[3] into four formations, the principal features of which are shown in the following section:

SECTION OF THE COMANCHE SERIES IN MULE MOUNTAINS, ARIZONA

	Feet
Cintura formation. Red, nodular shales with cross-bedded buff, tawny, and red sandstones. A few beds of impure limestone near base. (Surface eroded.)	1800
Mural limestone. Upper member, limestone, massive, hard, gray; lower member, limestones, thin-bedded, sandy	650
Morita formation. Buff, tawny, and red sandstones, alternating with dark red shales. Includes a few thin beds of impure limestone near top	1800
Glance conglomerate. Bedded conglomerate with rather angular pebbles, chiefly schist and limestone. (Unconformable on old rocks	0– 500

Some features of these rocks are shown in Plate 32b.

[1]Ransome, F. L., *op. cit.*, Prof. Paper 21, pp. 60-61.

[2]Gregory, H. E., *op. cit.*, p. 60.

[3]Ransome, F. L., *op. cit.*, Prof. Paper 21, p. 56.

The Glance conglomerate consists largely of local materials, mainly granite, schist, limestone, chert, and quartz, with more or less admixture of sand, and includes a few local deposits of reddish sandstone, especially

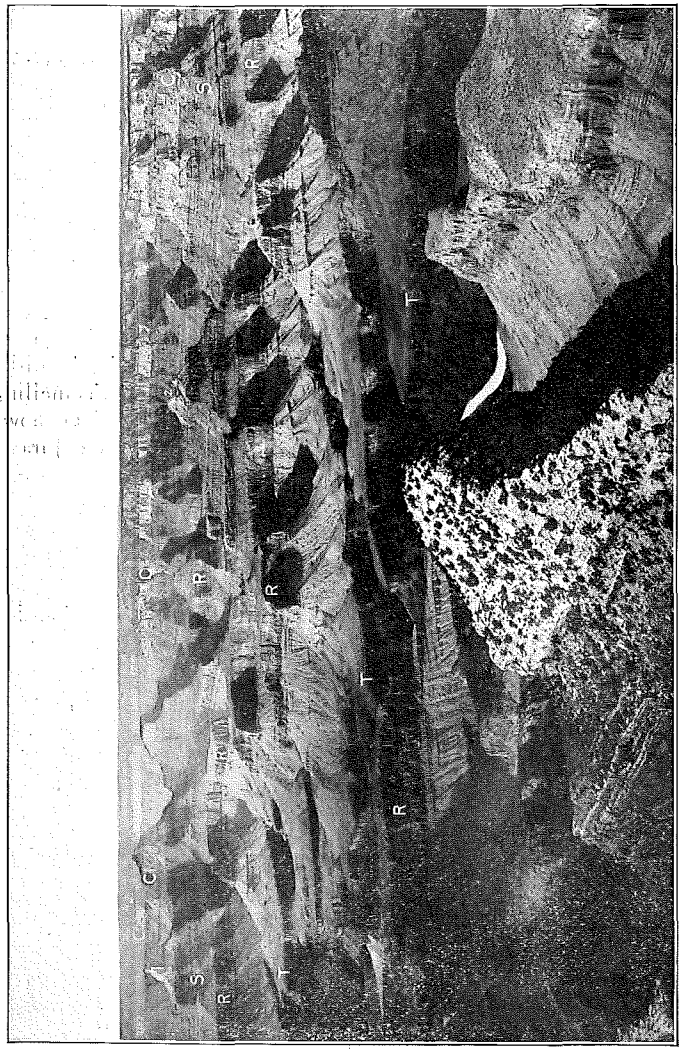


Plate 45. Looking northwest across Grand Canyon from Grand View Point. Kaibab Plateau in distance. 1, Zoroaster Temple; 2, Angel Gate; C, Coconino sandstone; S, Hermit red shale and Supai red beds; R, Redwall limestone; T, Tonto Platform.

in its upper part which is in general finer grained than the lower beds. The general thickness over a wide area north and east of Bisbee is from 50 to 75 feet, but it thins out at one point in that direction. To the

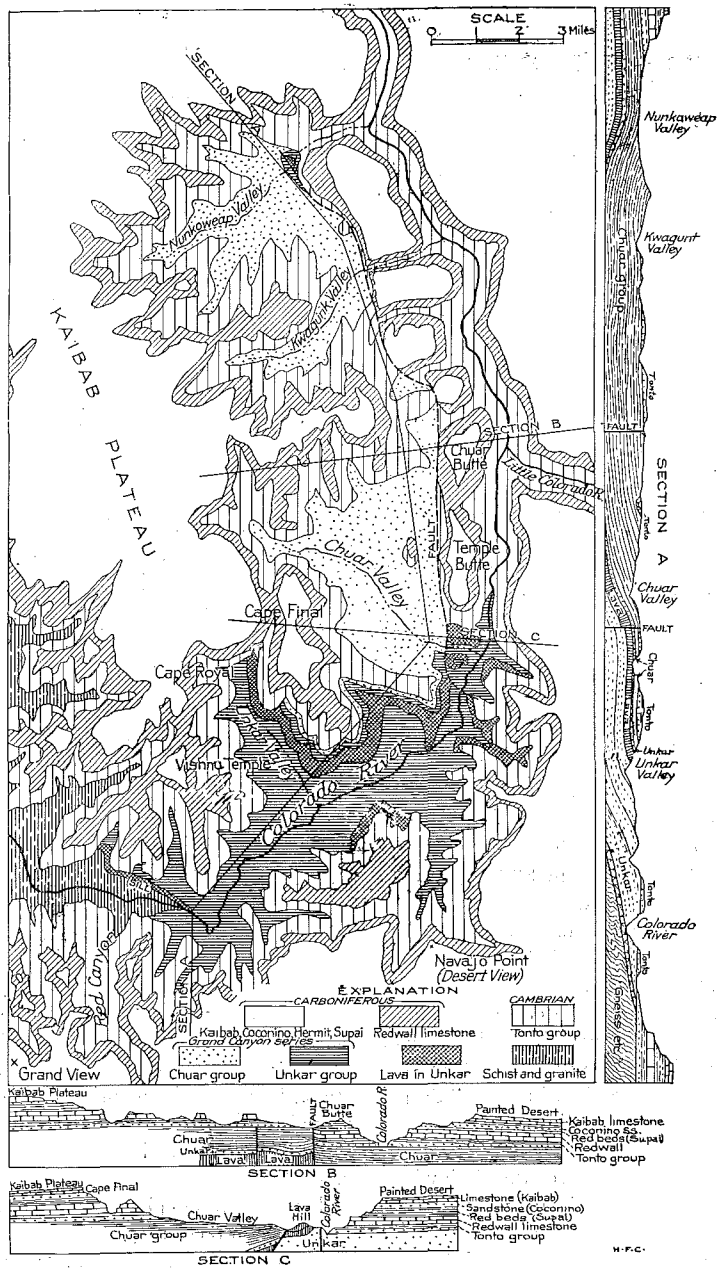


Plate 46. Geologic map of the Eastern Division of the Grand Canyon, after Walcott.

southwest, however, it lies in hollows, probably excavated in the Carboniferous limestone; some of these containing 500 feet or more, and one drill hole penetrated 653 feet. The Morita formation constitutes a broad area of the summit and northeastern portion of the Mule Mountains. Its outcrop presents a dull red or yellowish-brown appearance, the red generally predominating toward the base. The included red shales are mostly hard and compact and the presence of small, light gray, calcareous nodules is characteristic, especially on weathered surfaces. Some of the sandstone is cross-bedded and some of the upper beds are quartzitic. Ransome mentions a member of reddish-brown grit, 10 to 15 feet in thickness, about 1200 feet above the base of the formation, which interrupts the regular repetition of sandstone and shale members. The Morita beds appear not to be separated by unconformity from Glance below and Mural limestone above. The latter outcrops along the east side of Mule Mountains, but reaches the summit in the type locality, Mural Hill, northeast of Bisbee. It also occurs in some outlying knolls to the southeastward. It has two members, a lower one about 300 feet thick, consisting of thin-bedded, impure limestones, generally capped by about 25 feet of buff sandstone, and an upper member 350 feet thick in which predominate white, pure limestones, thick-bedded near base. In the lower member are sandy beds grading into cross-bedded, limy sandstone, with occasional thicker beds of lark gray limestone composed mainly of oyster shells. The Cintura formation, or uppermost division of the Comanche group, occupies a shallow syncline along the eastern slope of the Mule Mountains east and northeast of Bisbee. The thickness is about 1800 feet, with top eroded, and the rocks resemble the Morita formation, with the same reddish shales with gray, nodular concretions or lenses of gray limestone and tawny buff or pinkish cross-bedded sandstone in large part quartzitic. At base is buff quartzite 10 to 15 feet, then 100 to 150 feet of red shale, thin-bedded sandstones, and impure limestones, carrying *Turritella*; 700 to 800 feet of red, nodular shales, with a few beds of buff sandstone and lenses of limestone; 300 feet of flaggy, cross-bedded gray and buff sandstones, with partings of red shale and about 600 feet of reddish, nodular shales interbedded with flaggy, cross-bedded sandstones.

The Comanche rocks are extensively exposed about the Empire Mountain and along the east side of the Santa Rita Mountains, and small areas occur on the east side of the Patagonia Mountains and the west slope of the Santa Rita Mountains. They constitute Mt. Fagan and most of the surrounding hilly district. "Cropping thought to belong to this group of rocks or to the Triassic extends interruptedly along the railroad to and beyond Elgin." These areas have been mapped and described by Schrader,[1] who gives the following facts concerning them:

The lower beds are mostly of dull red color and in places conglomeratic, but the upper part of the group is mostly green to gray shale and sandstone, some of which is but slightly consolidated. The maximum

[1]Schrader, F. C., *op. cit.*, Bull. 582, pp. 51-54.

thickness is placed at 6,000 feet, but I believe this is greatly overestimated. The basal member as exposed near Helvetia and on the east slope of the Empire Mountains is a bed of conglomerate which grades into sandstone. The coarse materials comprise pebbles and boulders of

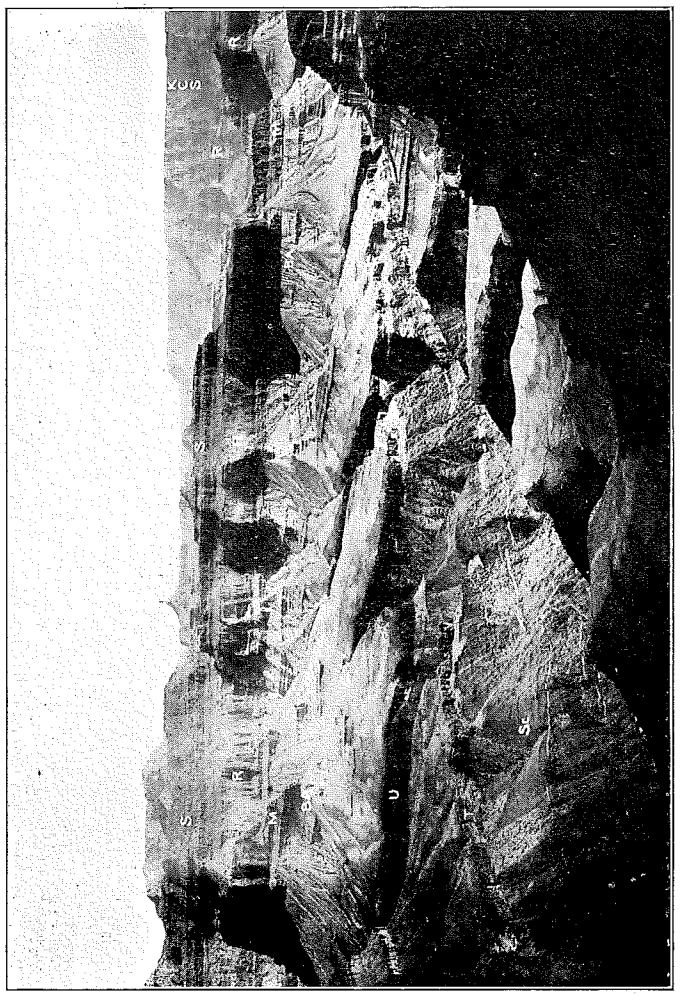


Plate 47. Grand Canyon at Point Sublime. Looking eastward. Point Sublime to extreme left. Sh, Shiva Temple; I, Isis Temple; Y, Yavapai Point; S, Schist, with dikes of granite, etc.; U, Unkar group; T, Tapeats sandstone; B A, Bright Angel shale; M, Muav limestone; R, Redwall limestone; S, Supai formation and Hermit shale; C, Coconino sandstone; K, Kaibab limestone.

limestone and quartz, and the beds lie with gentle dips on an irregular surface of Carboniferous limestone and other rocks. In the northern part of the Greaterville district there are thin-bedded, arkosic sandstone, dolomite, and mudstone locally altered to hornfels. On the west the

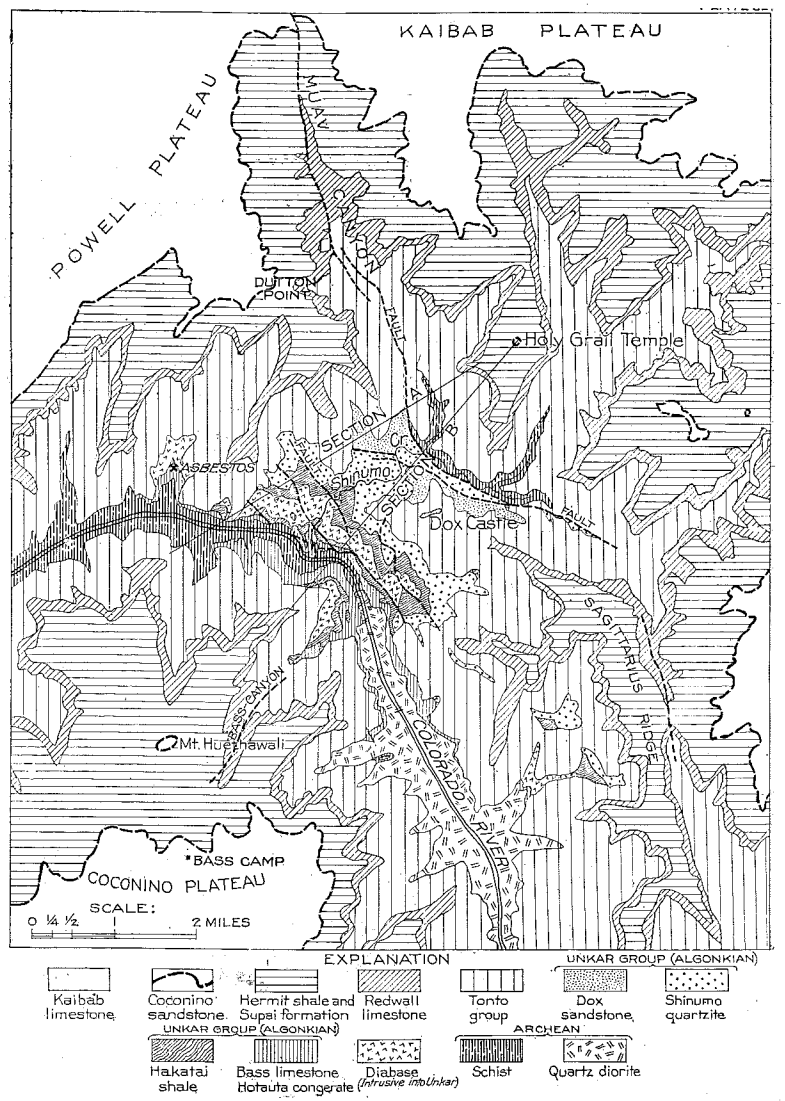


Plate 48. Geologic map of portion of the Grand Canyon about Shinumo Creek after Noble.

rocks lie on granite and the upper beds are covered by valley fill. In the southeastern part of this district the upper beds are of brilliant red hue, consisting mostly of heavy-bedded, massive shale with deep red to pink sandstone, conglomerate and grit. It is suggested by Schrader that some of the upper beds may be Tertiary and the lower strata may represent Triassic or even an earlier age.

Bryan[1] reports a thick succession of red sandstone, conglomerate, and shale east of the Montana mine in the Tumacacori Mountains, which he suggests is probably equivalent to the similar beds of Comanche age in the Patagonia Mountains. It is unconformably overlain by tuff. "Both east and west of Arivaca are red and green shales with incipient, slaty

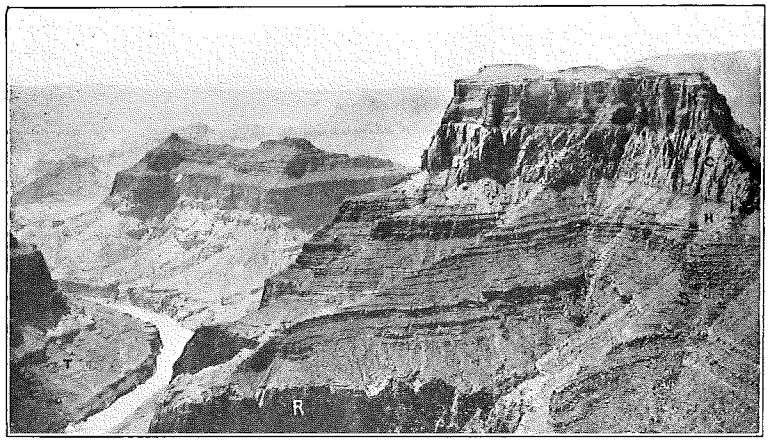


Plate 49a. Chuar Butte from east rim of Marble Canyon just north of the mouth of the Little Colorado River. Looking south by west. T, Tonto group; R, Redwall limestone; S, Supai formation; H, Hermit shale; C, Coconino sandstone; K, Kaibab limestone. Photo by G. C. Frazer.

cleavage which may be part of the same formation." He found also red shale and arkose sandstone at Agua la Vara faulted against gneiss of the Coyote Mountains and again at Pozo Blanco associated with limestone of supposed Carboniferous age.

Mr. Carl Lausen[2] has recently reported rocks of supposed Lower Cretaceous age extending along the west side of the south end of the Plomosa Mountains southeast of Quartzsite. I should not be surprised if the red shale and limestone of the Little Mountains west of Bouse proved to be of Cretaceous age. Rocks of somewhat similar character were found near the Dixie Mine, 8 miles west of Woosey Peak in the Gila Bend Mountains and in the Maricopa Mountains.

[1]Bryan, K., *op. cit.*, p. 24.
[2]Personal communication.

Fossils in the Comanche rocks occur mostly in the lower member of the Mural limestone. The following species have been identified by T. W. Stanton:

Orbitolina texana,
Glauconia branneri,
Lunatia pedernalis,
Ostrea sp.,
Pecten stantoni,
Trigonia stolleyi,
Trigona n. sp.,
Astrocoenia sp.,
Rhynchonella sp.,
Terebratella sp.,
Terebratula sp.,
"Caprina" sp. cf. C. occidentalis,
Turritella sp. cf. T. seriatim granulati,
Actaeonella sp. cf. A. dolium.

Dr. T. W. Stanton regards these fossils as indicating that the Mural beds correlate in large part with the Glen Rose limestone of Texas, with the upper part possibly extending as high as the Edwards limestone; in other words, that the rocks correlate with the Trinity group and possibly in part with the Fredericksburg group of the Comanche series of Texas. No direct paleontological evidence has been obtained as to the equivalence of the other formations of the Comanche of Arizona, but as they are in conformable succession, and as the Morita below and the Cintura formation above the fossiliferous Mural limestone are practically identical in character, it seems certain that the entire series is of Comanche age.

Fossils obtained by Schrader on the east slope of the Patagonia Mountains about one-half mile northwest of the Mowry mine, "where the trail of the Morning Glory mine crosses a ridge just southwest of the County State Road," were determined by T. W. Stanton as *Ostrea* sp., fragments of other bivalves suggesting *Chamidæ*, and a fragment of an ammonite probably *Aconthoceras* believed to be of Comanche age.

I found fossils in the shales and limestone on the east slope of the Dragoon Mountains a few miles southeast of Pearce. They were determined by T. W. Stanton as *Anomia lima?*, and some indistinct gasteropods *Ostrea* sp. *and Astarte?* sp., probably Comanche in age.

MID-CRETACEOUS UNCONFORMITY

In all areas of Upper Cretaceous rocks known in Arizona the strata lie unconformably on eroded surfaces of preceding formations and locally there is presented some difference in attitude. In the southern part of the State they lie mostly on Carboniferous limestone, as Triassic, Jurassic, and Lower Cretaceous rocks are absent. In the Arizona Plateau (Mogollon) they lie on eroded surfaces of Kaibab, Moenkopi, and Chinle beds without material difference in attitude. In the Black Mesa area they lie on McElmo? formation, mostly on a surface presenting many irregularities of configuration. (See Pl. 31a.) Gregory[1] refers to a locality in Moenkopi Canyon where the relief of the contact surface exceeds 80 feet in a quarter of a mile, and west and northwest of Ganado there are striking irregularities on which lie the basal conglomerate of the

[1]Gregory, H. E., *op. cit.*, p. 60.

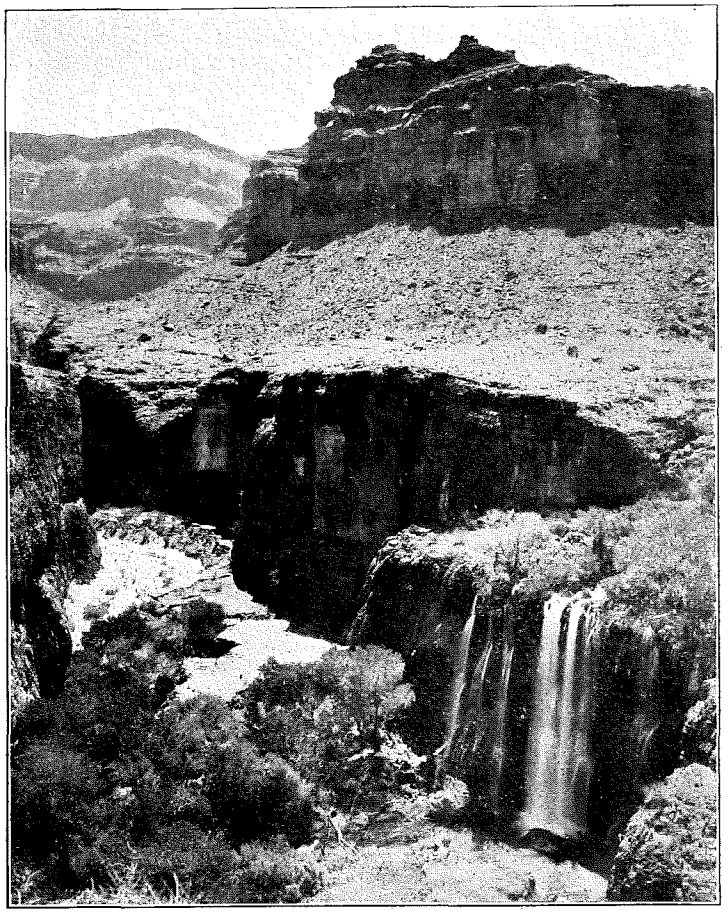


Plate 49b. Upper ledge of Redwall limestone at Havasu Falls of Cataract Creek. Looking east up Carbonate Creek. Red beds of Supai formation in slopes and cliffs in middle ground. Hermit shale, Coconino sandstone and Kaibab limestone in the distance.

Dakota formation. In places the material in this conglomerate has not had its source in McElmo rocks. The attitude of the strata of both formations is not notably different, but probably the hiatus represents a considerable length of geologic time.

UPPER CRETACEOUS ROCKS

Dakota sandstone.—The basal sandstone of the Upper Cretaceous in northwestern New Mexico and northeastern Arizona is usually referred to as Dakota sandstone. A similar sandstone underlies the basin of Black

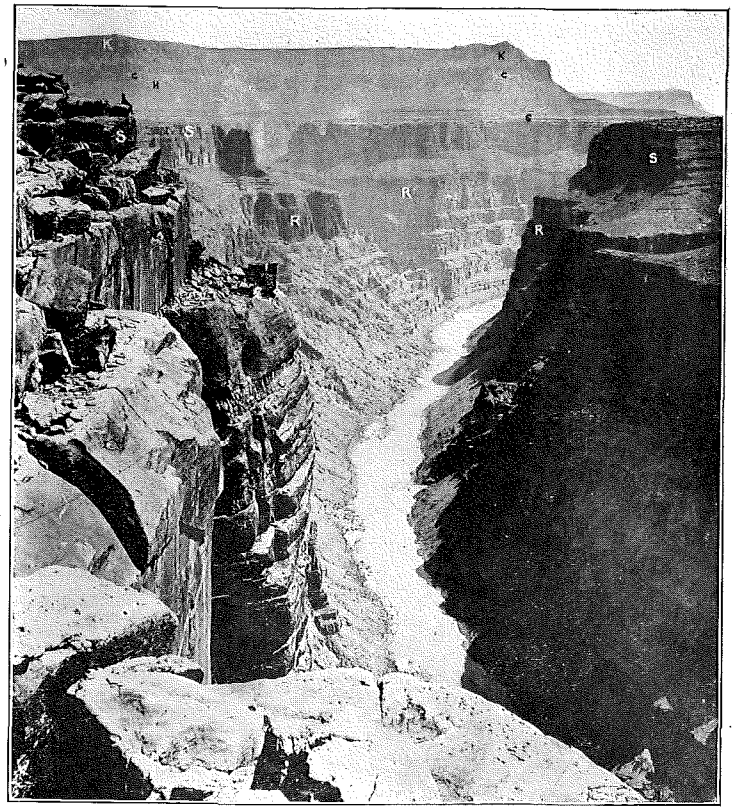


Plate 50. Canyon of Colorado River at mouth of Toroweap Valley. Looking upstream. K, Kaibab limestone; C, Coconino sandstone; H, Hermit shale; S, sandstone of Supai formation forming the "Esplanade;" R-R, Redwall limestone with Muav limestone and Bright Angel shale of Tonto group below.

Mesa, outcropping extensively along the edges of the area, and also underlies the Cretaceous plateau which extends across the State line southeast of Fort Defiance. The rocks are sandstones, mostly gray, hard, and coarse-grained, with included beds of shale, but presenting many local variations in character and succession. A basal conglomerate is a common feature, and local coal beds of lenticular form occur. There are marked changes in the character of the beds from place to place. The thickness varies from 50 to 200 feet in greater part and in places the formation is absent. Gregory[1] reports 45 feet of the formation near Lohali south-

[1]Gregory, H. E., *op. cit.*, p. 72.

west of Chinle, about half of which is coal and carbonaceous shale. It is 210 feet thick 6 miles southeast of Marsh Pass, and 295 feet at the mouth of Laguna Canyon just west of Marsh Pass; the amount increases westward in the north face of Black Mesa. At Blue Canyon it is

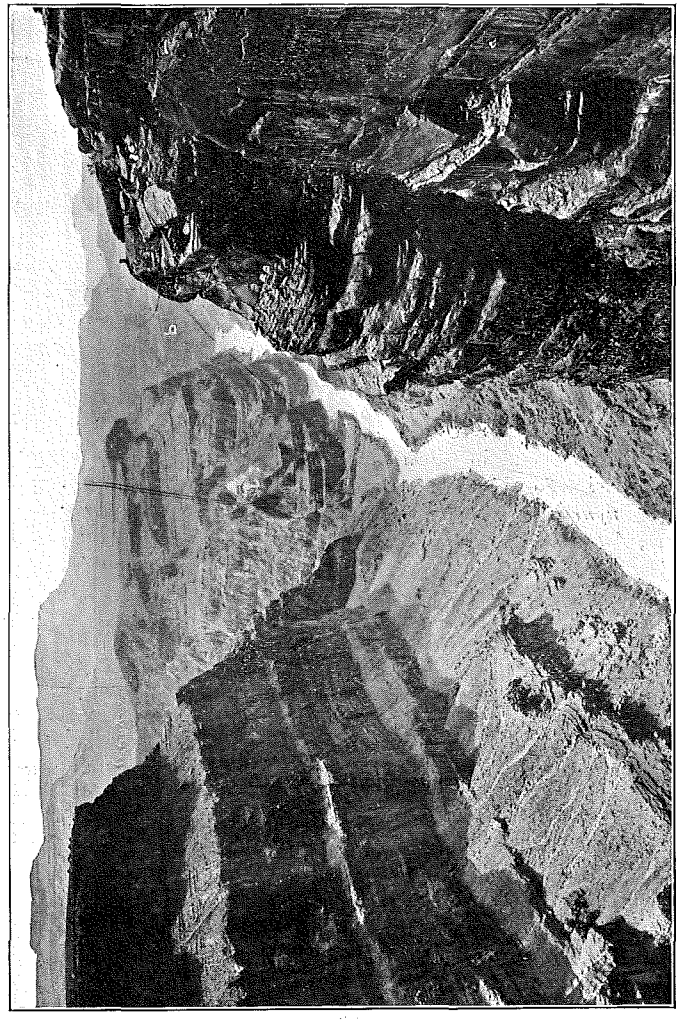


Plate 51. Redwall limestone cliff and esplanade-forming sandstone of Supai formation in Canyon of Colorado River at foot of Toroweap from a point not far east of Vulcan Throne. Mouth of Prospect Creek in middle ground near crossing of Toroweap Fault. Distant plateau capped by Kaibab limestone; b, basalt.

represented by only 15 feet of sandstone with iron oxide cement, and White Mesa is capped by 38 feet of sandstone containing a thin carbonaceous shale member. West of Ganado the sandstone is 40 feet thick, in the Hopi Buttes volcanic field a maximum of 160 feet was noted, and in Carrizo Mountain it is 170 feet thick.

In the region east and south of St. Johns, the Dakota sandstone lies unconformably on Chinle formation as shown in Plate 33b.

Plants of the Dakota flora were collected by Gregory at several localities. Thirteen miles west of Chinle he obtained *Salix* sp., *Andromeda pfaffiana* (?), and *Juglans* cf. *J. crassipes*. In sandstone capping the mesa in Steamboat Canyon, 15 miles west-northwest of Ganado, he found *Phyllocladus subintegrifolius*, *Ficus inæqualis*, *Ilex* sp. ?, with *Ostrea* sp., and *Corbula* sp.

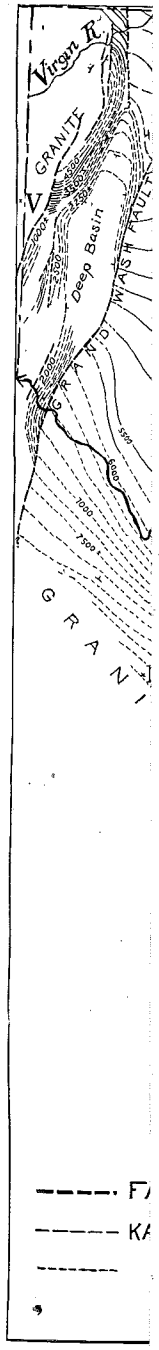
Pinkard formation.—In the vicinity of Morenci there are several small remnants of Upper Cretaceous sandstones and shales which have been called Pinkard formation.[1] The best exposures are on Silver Basin Creek 2 miles southwest of Morenci, and in Eagle Creek foothills 4 miles southwest of Morenci. Modoc Mountain is capped by a small mass and a larger one is exposed on the ridge at the head of Morenci Canyon. In all these places the strata are cut by igneous rock. The lower part of the formation is black shale which occupies a large area in Silver Basin; the upper part consists of alternations of shale and yellow-gray sandstone in part calcareous. The beds lie on an irregularly eroded surface of Modoc limestone (Mississippian) and their greatest thickness is at least 200 feet.

Abundant fossils found in calcareous sandstone 2½ miles south-southwest of Morenci were determined by Dr. T. W. Stanton as *Mactra cf warreneana*, *Pugnellus fusiformis*, *Glauconia coalvillensis*, *Corbula* sp., *Cardium* sp., *Astarte?* sp., *Cyrena?* sp., *Turritella* sp., and *Dentalium* sp.; these indicate a position in the Colorado group corresponding to the Benton shale. Numerous shells of a small species of *Astarte* were found in basal beds on the east side of Silver Basin 1½ miles southwest of Morenci.

Mancos shale.—The thick succession of shales lying between the Dakota sandstone and Mesaverde formation of northeastern Arizona, are known as the Mancos shale. At most localities it is easily separable from the underlying sandstone although possibly not everywhere at the same horizon. In most places the upper part of the formation presents a succession of beds of passage into the Mesaverde. The formation occurs extensively in the Black Mesa basin, which it underlies throughout, and it also occupies a small area along the east side of the Defiance uplift south of Fort Defiance.

Gregory[2] reports 550 feet of Mancos shale in the mesa front 20 miles northwest of Ganado; 428 feet near Jadito Springs 7 miles south of Keams Canyon; 295 feet at Shongopovi; 270 feet at Oraibi; 130 feet at Padilla Mesa; 310 feet or more at Howell Mesa; 565 feet in Chilchinbito Canyon 20 miles southeast of Kayenta; 620 feet at Lolomai Point near Marsh Pass, and 490 feet at Blue Canyon. In all these sections

[1] Lindgren, W., U. S. Geol. Surv. Geol. atlas, Clifton folio (No. 129) p. 105, 1905.
[2] Gregory, H. E., *op. cit.*, pp. 73-74.



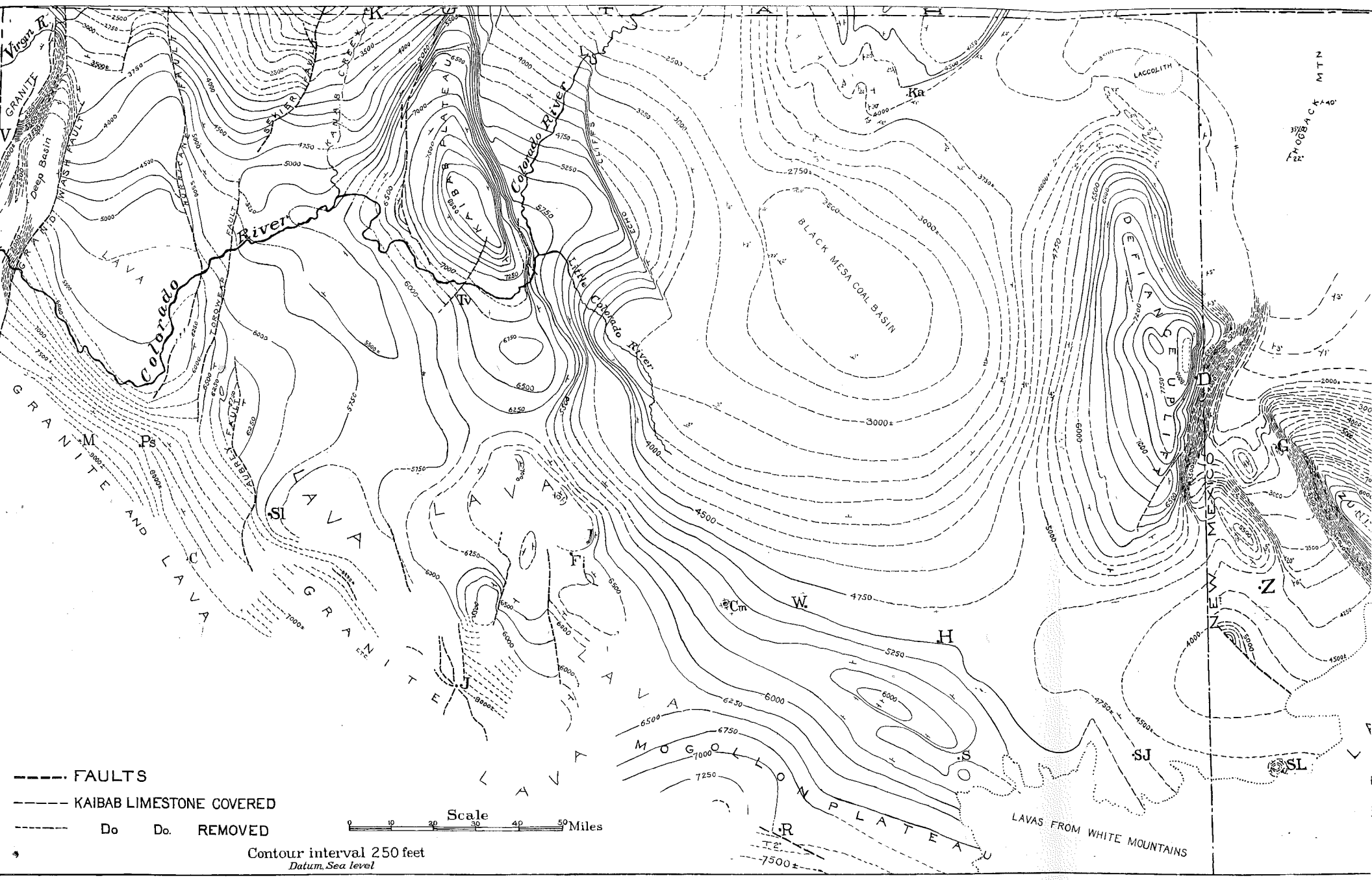


Plate 52. Map showing deformation of strata in Plateau region of Arizona, by contour lines at the base of the Kaibab limestone. By N. H. Darton. V, Virgin Mountains;; M, Music Mountain; Ps, Peach Springs; Sl, Seligman; C, Cross Mountain; K, Kanab, Utah; F, Flagstaff; L, Lees Ferry; Tv, El Tovar; Cm, Crater Mound; R, Ramer (Wallace) Ranch; J, Jerome; W, Winslow; H, Holbrook; Ka, Kayenta; S, Snowflake; D, Fort Defiance; SJ, St. John; SL, Salt Lake, N. M.; G, Gallup, N. M.; Z, Zuni, N. M.

Plate 53. Looking up canyon of Kanab Creek. Vermilion Cliffs in background. The lower beds are Supai formation, above which are Hermit shale, Coconino sandstone and Kaibab limestone, the latter forming the broad plateau.

three sandstone members are included and many beds of shells occur at various horizons.

Among the fossils collected by Gregory in the Mancos shale in the Navajo Country were *Ostrea congesta*, *O. lugubris*, *O. pellucida*, *O. petina*, *Gryphaea newberryi*, *Exogyra laeviuscula*, *E. columbella*, *Mactra emmonsi*, *Inoceramus labiatus*, *Prionotropis* sp., *and Camptonectes* sp.

I found that Upper Cretaceous strata occupy the crest of the Mogollon Plateau in its entire extension across Navajo County and probably

also across Apache County, although in the latter they are mostly covered by volcanic rocks. There are extensive exposures about Showlow and Pinedale, west of Pinetop, and at the head of various northern branches of Carrizo, Forestdale, and Cedar creeks. A large remnant also caps the highland west of the main fork of White River north of White River School; it contains a coal bed at one time mined for local fuel supply. Upper Cretaceous was also found underlying Tertiary strata and volcanic rocks in a wide area in the east-central part of Apache County. In the latter region there are large exposures along Zuni River and the head branches of Carrizo Wash east and northeast of St. Johns. Coal also exists in this area. In this region the Cretaceous lies on Chinle formation, as shown in Plate 33b, while in the Mogollon Plateau the underlying beds are Kaibab limestone and in places Moenkopi formation. There are extensive areas in which the strata are capped by gravel, boulders, and sand of supposed Tertiary age.

Veatch[1] has very briefly described the coal measures in the high part of the outlier of Cretaceous rocks west of Pinedale, giving many sections of the various coal beds included. Fossils collected by him comprised the following species: *Ostrea* sp., *Cyrena* sp.?, *Exogyra* cf., *E. laeviuscula* Roemer, *Cardium pauperculum*, *Corbula kanabensis*, *Plicatula hydrotheca*, and *Liopistha (Psilomya)* sp. These were determined by T. W. Stanton who regards them as Lower Colorado in age, or about the same age as the coal measures at Cedar City in southern Utah.

Fossils collected near the coal mine on Cottonwood Creek above White River School included the following species: *Pteria gastrodes*, *Ostrea* sp., *Cardium pauperculum*, *Corbula* sp., *Gyrodes depressa*, *Glauconia coalvillensis*, *Pugnellus fusiformis*, and *Fasciolaria* sp. In ledges on top of the plateau 2 and 2½ miles south of Showlow were collected *Ostrea* sp., *Cardium pauperculum*, *Callista orbiculata*, *Maetra emmonsi*, and *Gyrodes depressa*. These were all determined by J. B. Reeside, Jr., who states that they represent the Pugnellus fauna of the Carlile formation of the Benton.

Fossils found in Corduroy Canyon and Hop Canyon were ostreas and cardiums not specifically determinable.

Mesaverde formation.—Sandstones of the Mesaverde formation constitute the surface of the Black Mesa, and the western edge of the wide plateau which they occupy in New Mexico extends a short distance into Arizona in the ridge north of Lupton. Gregory[2] has described the character and relations of the rocks: "At the base are one or more heavy beds of sandstone 30 to 50 feet thick; these are succeeded by strata consisting of about equal amounts of thin sandstone and shale with many beds of coal. The top of the formation includes three or more beds of massive sandstone attaining thicknesses of 40 to 100 feet." (See Pl. 33a.) "In

[1]Veatch, A. C., Coal Deposits Near Pinedale, Navajo County, Arizona: U. S. Geol. Surv. Bull. 431, pp. 239-242.
[2]Gregory, H. E., *op. cit.*, pp. 75-76.

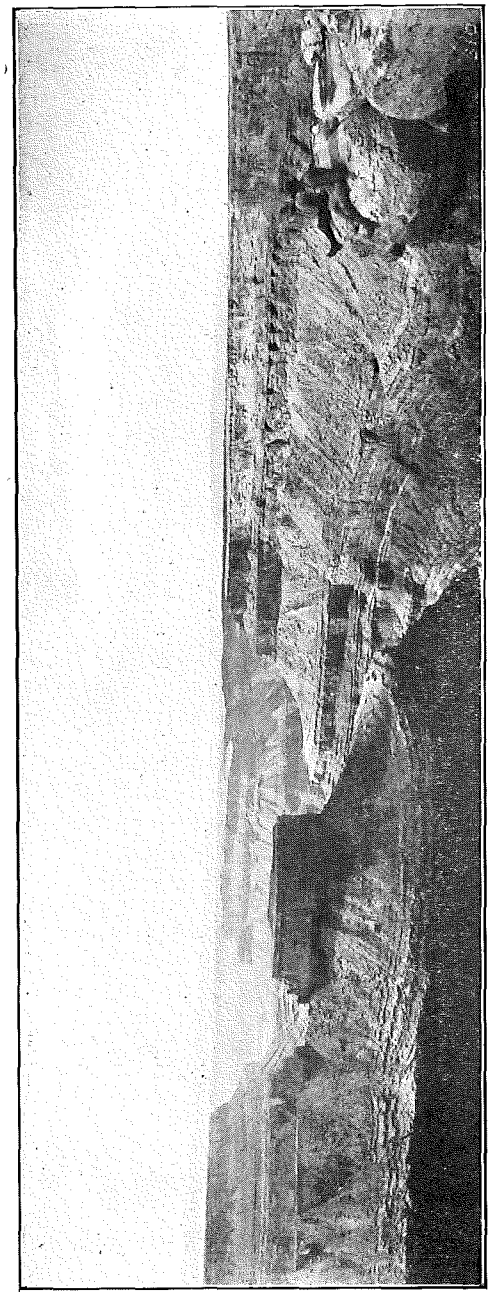


Plate 54a. Marble Canyon of Colorado River at a point 36 miles below Lees Ferry. Looking upstream. Kaibab Plateau in distance. Redwall limestone at bottom. Slopes of Supai formation and Hermit shale to cliff of Coconino sandstone and Kaibab limestone, the latter forming the wide plateau. Photo by La Rue.

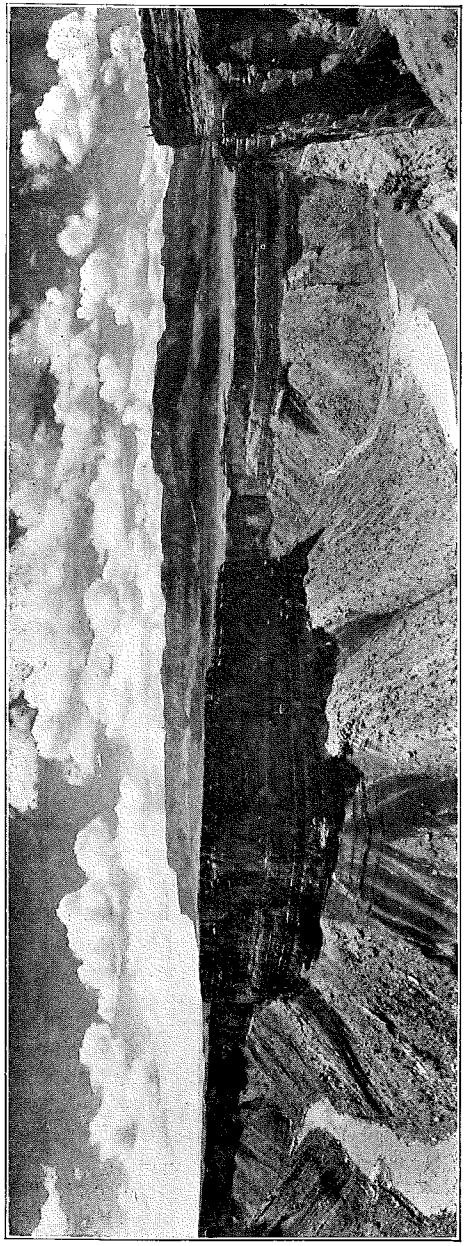


Plate 54b. Marble Canyon of Colorado River at the mouth of Soap Creek. Looking west to Vermilion Cliffs. Cliff in middle is red shale (Hermit-Supai), Coconino sandstone and Kaibab limestone. Shinarump conglomerate is in low cliff in background, beyond which are slopes of Chinle shale and cliffs of Wingate and Navajo sandstones. Photo by La Rue.

the Black Mesa area the thickness of the Mesaverde and the proportionate amounts of shale, sandstone, and coal vary widely; the formation is nearly twice as thick along the northeast rim of Black Mesa as in the zone extending from Salahkai to Oraibi," a difference probably in part due to erosion. At Salahkai Mesa, southwest of Chinle, 330 feet of Mesaverde remains, "the top 117 feet is coarse, cross-bedded sandstone in two massive beds separated by 22 feet of thin-bedded sandstone with many plant impressions. Below these upper sandstones are five groups of strata about equal in thickness, consisting of alternating clayey and sandy shales and thin-bedded sandstones." A section at the mouth of Keams Canyon includes sandstone, mostly yellowish, in members averaging about 50 feet thick, with several shale members 3 to 22 feet thick and two thin beds of coal in the middle, in all 288 feet. At Shongopovi, where the thickness is about the same, the bottom sandstone 80 feet thick is overlain by yellow and dark purple shale with thin beds of coal and at top is a 55-foot member of coarse sandstone in part conglomeratic. In these places the top of the formation has been removed by erosion, which is the case also in most of the Black Mesa rim. "In Moenkopi Valley, 6 miles east of Blue Canyon, where 220 feet of the Mesaverde is exposed, the section includes three strata of coarse sandstone or grit—two 45 and 12 feet thick at the bottom and a 25-foot bed at the top. Clayey shale and coal constitute 70 percent of the remaining 138 feet." "Along the northern rim of Black Mesa the Mesaverde attains a greater thickness than is known at any other place in northern Arizona. In this region the top sandstones are unusually thick and massive and the number of thin coal beds is abnormally large." In cliffs 18 miles southeast of Kayenta, Gregory found "the mesa rim to be a vertical wall 320 feet high of yellowish gray sandstone with inconspicuous lenses of shale, and six coal beds, in addition to eight or ten seams of matted plant fragments occurring below the sandstones." Some further information regarding the coal-bearing strata in the Black Mesa has been given by Gregory and Campbell.[1]

Plants and shells were found by Gregory[2] in various parts of the Mesaverde formation, and in New Mexico, near Tohatchi, remains of a turtle were obtained which is considered not older than Judith River formation. In upper sandstones on slopes of Chuska Mountains there were collected *Avicula?* sp., *Inoceramus sagensis?*, *Liopistha (Cymella)* sp., *Mactra formosa*, and other Montana forms. In bluffs northwest of Chinle were found *Ostrea pellucida*, *Inoceramus proximus*, and *Gervilla*, of Montana age.

Volcanic rocks.—In the Deer Creek basin in Gila County, south of Mescal Mountain, sandstones with Upper Cretaceous fossils are interbedded with a larger body of andesitic tuff and agglomerate which is about 1000 feet thick. There are also many dikes and possibly some igneous flows.

[1]Campbell, M. R., and Gregory, H. E., The Black Mesa Coal Field, Arizona: U. S. Geol. Surv. Bull. 330, pp. 229-238, 1911.

[2]Gregory, H. E., *op. cit.*, p. 75.

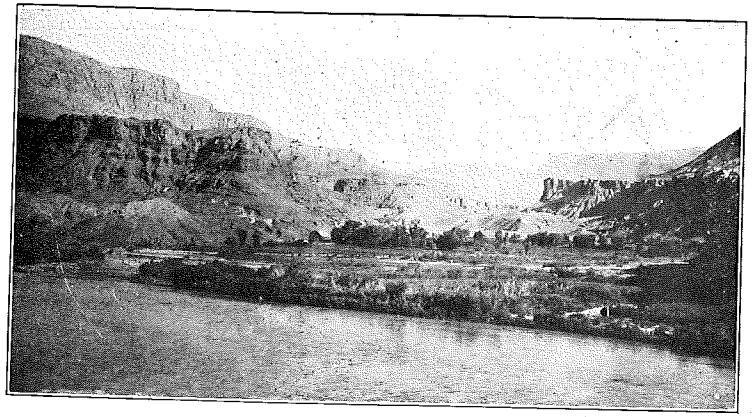


Plate 55a. Colorado River entering Marble Canyon about one mile below Lees Ferry. Looking southwest. Vermilion Cliffs in middleground and distance. Photo by La Rue.

Information regarding these rocks has been published by Walcott,[1] Campbell,[2] and Ransome.[3] The area extends eastward to the vicinity of Stanley

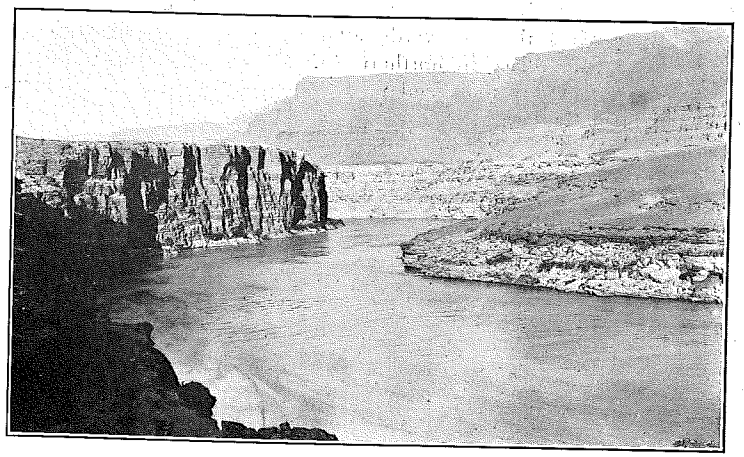


Plate 55b. Chinle shale and La Plata sandstone on the Colorado River at Lees Ferry. Looking northwest up canyon of Paria River. Photo by La Rue.

[1]Walcott, C. D., Description of the [Deer Creek] Coal Field: 48th Cong., 2d Sess., Senate Doc. 20, Appendix I, pp. 5-7, 1885.
[2]Campbell, M. R., The Deer Creek Coal Field, Arizona: U. S. Geol. Surv., Bull. 225, pp. 240-258, 1904.
[3]Ransome, F. L., The Copper Deposits of Ray and Miami, Arizona: U. S. Geol. Surv., Prof. Paper 115, pp. 56-57, 1919.

Peak, (Longitude 115° 20′), and Ransome noted that the exposures end about two miles west of Christmas. It is not unlikely that there are other occurrences of rocks of Cretaceous age among the unclassified volcanic rocks in various parts of southern and western Arizona.

TERTIARY AND QUATERNARY SYSTEMS

A large amount of sedimentary material was deposited in Arizona during the long period of Tertiary and Quaternary time, and there was great volcanic activity over wide areas in which vast volumes of igneous rocks were accumulated. Except in certain localities very little study has been given to either sedimentary or igneous rocks of these two periods.

Sedimentary rocks.—The various formations of Tertiary age which have been differentiated in western New Mexico have not been traced into Arizona, excepting, perhaps, in the Chuska Mountains, a range which extends across the boundary in the northeastern portion of the State. These formations have been described by Gregory[1] as *Tohachi shale* and *Chuska sandstone*, and are believed to be of early Tertiary age. The lower formation (Tohachi) is not stated to underlie the Tunitcha and Lukachukai ridges which constitute the northern extension of the Chuska Mountains. The Chuska sandstone is, however, a prominent feature in these ridges, where it forms a capping and high wall, its thickness ranging from 800 to probably more than 1,000 feet. The rock is a sandstone, consisting of quartz varying in texture; most of it is thinly bedded, some of it cross-bedded, and it ranges from gray with pinkish cast to white and less commonly brown. The grain is medium to fine and most of the rock varies from moderately firm to quartzite. No fossils were found, but it is suggested that possibly it may be correlated with the Wasatch formation of north-central New Mexico.

Wide areas of Tertiary deposits cover the mesas about Ganado and extend south from that place to the edge of the Rio Puerco valley. The principal materials are light colored sands and soft sandstone of various kinds, with several thin deposits of volcanic ash. Gregory mentions an exposure of 240 feet of this material 10 miles southeast of Keams Canyon, and small outliers occur in the Hopi Buttes, notably at White Cone, where there are 245 feet of alternations of sandstone and volcanic ash with interbedded soft shale members, some of which are banded gray, red, white, pink, or green.

I found that similar sands, loams, and gravels cover a very wide area adjoining the Puerco River Valley in the central part of Apache County. They constitute the high plateau of the divide south of Allantown, Houck, Chambers, and Navajo and extend south to the valley of Zuni River where they overlap the Upper Cretaceous rocks. Outliers, consisting largely of travertine, cap the Twin Buttes, two conspicuous objects on the north side of Little Colorado River near Hunt. Tertiary deposits extend

[1]Gregory, H. E., *op. cit.*, p. 79.

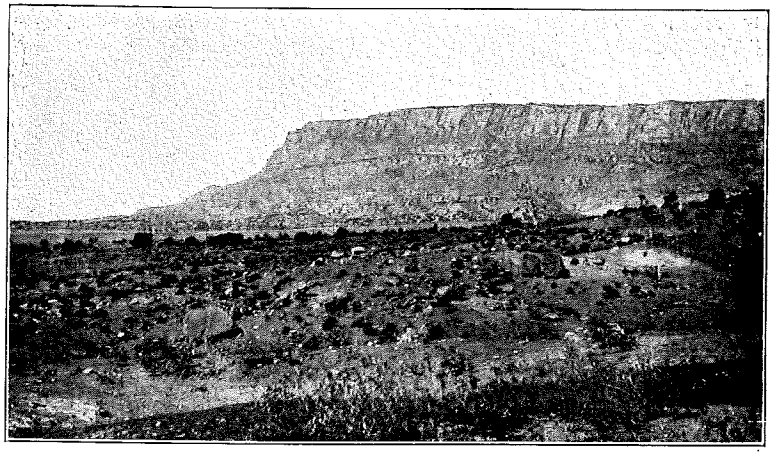


Plate 56a. Vermilion Cliffs west of Pipe Spring, southwest of Fredonia, Arizona. Slopes of Chinle formation in foreground.

far southward under the great lava flows of the Concho to Springerville area, and they are extensively exposed in the road and slopes south of the latter place. The cap on the ridge or mesa east and southeast of St. Johns, includes old, hot spring cones and travertine deposits. There are many striking exposures of the Tertiary beds along the State line east and southeast of Springerville and Nutrioso, one of which is shown in Plate 35a.

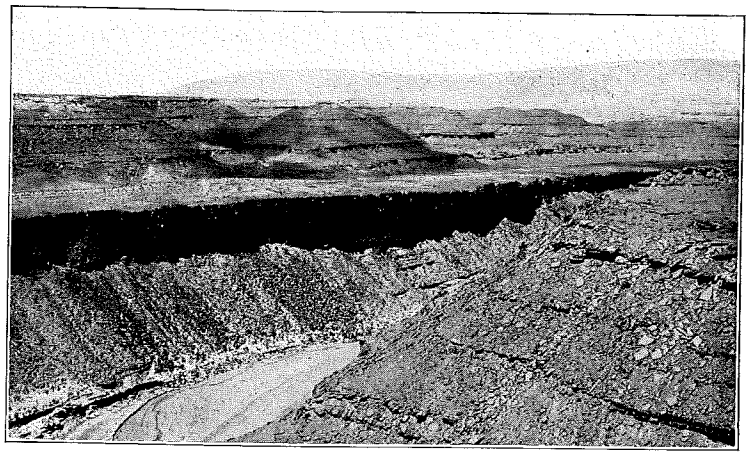


Plate 56b. Canyon of Little Colorado River 1 mile below mouth of Moenkopi Wash. Coconino Point in background. Canyon cut in Moenkopi strata and top of Kaibab limestone. Shinarump conglomerate caps mesas in middle distance. A basalt flow forms terrace terminating in dark cliff above stream. Photo by Gregory.

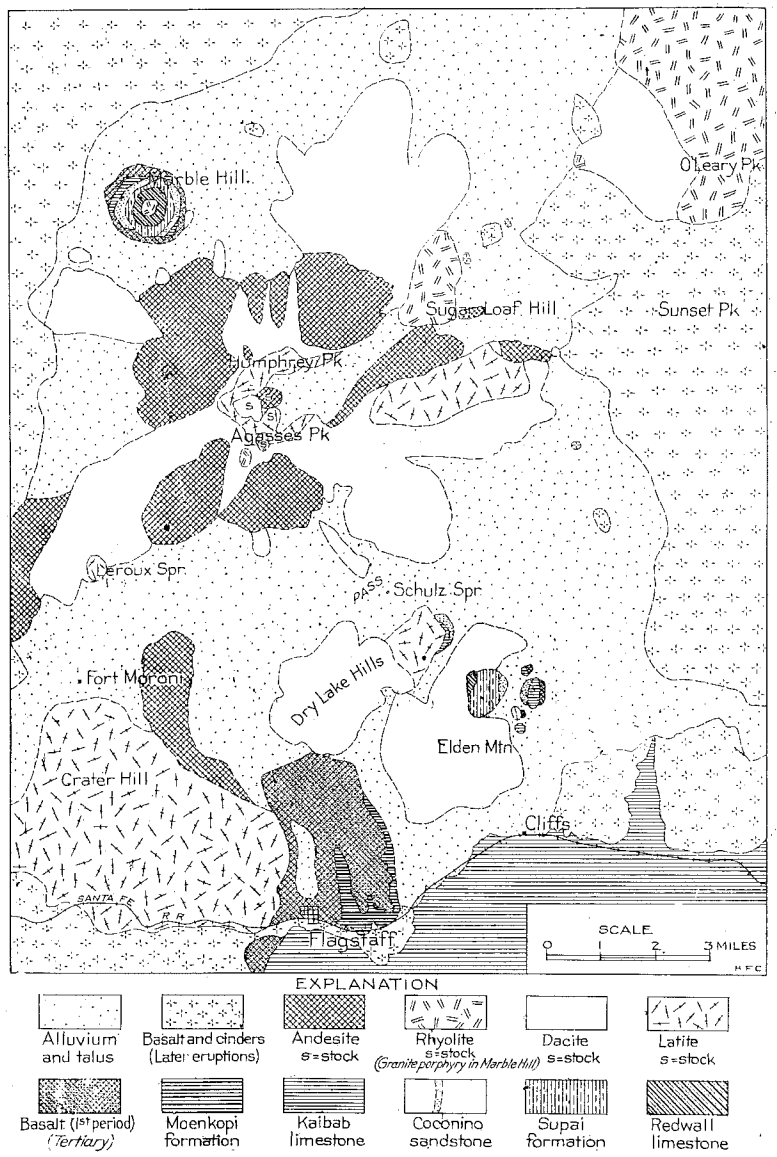


Plate 57. Geologic map of the San Francisco Mountains, after Robinson.

Near Alpine the material is mostly sandstone, in part conglomeratic, and it outcrops at various places under the volcanic flows.

Strata supposed to be the western extension of these deposits appear in the western slope of the White Mountain volcanic district on the east side of the valleys of both forks of the White River, and they also cap the divide west of the west fork of the White River where they extend to the edge of the valley of Corduroy Creek. Big Mountain, an outlying butte on this divide, consists of gravels. Deposits of gravels and boulders underlie the great lava flows of Natanes Plateau along the south side of the valleys of White River and Black River, cap the Mogollon Plateau across Navajo County, and constitute the top of many of the buttes and high mesas in the divides between Carrizo and Canyon creeks in the Fort Apache Indian Reservation. (See map, Pl. 65.) The correlation of these deposits with any division of the Tertiary is not possible at present, and some of them may prove to be early Quaternary.

Schrader[1] had the opinion that strata of Tertiary age might underlie parts of the region adjoining the Santa Rita, Empire, and Patagonia mountains. He found an exposure in Adobe Canyon, 5 miles east-southeast of Old Baldy, having the following components:

SECTION OF TERTIARY ROCKS IN ADOBE CANYON, 10 MILES NORTH-NORTHWEST OF PATAGONIA, ARIZONA

	Feet
Coarse conglomerate, pebbles of volcanic rock, etc.	200
Shale, red and green, few thin layers sandstone and fossiliferous limestone	150
Grits and sandstone, red with some thin beds of shale	100
Shale, greenish, concretionary and calcareous beds, fossils	100?
Concealed	50±
Conglomerate, volcanic rock, sandstone and shale, on red shale, quartzite, sandstone, etc., of supposed Bisbee group	50

Fossils obtained in this exposure were found by T. W. Stanton to include the following: *Unio*, several species, one cf. *U. recioides* White; *Viviparus* cf. *V. wyomingensis* Meek, and *Phyea* cf. *pleromatis* White. These are fresh water forms regarded as probably Eocene in age.

Schrader states that similar beds appear along Santa Cruz River and Sonoita Creek and east of Calabasas, which were noted by Dumble,[2] who regarded them as part of the Baucari division (probably Pliocene) of the State of Sonora, Mexico.

Gidley,[3] in describing fossil vertebrates recently collected in the San Pedro Valley, expresses the opinion that the fossil-bearing beds, which are low in the valley, are of Pliocene age and probably a late stage of that epoch. The assemblage of fossils indicates a rather warm and moist climate, similar to that now existing in southern Mexico.

[1]Schrader, F. C., *op. cit.*, pp. 54-55.

[2]Dumble, E. T., Notes on the Geology of Southeastern Arizona: Am. Inst. Min. Eng. Trans., vol. 31, p. 697, 1902.

[3]Gidley, James W., Preliminary Report on Fossil Vertebrates of the San Pedro Valley, Arizona: U. S. Geol. Surv., Prof. Paper 131-E, pp. 120-121, 1922.

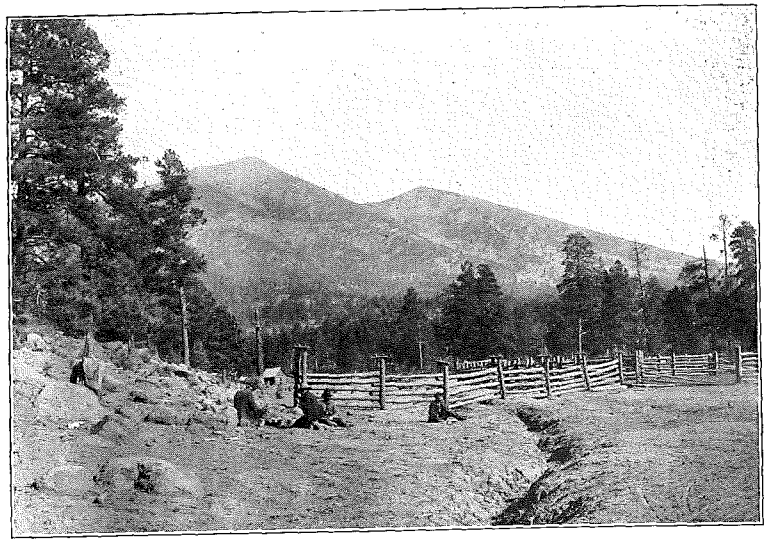


Plate 58a. San Francisco Peaks northeast of Flagstaff.

In the wide valley east of Virgin Mountains are several deposits of Tertiary and Quaternary age. Of the former Longwell[1] has defined the *Horse Spring* formation (Miocene?) which consists of 2,500 feet of sandstone, limestone, magnesium carbonate, shale, tuff and gypsum and basal conglomerate (Overton).

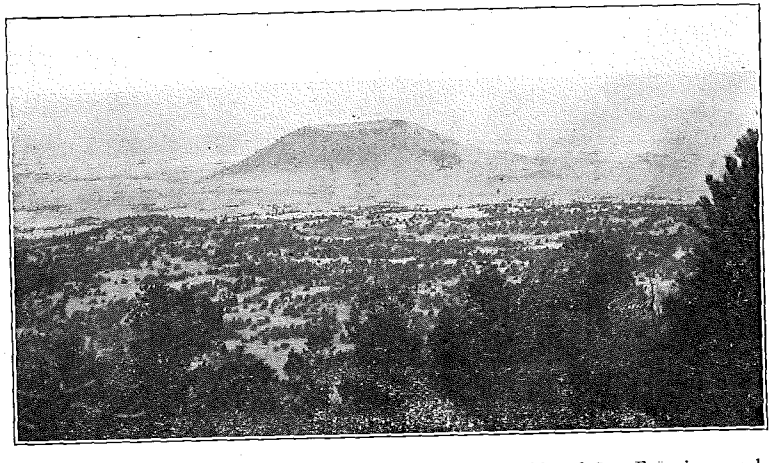


Plate 58b. Recent cinder cone and lava flow on east side of San Franciscan volcanic field. Photo by Gilbert.

[1]Longwell, C. R., loc. cit., pp. 52-54.

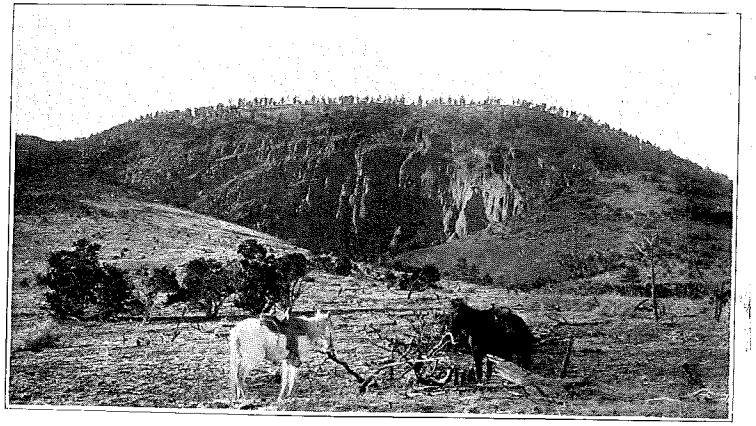


Plate 59a. Ash cone of Red Mountain at head of Hull Wash, 30 miles north of Flagstaff. Photo by Gilbert.

In a reconnaissance of the Papago Country in southwestern Arizona, Bryan[1] found outcrops of sediments of supposed Tertiary age at various points, notably south of Ajo, near Tule well, near Cabeza Prieta, at Antelope Hill, south of Baker Peak, north of Table Top, and at Comobabi. In general these rocks are composed of coarse, poorly sorted, arkosic material in part conglomeratic. They range in thickness from 50 to more than 1,000 feet and are classed as Tertiary because of their intimate association with the succession of volcanic rocks of that period.

Jenkins[2] has described extensive deposits of lake beds in the basin

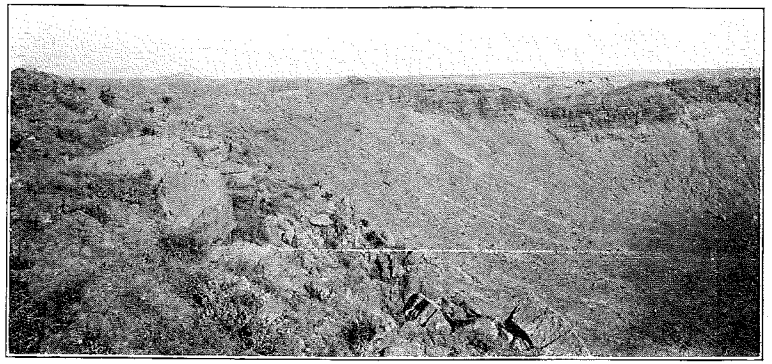


Plate 59b. Part of Crater Mound (Coon Butte) southwest of Winslow, Arizona, showing upturned Kaibab limestone and rim of ejected fragments on the thin edge of Moenkopi red beds. Photo by Gilbert.

[1]Bryan, K., *op. cit.*, p. 26, and map.
[2]Jenkins, O. P., Verde River Lake Bed Near Clarkdale, Arizona: Am. Jour. Sci., vol. 5, pp. 65-81, 1923.

traversed by the Verde River in Yavapai County. They consist of gravels, sands and clays, with included limestones in large amount, and a very interesting series of saline compounds. The thickness is estimated at 1400 to 2000 feet, as indicated by deep drill hole records.

The name *Greggs breccia* was applied by Lee[1] to the detrital filling in the Grand Wash and Hualpai depressions at and near the Colorado River. Its thickness is 1400 feet. "It is composed of coarse, unassorted and poorly stratified material consisting largely of blocks of crystalline rock similar to the granite and gneiss of the Virgin Mountains to the west. Toward its top the detrital material is cemented with lime carbonate and in places the upper 200 feet consists of travertine containing few rock fragments. This travertine is best exposed south of the Colorado River and east of Greggs Ferry where it caps conspicuous cliffs which rise 1400 feet or more above the river." A view of this travertine is given in Plate 35a. As the breccia was deposited before the Grand Canyon was excavated to its present depth, it is either later Tertiary or early Quaternary in age.

Bancroft[2] has suggested that breccia at the mines of the Corona Copper Company, 20 miles northeast of Bouse, and also in Battleship Mountain, 15 miles northeast of Bouse, may represent the Greggs breccia. A similar breccia of rhyolite fragments was noted by him just southeast of Casteneta Well, in southern Mohave County.

Lee[3] gave the name *Temple Bar conglomerate* to a thick deposit of sand and gravel filling valleys in western Arizona but of earlier date than the recent alluvium and wash on slopes. The type exposure is at Temple Bar, on Colorado River, near the mouth of Virgin River, where the deposit is loosely cemented into soft conglomerate, which, together with included sheets of basalt, constitutes nearly perpendicular cliffs of considerable height. "Where exposed along the Colorado the Temple Bar conglomerate is evidently a river deposit but it merges laterally into deposits of irregular mountain wash in some places, and possibly into lacustrine deposits at others. It rests unconformably upon the Greggs breccia and older formations and is apparently equivalent in age to the widespread detrital accumulation filling the low places of the Southwest generally and forming the desert plains of Arizona and parts of southern California." Lee compared it to the Gila conglomerate but stated that most of it is not so well consolidated as the latter. Some flows of basalt, from a few feet to 800 feet thick, are included in Temple Bar conglomerate.

Blanchard[4] described some interesting details of the relations and components of the Temple Bar conglomerate on slopes of the western part of

[1]Lee, W. T., Geological Reconnaissance of a Part of Western Arizona: U. S. Geol. Surv., Bull. 352, p. 17, 1908.
[2]Bancroft, H., *op. cit.*, p. 31-32.
[3]Lee, W. T., *op. cit.*, p. 17.
[4]Blanchard, R. C., *op. cit.*, pp. 22-26.

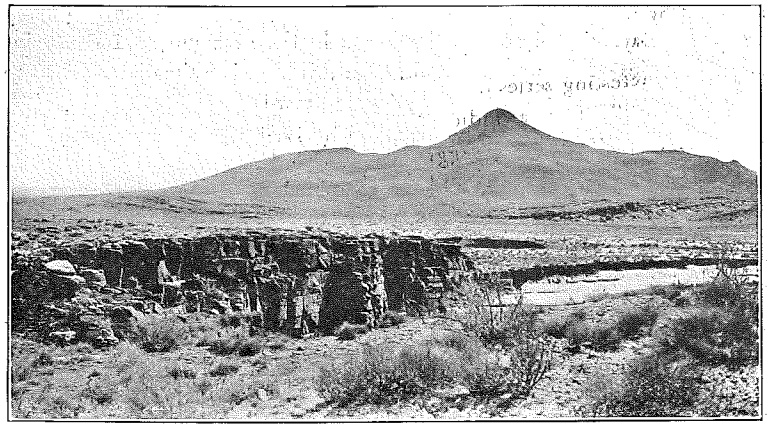


Plate 60a. Woodruff Butte, 10 miles southeast of Holbrook, Arizona. Cap of basalt on Chinle shale. Shinarump conglomerate and Moenkopi formation on slopes. Coconino sandstone in foreground. Photo by C. E. Major.

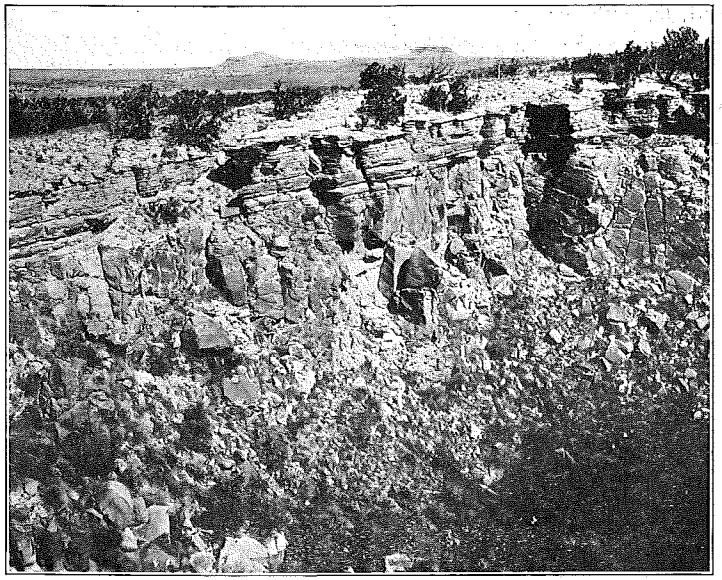


Plate 60b. Kaibab limestone on Coconino sandstone (?) in sink hole at The Sinks, 15 miles southwest of Holbrook, Arizona.

the Buckskin Mountains in the northwestern part of Yuma County, where much of the formation is a hard red sandstone. It is capped in places by a 5 to 50-foot bed of rhyolite tuff, which is overlain by a flow of rhyolite porphyry and basalt. He found fossils at the base of the tuff which W. H. Dall determined as *Bittium* and a probable young *Corbicula*, believed to be Pliocene in age.

Lee[1] suggested the name *Chemehuevis gravel* for a gravel deposit lying unconformably on the Temple Bar conglomerate in the bluffs along the Colorado River from the mouth of the Grand Canyon to south of Yuma. It is exposed in characteristic development in many open valleys from Bulls Head southward, and although in places 700 feet thick, it occupies a narrow zone along the valley, having been deposited during an aggrading stage of the river. It is supposed to be of early Quarternary (Pleistocene) age.

The name, *Gila conglomerate*, was given by Gilbert[2] to the coarse conglomerate which occupies many of the valleys of central eastern Arizona. The rock has been found in a wide area in the State, so that the name has been used extensively, even being applied in some cases to beds older (Pliocene) than the typical Gila which is classed as Quaternary. It has been assumed that this formation occupies most of the broad intermontane valleys throughout the southern part of Arizona, because in places where erosion discloses the subterrain of these valleys it is found to be coarse conglomerate. Locally the formation is tilted to various angles and in places cut by faults. At many localities it includes flows of basalt or other igneous rocks and beds of tuff. There are extensive exposures of the formation all along the Gila River drainage basin, including many places in the mountains, where remnants of it mark old valley levels. A notable body of the Gila or a similar conglomerate, occurs at Peach Springs, occupying a depression in the Redwall limestone. It is from the base of this conglomerate that the water issues at Peach Springs pumping station.

The Gila conglomerate and associated formations in part of the Gila Valley in the San Carlos Indian Reservation have been briefly described by Schwennesen.[3] He states that the Gila conglomerate consists of material ranging from fine sand to boulders several feet in diameter cemented to a loose rock which forms cliffs in many places. It varies greatly from place to place in components and texture, and gravel and boulder beds merge into sand deposits. It extends up the slope of the Turnbull Mountains to an average altitude of about 4200 feet. The maximum thickness is estimated at not less than 1000 feet. On the Gila conglomerate in this area lie sandstones and tuffs with local beds of limestone and marly clay,

[1]Lee, W. J., *op. cit.*, p. 18, Bull. 352.

[2]Gilbert, G. K., Report of Explorations West of the 100th Meridian (Wheeler), vol. 3, pp. 540-541, 1875.

[3]Schwennesen, A. T., Geology and Water Resources of the Gila and San Carlos Valleys in the San Carlos Indian Reservation: U. S. Geol. Surv., Water-Supply Paper 450 (a), pp. 7-9, 1919.

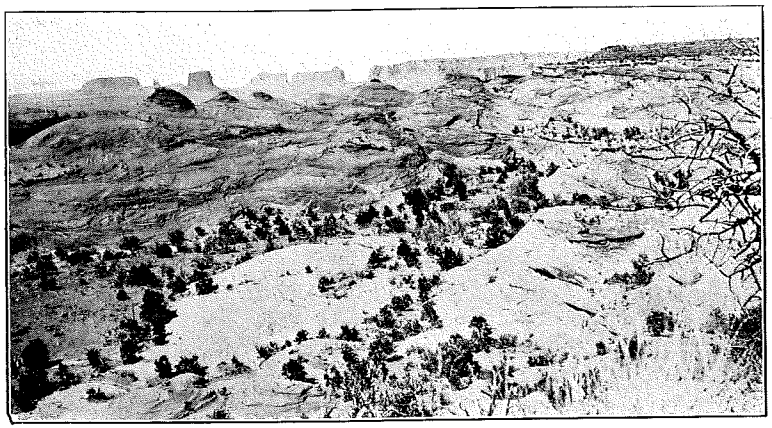


Plate 61a. Monument Valley from a point about 12 miles northeast of Kayenta. Coconino sandstone in foreground. Moenkopi formation, with "Oljeto sandstone member" in distance. Photo by Gregory.

which are believed to have been deposited in standing water that at one time occupied the valley to a considerable height.

These sandstones are soft, fine-grained, well stratified, and of pale buff color, interbedded with thin layers of hard sandstone in part of coarse texture. The tuffs, marly clays, and light gray sandstones occur principally in the region extending from the Triplets northward to San Carlos River and southward to the Gila River. The maximum thickness is not known, but it is estimated that it may be 800 feet at San Carlos and 700 feet near Peridot. The cause of the lake is not known, but the dam was un-

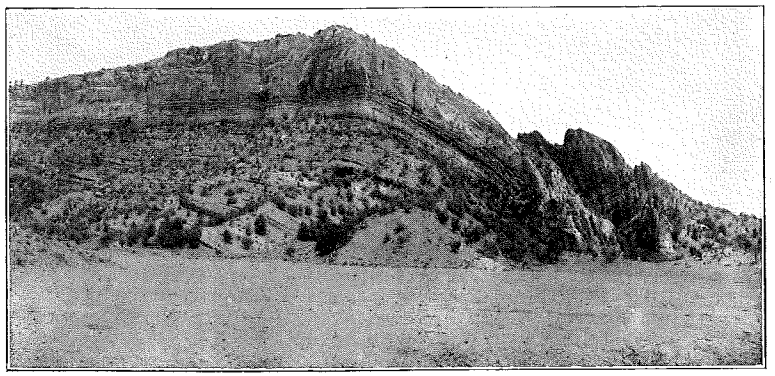


Plate 61b. Supai red beds and Coconino sandstone on east side of Defiance Uplift at fault 8 miles south of St. Michaels. Looking north.

doubtedly at the gorge in the mountain front a few miles west of San Carlos, near the place of the projected San Carlos Dam.

Volcanic rocks.—A great proportion of Arizona is covered by volcanic rocks, largely the products of eruptions in Tertiary time. Owing, however, to lack of data, it is not possible to make precise correlations. It is known that some of the volcanic rocks in certain districts are of Cretaceous age and others are early Quaternary. The later Quaternary eruptives are more readily separated. The Tertiary and early Quaternary volcanic rocks are largely rhyolites, dacites, andesites, and latites, but there were also outflows of basalt at various times. Most of the latest outflows of Quaternary time are basalts and some of these are so fresh in appearance as to suggest that they were erupted only a few centuries ago.

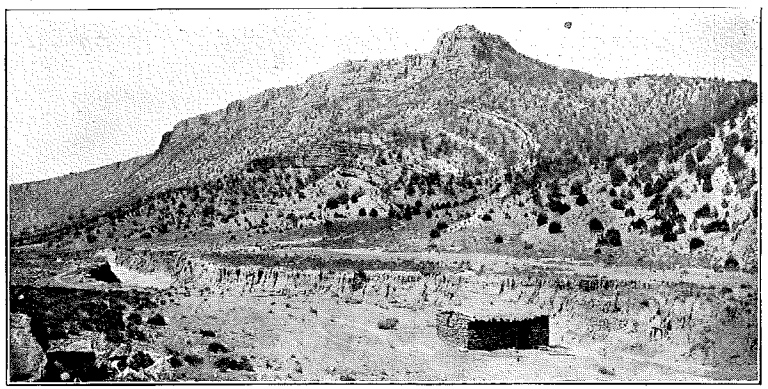


Plate 61c. Defiance uplift at canyon of Black Creek 15 miles south of St. Michaels. Looking southwest (downstream). The great arch is in red beds of Supai formation, the cliff above is Coconino.

The character and relations of the great series of volcanic rocks of the San Francisco Mountain area on the Arizona Plateau have been described in detail by Robinson.[1] The earliest and latest flows and cinder cones are of basaltic lava and there is a thick intermediate series of lavas ranging from andesite to rhyolite constituting cones, flows, and lacolithic masses. Thick masses of dacite overlain by andesite constitute San Francisco Peaks, large masses of rhyolite occur in Sitgreaves, Kendrick, and O'Leary peaks, andesite overlain by dacite makes up Bill Williams Mountain, and latite and dacite make up Mormon Mountain. Excepting the basalts, the character of rocks as well as their sequence varies somewhat in the different peaks, a fact which Robinson believes to indicate "that lavas of diverse composition were erupted at the same time at various points throughout the region" and "that the differences in composition of the individual

[1]Robinson, H. H., The San Franciscan Volcanic Field, Arizona: U. S. Geol. Surv., Prof. Paper 76, 1913.

lavas as well as their order of eruption at each cone were due to purely local causes."[1] It seems probable, however, that most of the large dacite flows were simultaneous.

The succession of Tertiary? volcanic rocks in south-central Yavapai County has been described and mapped by Jaggar and Palache.[2] They found that the rhyolite tuff is apparently the oldest member, probably with contemporaneous flows of silicious lava. Next above the tuff is andesitic agglomerate representing the explosive phase of an early eruptive period which culminated in large outflows of andesitic lava, most of them coming from a region southwest of this area, and accompanied by some basalt. Then came extensive flows of basalt in successive outpourings to an aggregate of 500 feet, which now cap wide areas of high mesas. These came mostly from the northwest and northeast, only one conduit being found in the Bradshaw quadrangle.

Many of the mountains in the Papago region in southwestern Arizona consist entirely or largely of lavas of the Tertiary succession. This is the case in the Growler, Ajo, Sauceda, Sand Tank, Dripping Spring, Batamote, Childs, Crater, Table Top, Nariz, Artesa, Quijotoa, Alesna, and Cerro Colorado mountains and parts of other ranges. These lavas also appear in many small ridges rising above the desert flats. They have been mapped by Bryan[3] who also gives many interesting facts regarding them. They comprise a variety of rocks, many in extensive flows separated to some extent by deposits of tuff and agglomerate. It is stated that in the Growler, Ajo, Quijotoa, and Sand Tank mountains the thickness is 1200 to 1500 feet and it may reach 2000 feet. The sheets are considerably tilted and faulted and the mountain masses which they constitute are deeply eroded. But few centers of eruption have been recognized excepting perhaps Batamote Mountain, which as Bryan suggests may be a dissected volcano.

Bancroft[4] describes the occurrences of younger igneous rocks in the southern part of Yuma County and the adjoining southwestern corner of Yavapai County. He states that the low hills northeast of Bouse consist of andesitic breccia and lava flows, and a large part of the summit of Plomosa Mountains is capped by basalt of "Quaternary age" lying in part on probable Tertiary andesites, the whole being about 1500 feet thick. He mentions a small mass of rhyolitic breccia 4 miles northwest of Bouse and states that Bullard Peak, about 10 miles north of Golden, consists of very basic andesitic material.

Many mountains in the central part of Yuma County and the western part of Maricopa County consist of volcanic rocks of supposed Tertiary age. Probably the largest mass presented is in the S H Mountains, but the Castle Dome, Eagletail, Bighorn, Painted Rock, Trigo, and Gila Bend

[1]Robinson, H. H., *op. cit.*, p. 173.

[2]Jaggar, T. A., Jr., and Palache, *op. cit.*, folio 126.

[3]Bryan, K., *op. cit.*, map.

[4]Bancroft, H., *op. cit.*, pp. 30-31.

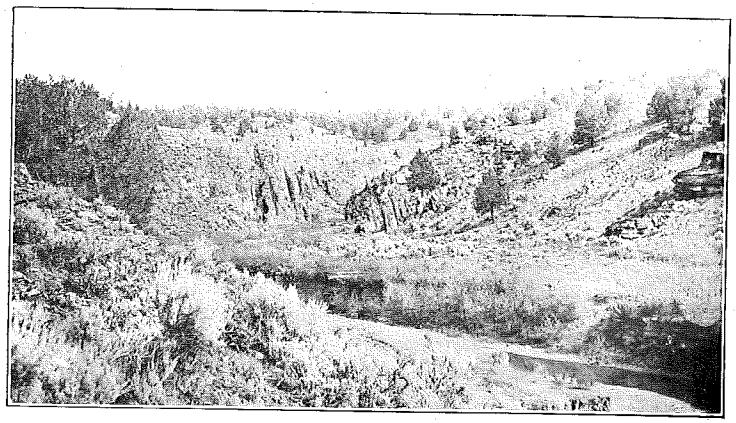


Plate 62a. Pre-Cambrian quartzite overlain by red beds of Supai formation in Quartzite Canyon 3 miles northwest of Fort Defiance, Arizona. Looking northwest. C-C, contact.

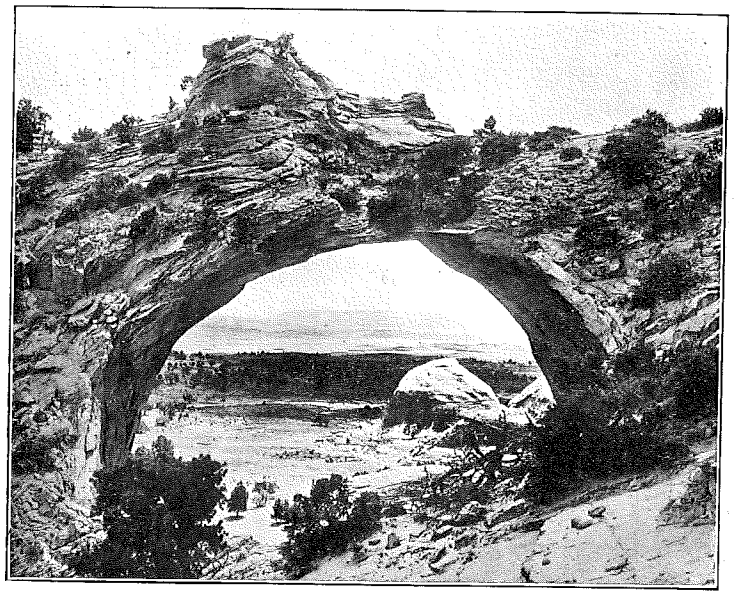


Plate 62b. Natural bridge in Coconino sandstone southwest of Fort Defiance. Looking northeast over valley of Chinle beds to mesas of Mesaverde formation in New Mexico.

mountains are also built of thick successions of lava flows. The lavas are mostly acidic and in thick sheets, and considerable rhyolitic tuff and agglomerate are included. Ross[1] gives many data regarding this region. He found very few intrusive masses but mentions plugs or volcanic feeders in the Plomosa, Dome Rock, and Eagletail mountains. Court House Rock, a very prominent feature on the north side of the Eagletail range, nearly 1000 feet high and only a few hundred feet in diameter, is an example. An irregular sheet of gabbro is intruded in Tertiary sandstones on Black Butte northwest of Bouse; this butte is capped by basalt either of late Tertiary or early Quaternary age. There are thick basalt caps on various mountains in western Yuma County which Ross considered to be of Tertiary age because they are much older than the basalt flows at lower levels in the valleys.

Blanchard[2] has given some details regarding late Tertiary and Quaternary igneous rocks in the western part of the Buckskin Mountains in the northwestern part of Yuma County. The Temple Bar conglomerate is overlain by rhyolite tuff and this in turn is followed by a flow of rhyolite porphyry (classed as Quaternary). The general mesa is covered by a wide sheet of basalt probably of Quaternary age.

The succession of volcanic rocks in the Tucson Mountains west of Tucson have been described by Jenkins and Wilson.[3] On the western side of the range are granitic and porphyritic rocks which may be older than Tertiary. Next above and flanking the eastern, northern, and southeastern sides of the range are flows of rhyolite and andesite, with tuffaceous deposits of both types and probably also some intrusive stocks. Still younger are basalt lava flows which are prominent in the Tumamoc and Black Hills where their relations and rocks have been described by Tolman[4] and Guild.[5] There are intercalated tuffs (rhyolitic) and gravel and sand deposits among these later lavas.

Southwest of Amole Peak in the Tucson Mountains there is a thick series of red shales and sandstones overlain by arkosic sandstone of buff color, cut by acid dikes. This series appears to me to be a sedimentary succession of Tertiary age.

A considerable variety of igneous rocks, largely of Tertiary age, has been mapped and described by Schrader[6] in the Santa Rita-Patagonia Mountain region. The highest summit, Old Baldy, of the former consists of rhyolite. The apparent chronologic order is rhyolite, quartz latite porphyry, older andesite, tuff and agglomerate, younger andesite and older basalt. Schrader suggests that the rhyolite may be of Miocene age.

[1]Ross, C. R. P., *op. cit.*, pp. 186-188.

[2]Blanchard, R. C., *op. cit.*, pp. 23-30.

[3]Jenkins, O., and Wilson, E. D., *op. cit.*, pp. 11-15.

[4]Tolman, C. F., Jr., Geology of the Vicinity of Tumamoc Hills: Carn. Inst., Pub. 113, pp. 67-83, pls. and map, Washington, 1907.

[5]Guild, F. N., Petrography of the Tucson Mountains, Pima County, Arizona: Am Jour. Sci., vol. 20, pp. 313-318, 1905.

[6]Schrader, F. C., U. S. Geol. Serv. Bull. 582, *op. cit.*, pp. 70-76.

The quartz-latite porphyry rests on and is intruded into the quartz monzonite and apparently also into the granite porphyry, but its relations to the rhyolite are not apparent and it may be the older. It is overlain by older andesite but as the latter is cut by rhyolite dikes the time sequence is somewhat doubtful. The tuff and agglomerate appear in the valley at Nogales and extend along the east side of the San Cayetano Mountains and there is a small exposure on the north slope of Mt. Allen near Salero. Rhyolitic material predominates although in places there are andesitic components. It is capped by younger andesite in Mt. Allen and this rock also lies on and intrudes rhyolite and other rocks. Basalt cutting the

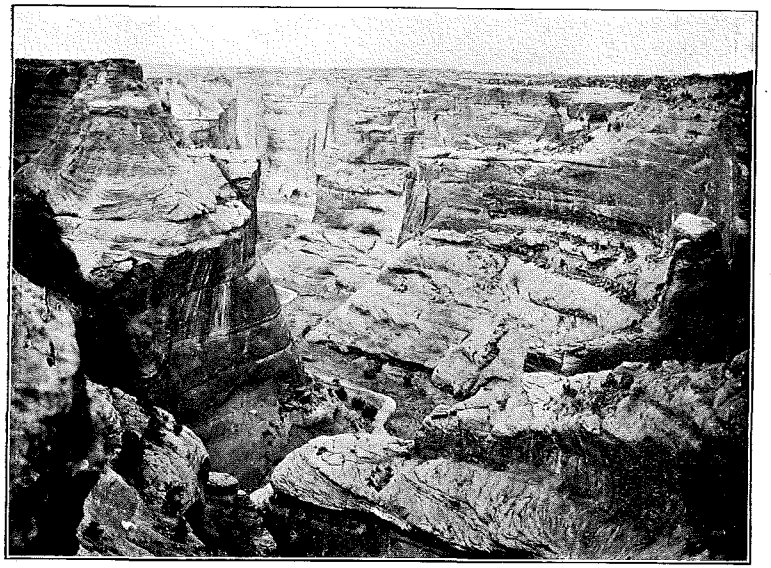


Plate 63a. Coconino sandstone in Canyon de Chelly, 5 miles east of Chinle. Looking north down a side canyon.

younger andesite and other igneous rock is the latest member, but the dikes may be feeders of latest Tertiary or early Quaternary flows. A remnant of one of the latter caps the mesa 3 miles east of Nogales.

The succession of igneous rocks in the southern part of the Black Mountains has been recently set forth by Ransome.[1] This succession lies on the irregular surface of pre-Cambrian granitic rocks and consists of several thousand feet of lavas of various kinds, with intercalated fragmental material. There is a general low dip to the east. Some of the lavas are widespread and uniform in relations over large areas, while

[1]Ransome, F. L., Geology of the Oatman Gold District, Arizona; A Preliminary Report: U. S. Geol. Surv., Bull. 743, 1923.

others are of small extent. Dikes and other intrusive bodies also occur. In places at the base is a coarse breccia containing volcanic material, sandstone and shale, 100 to 200 feet thick. Overlying and overlapping this deposit is a widespread body of trachyte formerly known as the "older andesite" or "basal andesite," probably as much as 2800 feet thick; part of it may be intrusive. In the southern part of the district this is followed by a local flow of but slightly different trachyte, which appears to attain a thickness of 1000 feet. Locally it is separated from the lower trachyte by sandy beds which are 115 feet thick. Next above this trachyte is the Oatman andesite, in part intrusive, which may be as much as 2700 feet

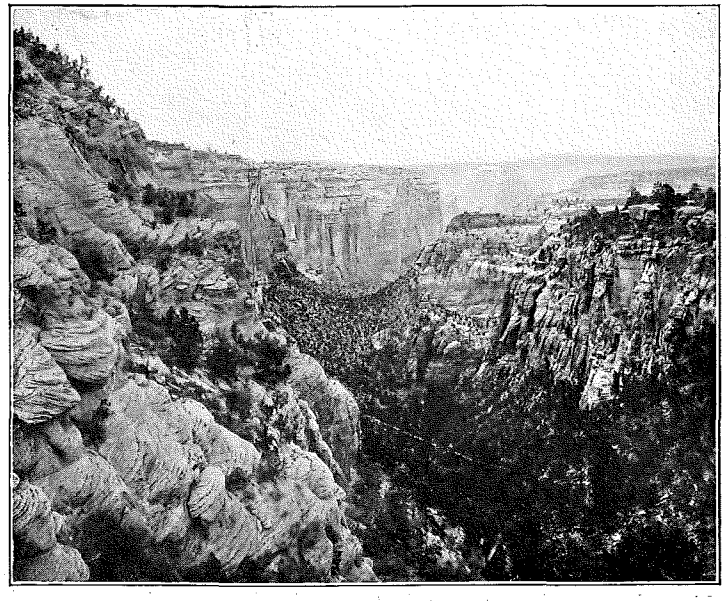


Plate 63b. Coconino sandstone near Canyon de Chelly just south of Monument Creek. Looking northeast along a fault which drops Shinarump conglomerate to right. Canyon de Chelly in distance.

thick. It is this igneous mass that the Tom Reed and United Eastern mines penetrate to a depth of 1500 feet. Above this andesite and forming the greater part of the Black Mountains east of Oatman, are 3000 to 4000 feet of latite composed of many flows of varying character and probably including some glassy rhyolite and layers of tuff. Above the latite are bodies of brown trachyte, about 250 feet thick, and of local extent. Resting partly on the great latite and partly on this overlying trachyte is a body of cream colored tuff, in places 200 to 300 feet thick, exposed in the high slopes east of Gold Road. Above the tuff is a local body of glassy, spherulitic rhyolite, 500 to 600

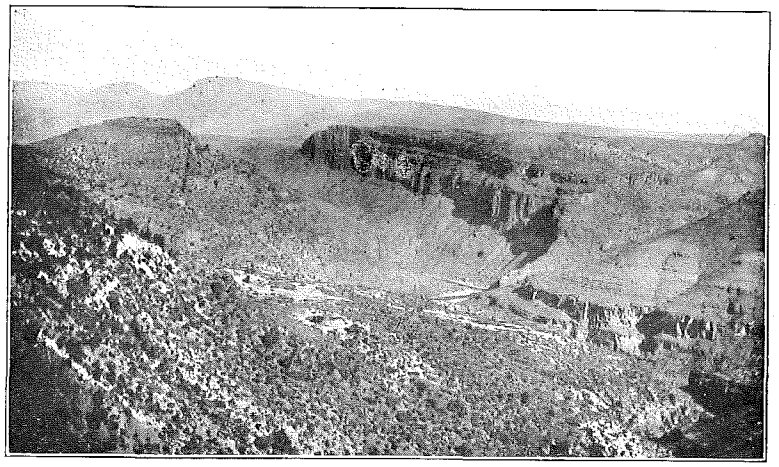


Plate 64a. Great cliff of Dripping Spring quartzite on the Salt River just above mouth of Canyon Creek. Looking northwest from near Regal Mine. Sombrero Butte in distance to left; Mescal limestone on ridge in middle ground to right.

feet thick, forming the top of Battleship Mountain and other peaks to the north and east. In the high mesas south of Sitgreaves Pass is a capping of black olivine basalt which, with associated tuffs, attains a maximum thickness of about 1000 feet.

The igneous rocks of northwestern Arizona were examined by Lee[1] at a number of places. He states that they constitute broad sheets with an aggregate thickness exceeding 3000 feet and that the oldest member is a porphyritic andesite lying on the granite. Next above are rhyolite ash, tuffs and flows and higher andesites. The latter are "conspicuously exposed in the Black Mesa, White Hills, Kingman Mesa, and Aquarius Mountains," but extend beyond the area mapped and farther south occur in extensive masses in the Chocolate and Dome Rock ranges. It is suggested that some of the older basalts may be Tertiary. They cut and overlie the rhyolites and andesites and in part at least occupy valleys supposed to have been cut in late Tertiary time. Petrographic descriptions of some of these rocks have been given by Johannsen.[2]

[1]Lee, W. T., *op. cit.*, p. 16.

[2]Johannsen, Albert, Notes on the Igneous Rocks of Western Arizona: U. S. Geol. Surv., Bull. 352, pp. 81-82, 1908.

PART II—DESCRIPTIVE GEOLOGY

MOHAVE COUNTY

Virgin Mountains-Beaver Dam Mountains.—There extends across the northwestern corner of Arizona a high, rugged ridge, known as Virgin Mountain south of Virgin River and Beaver Dam Mountain north of that stream. The separating canyon is about 10 miles long, and in places has walls more than 2000 feet high. The culminating summits of the Virgin Mountains are Virgin Peak, in Nevada, not far from the State line, and Mt. Bangs, a prominent peak southeast of Littlefield. No data of importance are on record regarding the range excepting the reconnaissance from a distance by Marvine.[1] My observations were a rapid reconnaissance in which I ascended the west slope at several places, traveled along the eastern flanks, and passed down the great canyon of the river. The map (Pl. 39) and sketch section in Fig. 3 show most of the relations. The west front of the mountain is very steep and ordinarily would be ascribed to a fault, but I found no direct evidence of one, unless perhaps locally west of Mt. Bangs and this part of the range may be a regular anticline with its western slope laterally eroded along the Virgin Valley.

The rocks exposed comprise massive granite, apparently of pre-Cambrian age, and associated with white quartzite which is conspicuous in the vicinity of Mt. Bangs. The Tonto group, about 650 feet thick, consists of basal Tapeats sandstone and an overlying series of gray and greenish shales with sandstone layers in which many *Lingulae* and trilobites were found. Exposures of this group are excellent in the slopes north of Mt. Bangs and in the outcrop crossing the range east and north and northwest of Virgin Peak. The Redwall limestone, about 2000 feet thick, presents superb exposures in Virgin Canyon, which, however, does not quite reveal the base of the formation. Reeside and Bassler saw part of this section and found Pennsylvanian fossils near the middle of the limestone succession.

The Redwall exposures are extensive in the Virgin Peak area and southward and in the Grand Wash Cliffs, 20 miles east. The Supai formation, consisting of red shale and sandstone, is exposed for several miles in the canyon of Virgin River east of the main fault, and again in the easternmost of the larger dislocations. Much of the rock is red, but a considerable portion is buff. Farther north, along the road which crosses the Beaver Dam Mountains in Utah, most of the red color gives place to buff, and coarse materials predominate, so that the formation resembles

[1]Marvine, A. R., U. S. Geol. uSrv. W. of 100th Mer., vol. 3, 1875, pp. 194-196 and maps.

[1]Reeside, J. B., and Bassler, H., *op. cit.*, Prof. Paper 129, p. 66.

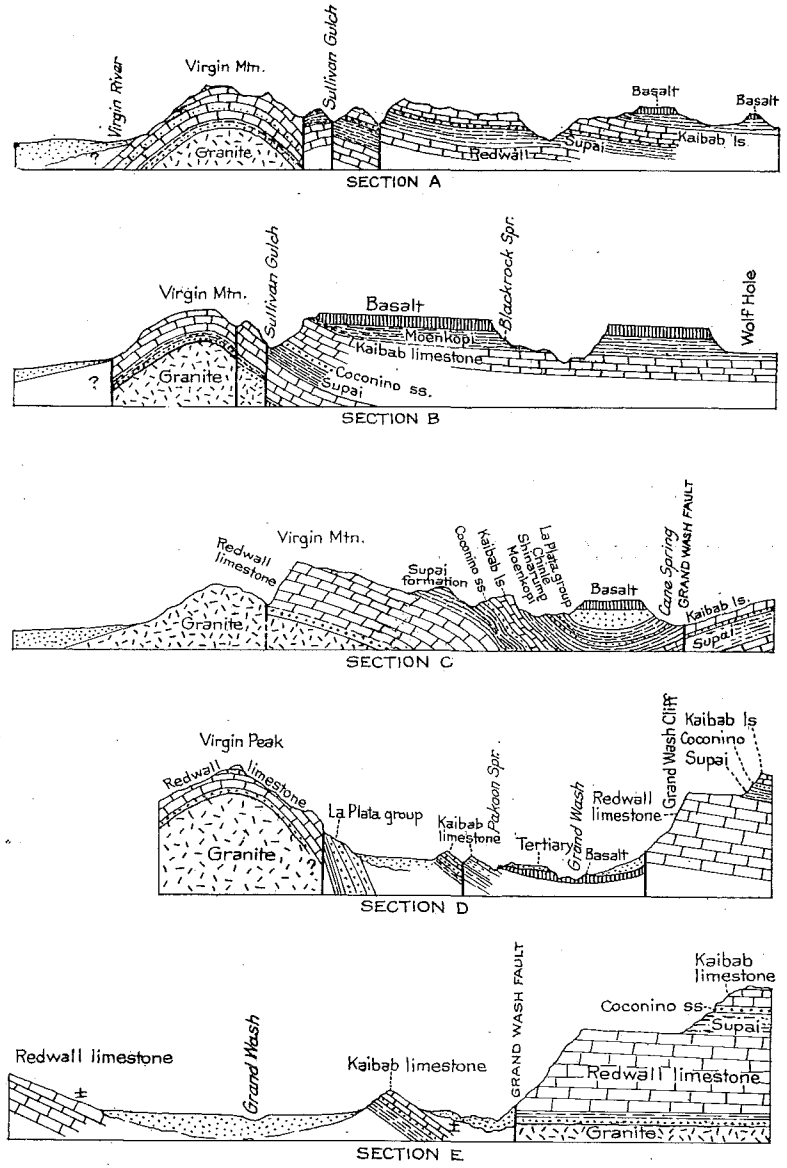


Fig. 3.—Sketch sections across Virgin Mountains along lines shown on the map in Plate 39.

the Coconino sandstone. The Supai is exposed east of the fault on the east slope of the Virgin Mountains, and again in the Grand Wash Cliffs a short distance south of Cane Spring and in two small faulted blocks west of Pakoon Spring. The Supai formation in this area is everywhere overlain by the Coconino sandstone, less than 80 feet thick but highly characteristic in its texture and cross-bedding. Some of it on Virgin River is of bright, greenish-yellow tint. The Kaibab limestone, 400 to 500 feet thick, appears conspicuously in the dropped block east of the Virgin Mountain and in the slopes adjoining the upper part of the canyon of the Virgin River. Its character in the latter area has been described by Reeside and Bassler,[1] who have also described the Moenkopi beds in the adjoining area about St. George, Utah. This formation, with its conspicuous pale, greenish-white shale member, the Shnabkaib, extends south through Cane Spring and is well displayed in the dropped block east of the middle of the Virgin Mountains. In this block it is overlain by the Chinle formation, largely red shale, next above which are red Jurassic sandstones which are extensively covered by basalt on the wide mesas east of the Virgin Mountains. Part of this lava is interbedded in the Horse Spring formation (Tertiary), which occupies the Pakoon and Grand washes. The basalt just east of Mt. Bangs reaches an altitude of about 7200 feet at the foot of South Mound, which apparently is an old cone from which this lava was ejected.

Grand Wash Cliff.—The very prominent west-facing escarpment due to the Grand Wash fault begins in the northwestern corner of the State and extends southward a distance of 100 miles, if the Cottonwood and Aquarius cliffs are to be regarded as its southern prolongation. The fault, however, ceases to be evident a few miles south of latitude 36°. At the north the fault appears to begin in the Moenkopi beds west of Wolf Hole. Thence southward its throw increases greatly, for in a few miles, at Cane Spring, it presents relations shown in Section A, Fig. 4, and at Secret Canyon, near latitude 36° 30′, those shown in Section B. From the latter place southward the throw continues to increase and the low lands of Grand Wash Valley widen and deepen so that the great cliff of uplifted limestone on the east side of this valley becomes an impressive feature. Here the Redwall cliff, as shown in C, Fig. 4, is 1250 feet high and short canyons from the east give rise to a variety of deep alcoves and high buttresses. The surmounting mesa extends east from 2 to 4 miles, to another "step" fully 1000 feet high capped by Kaibab limestone, constituting the Shiwits Plateau. The latter is largely covered by basalt.

The section, Fig. 5, given by Gilbert[2] shows some general relations of the Grand Wash Cliff at the Colorado River and of the several tilted fault blocks west to Iceberg Canyon. At the former place the strata comprise alternating sandstones and limestones (Pennsylvanian) 510 feet, massive limestone in a sheer cliff 800 feet, limestones and limy shale 1365

[1]Reeside, J. B., and Bassler, H., *op. cit.*, see pages 99-103 of this report.
[2]Gilbert, G. K., *op. cit.*, p. 54.

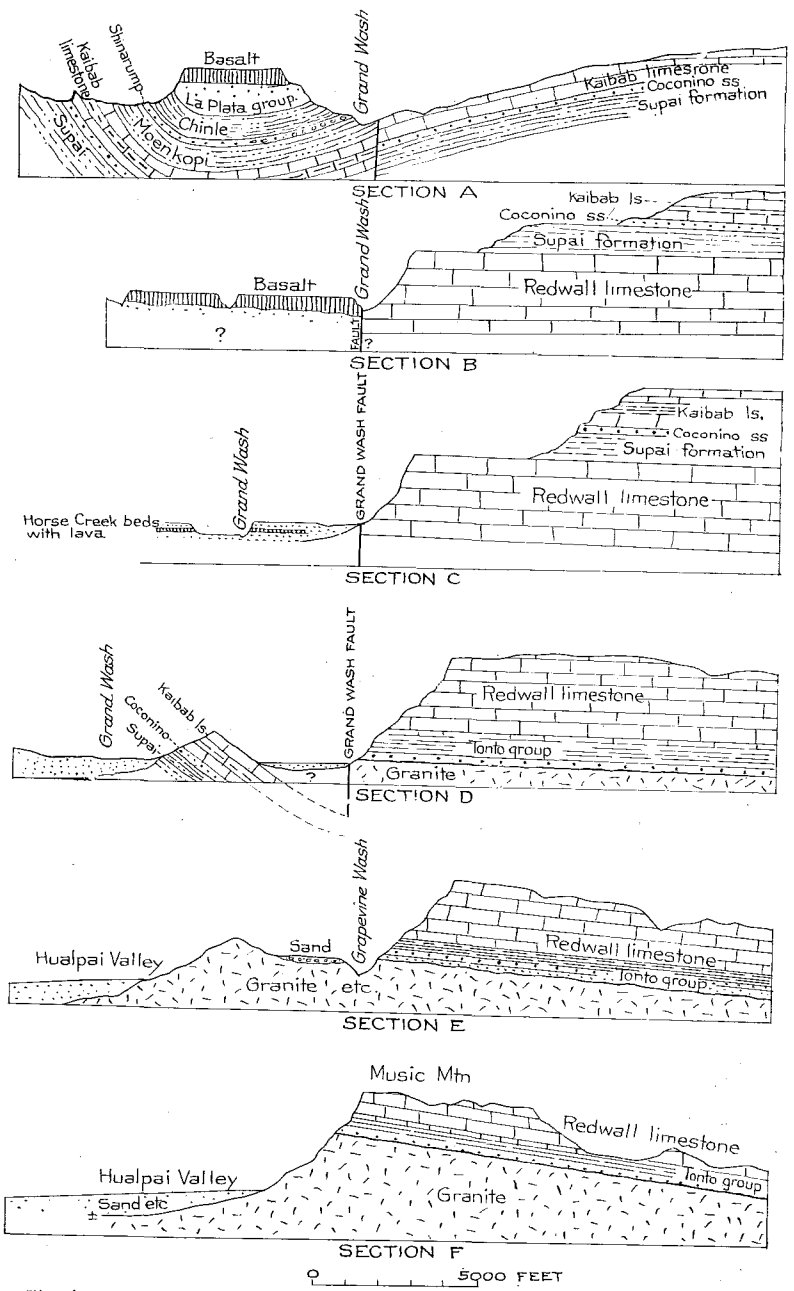


Fig. 4.—Sections of Grand Wash Cliff: A, Cane Spring; B, near Secret Canyon; C, near latitude 36° 15′; D, at lower end of Grand Canyon; E, in T. 29, R. 16; F, at Music Mountain.

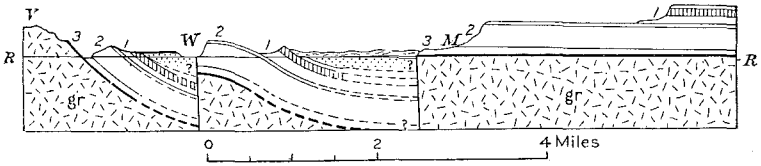


Fig. 5.—Section of Grand Wash fault and features west on Colorado River, by Gilbert: M, west end of the Grand Canyon; V, Virgin Mts.; W, Grand Wash; 1, Kaibab and Coconino; 2, Redwall; 3, Tonto group; gr, granite.

feet, presumably the basal Redwall, marbled limestone 75 feet (Muav), shales and thin sandstones 600 feet, and dark red massive sandstone, (Tapeats) 80 feet on granite, the upper surface of which is 90 feet above the river. Lee[1] verified part of the section, but 12 miles farther south found that the white sandstone is 80 feet thick, the shale has diminished to 200 feet, and in the pass a few miles south of Music Mountain the granite is capped by 50 feet of sandstone (Tapeats) with 300 to 400 feet of shale above. In this zone of outcrop extending from Grand Canyon to Music Mountain and eastward to Peach Springs, I found that the beds above the basal sandstone were mostly slabby limestone, very closely resembling the peculiar El Paso limestone of southwestern New Mexico.

The granites exposed about the Music Mountain mining district east of Red Lake have been briefly described by Schrader.[2] He found, besides the pre-Cambrian granite, a younger intrusive of fresh-looking, medium grained, gray biotite granite, allied to quartz monzonite, and locally so coarse as to suggest pegmatite. The older granite has well marked schistosity trending N 30° E. and dipping 65° southeast. Dikes of diabase were noted, including one sheeted mass about 150 feet thick.

Cottonwood and Aquarius Cliffs.—The Grand Wash Cliffs are continued southward by the Cottonwood and Aquarius cliffs, the latter finally merging into the Aquarius Mountains. The Santa Fe Railroad follows Truxton Wash which cuts a cross section through the plateau.

Lee[3] gives the following section at White Cliff Canyon 20 miles south of Hackberry.

Fig. 6.—Sketch section across White Cliff Canyon, Arizona: 1, Andesite flow; 2, granite; 3, andesite tuff; 4, basalt flow; 5, stratified volcanic ash.

[1]Lee, W. T., *op. cit.*, Bull. 352, p. 19.
[2]Schrader, F. C., *op. cit.*, p. 143.
[3]Lee, W. T., *op. cit.* Bull. 352, p. 20.

The andesite flow lies on tuff, the two having a thickness of 200 feet. The basalt flow is 1200 feet lower and consists of several layers of ash, tuff, and flow. The granite surface is very irregular and in places to the east it rises to and above the plateau surface.

Hualpai Plateau.—I believe it will be well to apply the name Hualpai Plateau to the wide plateau of Redwall limestone extending across the Hualpai Indian Reservation and southeastward through the Yampai Divide to Juniper Mountains. Its western edge is the southern extension of the Grand Wash Cliff and to the north and northeast it is cut off by the lower part of the canyon of the Colorado River. Its altitude is about 5000 feet to the north and south but in Music Mountain it attains an elevation of 6800 feet. It is crossed by the Santa Fe Railroad at Yampai at an elevation of 5583 feet. In general it is a cuesta with gentle slope to the northeast or east at the low angle of dip of the limestone. Looked at broadly it is the first great step in the rise from the deserts and granitic low lands of western Arizona to the high Coconino plateau which finally, in the Aubrey Cliff, attains an altitude of 7000 feet or more.

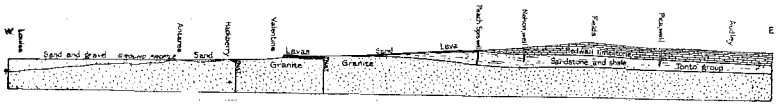


Fig. 7.—Section showing relations of rocks along Santa Fe Railroad between Audley and Louise, Arizona. Vertical scale is 5 times horizontal.

Much of the surface of this plateau is a bare sheet of limestone with more or less local soil. It is trenched by arroyos which from Peach Springs Draw westward develop into very deep canyons emptying into the Colorado River. In the Peach Springs district there is a thick mantle of gravel and sand of an old river deposit which covers a large part of four townships. There are also outlying areas of this deposit west of Milkweed (Spencer) Canyon and near Blue Mountains northeast of Nelson. Lavas lie on part of this gravel cover, notably near Peach Springs and Milkweed Springs, and several small remnants of a flow of basalt occur low in the canyon of Colorado River above, at and below the mouth of Diamond Creek. In the southern part of Townships 27, Ranges 11 and 12, gravel and sand occupy a low valley which extends from a barnch of Peach Springs Draw to a branch of Spencer Canyon about 500 feet below the plateau level. It is an abandoned channel which was cut by a stream of considerable size during an earlier period of the topographic development of the region. Small outliers of Supai formation occur on the plateau in Township 28, and north of Nelson a wide area of the formation extends westward from the foot of the Aubrey Cliffs. A well at Peach Springs Station beginning at base of the Redwall Cliff is reported to reach granite at 1003 feet. There appear to be

but few special features of structure in this great plateau. The Colorado River cuts through it a trench about 3000 feet deep, of which the lower part is in granite. This trench follows the strike very closely from the mouth of Diamond Creek to the western end of the canyon at the Grand Wash Fault. (See Pls. 40a and 52.) In Diamond Creek and the lower part of Peach Spring Draw there is a small fault which was noted by Gilbert[1]. I traced its extension up the main canyon for some distance and R. C. Moore[2] found that it crosses the river in the big bend a short distance above the mouth of Andrus Wash. Therefore it is not the southern extension of the Hurricane fault, which appears to die out in the slopes southeast of Granite Park. The relations that I observed are shown in Fig. 8.

Black Range.—This long mountain range extends through the western part of Mohave County from Boulder Canyon of Colorado River to the Santa Fe Railroad near Franconia station, a distance of about 100 miles. Its core or base consists of pre-Cambrian granite and gneiss which rises into high ridges in Mount Perkins and Mount Wilson. These rocks are extensively overlain by a thick succession of volcanic rocks largely of Tertiary age, which constitute the high central ridges in most places, especially south of Union Pass.

Ransome[3] has recently described the relations in the Oatman district which are representative for the entire southern part of the range. The section in Fig. 9, reproduced from his report, shows the principal features.

The pre-Cambrian crystalline rocks are bared at only a few places in the lower lands on the west flank of the range. They are chiefly granitic and are invaded by porphyry and cut by rhyolites and other intrusive rocks. The upper surface of the granitic floor appears to be irregular. The overlying volcanic rocks are in a fairly regular succession, probably at least 10,000 feet thick, with various members, most of them widespread, others of local extent, dipping gently to the east and piled up in that direction. The members of this succession are briefly described on pages 169-170.

Schrader[4] has described the geologic features in various mines near Union Pass and Secret Pass. The general relations of the principal rocks are shown in Fig. 10. The Catherine and Pyramid mines, which are far down on the western slope, are in coarse, red pre-Cambrian gneiss or sheared granite. In the mining district on the east slope a few miles northeast of Mt. Perkins, Schrader found the relations shown in Fig. 11.

[1]Gilbert, G. K., Report of Explorations West of 100th Meridian, Vol. III, p. 55, 1875.

[2]Personal communication.

[3]Ransome, F. L., Geology of the Oatman Gold District, A Preliminary Report: U. S. Geol. Surv., Bull. 743, 58 pages, pls., 1923.

[4]Schrader, F. C., Mineral Deposits of the Cerbat Range, Black Mountains, and Grand Wash Cliffs, Mohave County, Arizona: U. S. Geol. Surv., Bull. 397, pp. 203-214, 1909.

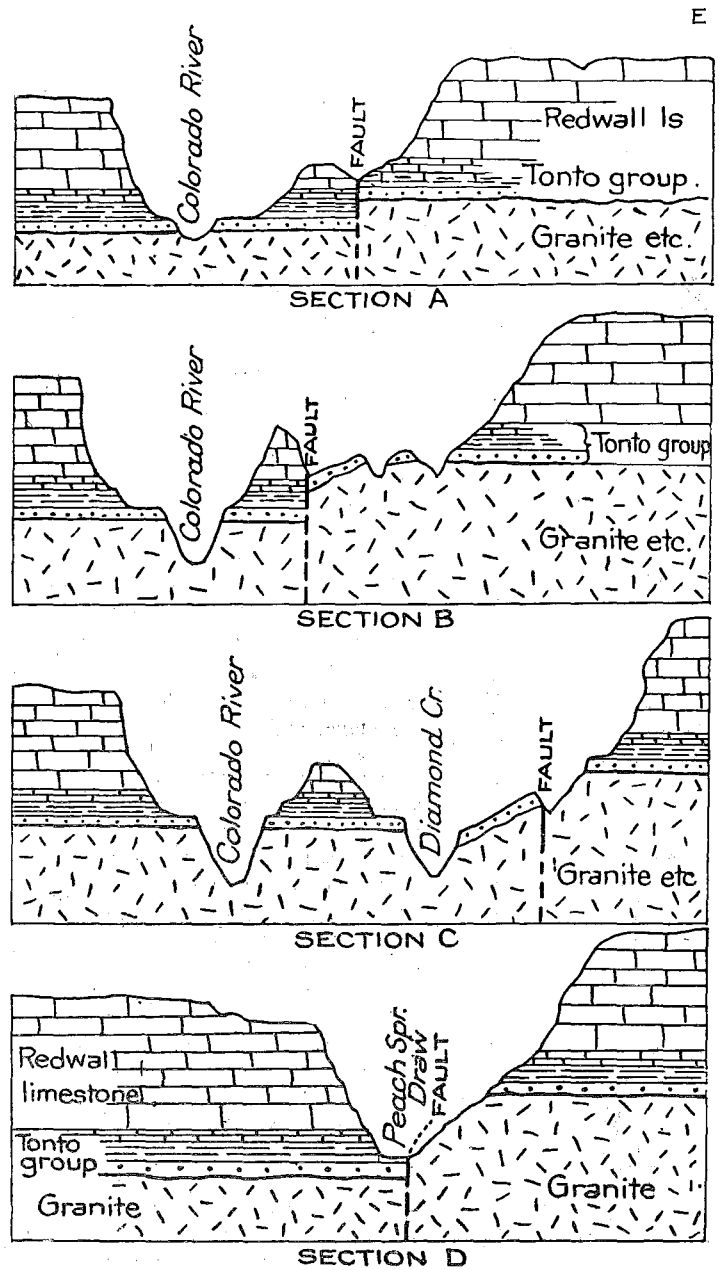


Fig. 8.—Sketch sections of fault at mouth of Diamond Creek north of Peach Springs, Arizona. Section A, 2 miles north of mouth of Diamond Creek; B, at mouth of Diamond Creek; C, 1 mile above mouth of Diamond Creek; and D, on Peach Springs Draw, 2 miles above its mouth.

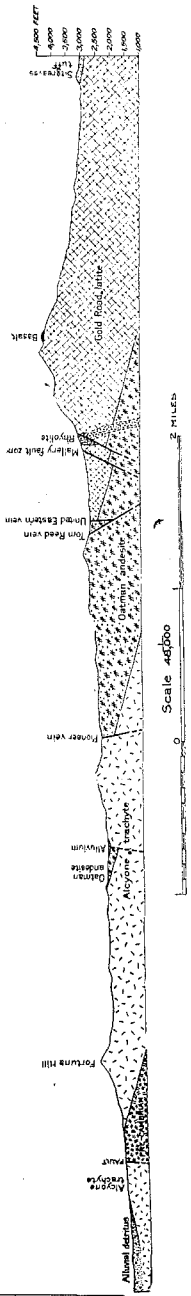


Fig. 9.—Section across the Oatman district in the Black Range, by F. L. Ransome. The section which runs East 20° North passes through Oatman.

Cerbat Mountain.—Cerbat Mountain consists of pre-Cambrian granite and gneiss capped in places by volcanic rocks, especially to the south, where, in the Kingman region, there is a thick succession of Tertiary volcanic rocks. The relations of this succession in the vicinity of the Santa Fe railroad, are shown in Fig. 12.

Schrader[1] has described the geology of the Cerbat Mountains and the relations of the rocks at the many mining districts in them. The principal pre-Cambrian rocks are gray granite, gneissoid granite, and hornblende, mica, and garnet schists. Through Mineral Park and toward Chloride there are intruded masses of younger granite porphyry with which most of the mineral deposits are associated. Dikes of pegmatite, aplite granite, diabase, vogesite, minette, and rhyolite cut the other rocks. A younger granitic rock in an area north of Chloride has considerable schistosity. Along the western slope of the range are volcanic rocks, principally rhyolite. There are flanking masses of basalt at the northwestern end and along the eastern slope of the range, which are probably of Quaternary age.

White Hills.—The group of ridges known as the White Hills lies between Hualpai Wash and Detrital Valley north of the Cerbat Mountains, and contains the White Hills and Gold Basin mining districts. The rocks are closely similar to those of the latter range—pre-Cambrian granite and gneiss overlain in part, especially to the south and east, by Tertiary volcanic rocks consisting principally of gray, vesicular, altered hornblende augite andesite or possibly latite. Agglomerate also occurs, and some of the peaks are capped by vesicular olivine basalt.

Hualpai Mountains.—This prominent desert range consists of pre-Cambrian granite and gneiss cut by dikes of porphyry and other intrusive rocks. The abrupt western front is supposed to be caused by

[1]Schrader, F. C., *op. cit.*, pp. 49-118.

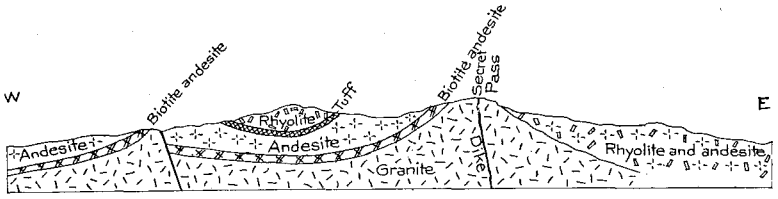


Fig. 10.—Section across Black Mountains at Secret Pass (Schrader).

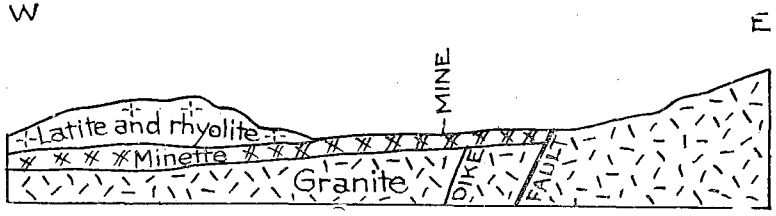


Fig. 11.—Cross section of rocks at the Mockingbird Mine, 5 miles northeast of Mt. Perkins.

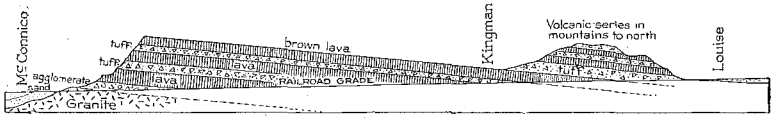


Fig. 12.—Section across the south end of the Cerbat Range along the Santa Fe Railroad.

a north-south fault with drop on the west side. On this side are ridges and outlying knobs of Tertiary volcanic rocks extending down to the plain.

Mohawk and Chemehuevis mountains.—The Mohave Mountains consist of a central area, including the well known "Needles" and a series of ridges extending southeastward. The rocks, according to a very brief description by Lee,[1] consist of granite gneiss and Tertiary volcanic rocks.

"The Needles are irregular pinnacles resulting from the erosion of the mass of effusive rock which formerly extended across the Colorado River and was later dissected by that river in cutting its present canyon."

In connection with manganese deposits in the Chemehuevis Range, Jones[2] mentions a district 40 miles above Parker in which he found small hills consisting of gneiss, diorite, and granitic rocks of pre-Cambrian age, overlain by sandstone and basalt of late Tertiary or Quaternary age.

Artillery Mountains.—According to a brief notice by Lee,[3] the Artillery Mountains which form a small group near the head of Williams

[1]Lee, W. T., *op. cit.*, pp. 27-28.
[2]Jones, E. L., *op. cit.*, pp. 151-152.
[3]Lee, W. T., *op. cit.*, pp. 22-23.

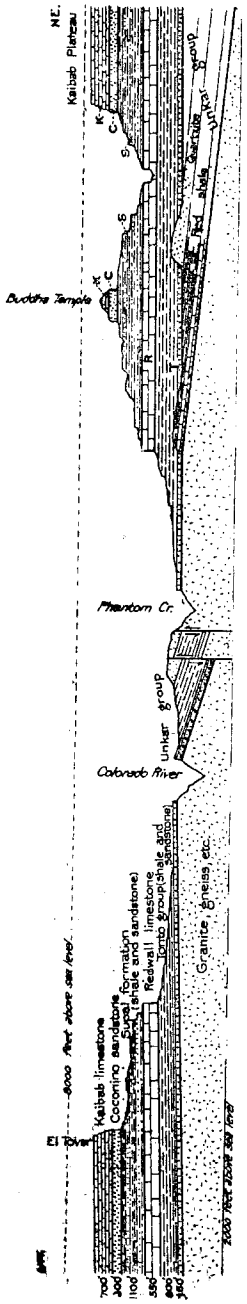


Fig. 13.—Section across the Grand Canyon at El Tovar Hotel throug h Buddha Temple to Kaibab Plateau. K, Kaibab limestone; C, Coconino sandstone; S, Hermit shale and Supai formation; R, Redwall lim estone; T, Tonto group.

River, consist of coarse-grained granite, overlain to the south by thick masses of Tertiary volcanic rocks. The sharp peak giving name to the range is thought to be a volcanic neck. Jones[1] states that the peak consists of basalt which extends to Signal Canyon. The mesa consists of basalt caps underlain by sandstone, clay, and conglomerate in part dipping 35° and broken to some extent by faults. Underlying granite and schist are exposed in a canyon in the west central part of section 33, T. 17 N., R. 13 W., about 6 miles west of Alamo. Jones describes the relation at various manganese prospects in this region.

COCONINO COUNTY

Grand Canyon.—The geology of the Grand Canyon is a large subject, which can be treated only briefly here. Further details, however, may be found in publications by Dutton, Gilbert, Walcott, Davis, Noble, and Darton, cited in the foot-notes.

Although the Grand Canyon is 200 miles long, the larger elements of its stratigraphy and structure are remarkably uniform. (See cross section, Fig. 13.) It is a trench cut deeply by the Colorado River across the dome-shaped uplift of the high plateau of northern Arizona. This plateau is built of nearly horizontal limestones and sandstones lying on a floor of pre-Cambrian gneiss and granite which is more or less deeply trenched in the deeper parts of the canyon. In places there is an intervening group of tilted sandstones, limestone, and shale of Algonkian age, mostly in wedge-shaped, downfaulted blocks. The ordinary relations are shown in the section, Fig. 13.

[1]Jones, E. L., Jr., Bulll. 710d, *op. cit.* p. 145.

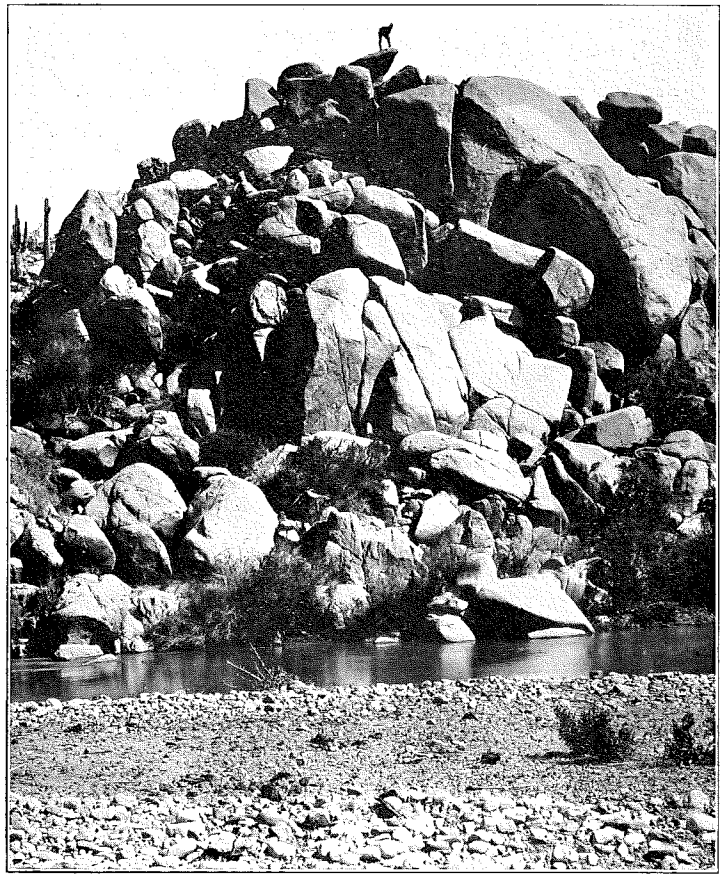


Plate 64b. Pre-Cambrian granite on Salt River at mouth of Ash Creek. Photo by U. S. Reclamation Service.

In the map (Plate 43) and cross section (Fig. 14) are shown the principal features in the El Tovar-Bright Angel district and for some distance east and west. The map (Fig. 15) shows the distribution of formations in the western part of the National Monument as far west as the mouth of Havasu Canyon or Cataract Creek, based on a new topographic map by the U. S. Geological Survey. This does not show a small fault and several small exposures of schist and rocks of the Grand Canyon group just below the mouth of Tapeats Creek observed by R. C. Moore on his recent trip down the canyon.[1] The structural relations of the general area are represented in Plate 52, which shows that the Colo-

[1]Personal communication.

rado River has been deflected to the southward by the increased doming in the Kaibab Plateau (Buckskin Mountain), which probably had already attained prominence when the course of the river was initiated.

The geology of the canyon near El Tovar and eastward to Grand View and Desert View is described in considerable detail in the Story of the Grand Canyon.[1] The succession of rocks in the canyon walls comprises the Kaibab limestone of the plateau surface, the Coconino sandstone making a characteristic gray cliff along the upper canyon wall, the red Hermit shale and the sandstone and shale of the Supai formation in slopes and steps of bright red color, the high cliff of Redwall limestone which is everywhere conspicuous in many out-reaching buttes and buttresses, the Muav limestone, consisting of slabby to massive beds mostly in the lower part of the same cliff as the Redwall, the Bright Angel shale in long greenish slopes, and the Tapeats sandstone generally forming a platform far down the canyon. Below this platform is the deep inner gorge in the schist and granite which extends up the canyon to Grand View and westward to the Shinumo region. In places low down in the canyon and its side valleys are seen masses of the red quartzites, shales, and limestone of the Unkar group downfaulted as huge wedges on the basement schist. In a recent examination of the Unkar rocks in the canyon of Bright Angel Creek I was greatly impressed with the close resemblance of the Bass limestone, near the lower part of the Unkar group, to the Mescal limestone of the Apache group of central Arizona. The alteration of some of the beds to chrysotile (asbestos) by the intruded sills of diabase, and the character and relations of these sills themselves are very similar to the features presented in the Apache group. The section at this place is described on page 26.

The relations of the Grand Canyon series in the eastern section of the Grand Canyon have been set forth by Walcott,[2] and the following statements are condensed from his reports. The map and sections are reproduced in Plate 46 and stratigraphic sections are given in pages 24-25 of this bulletin.

The faults in this eastern area present many interesting features, and the occurrence of several great lava flows in the Chuar succession is a very impressive fact. The Butte fault, which extends from Nunkoweap Creek to below the mouth of Chuar Creek, shows movement in both pre-Cambrian time and post-Paleozoic time, in both cases with considerable local crushing and uptilting of the beds. This tilting on the west side

[1]Darton, N. H., Story of the Grand Canyon of Arizona, a Popular Illustrated Account of the Rocks and Origin: Editions in 1917, 1919, 1920, 1921, and 1922, Fred Harvey, Kansas City, 80 pages, maps, and cuts.

[2]Walcott, C. D., Study of a Line of Displacement in the Grand Canyon of the Colorado in Northern Arizona: Geol. Soc. Amer. Bull., vol. 1, pp. 49-64, 1889. Pre-Cambrian Igneous Rocks of the Unkar Terrane in the Grand Canyon of the Colorado, Arizona, with Notes on the Petrographic Character of the Lavas, by J. P. Iddings: U. S. Geol. Surv., 14th Ann. Rept., pp. 497-524, map, Pls., 1895, and Algonkian Rocks of the Grand Canyon of the Colorado; Jour. of Geol., vol. 3, pp. 312-330, Pl., 1895.

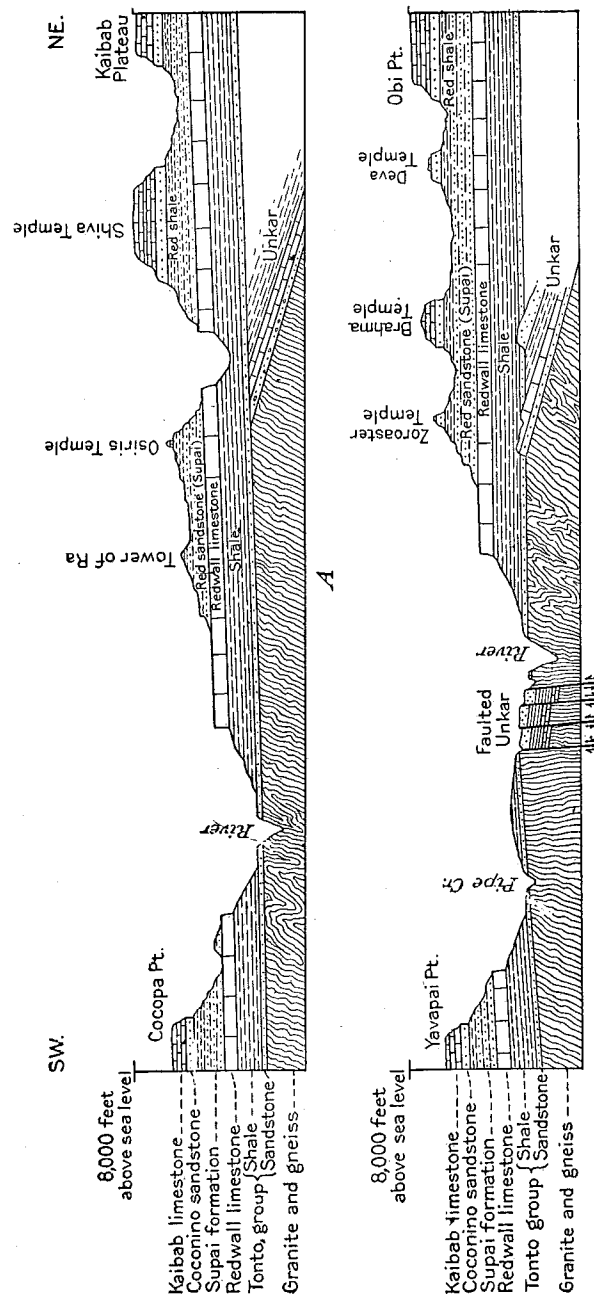


Fig. 14.—Sections across Grand Canyon, Arizona, looking west. A, from Cocopa Point through Tower of Ra, and Osiris and Shiva temples to Kaibab Plateau at Tyo Point; B, from Yavapai Point through Zoroaster, Brahma, and Deva temples to Kaibab Plateau at Obi Plateau.

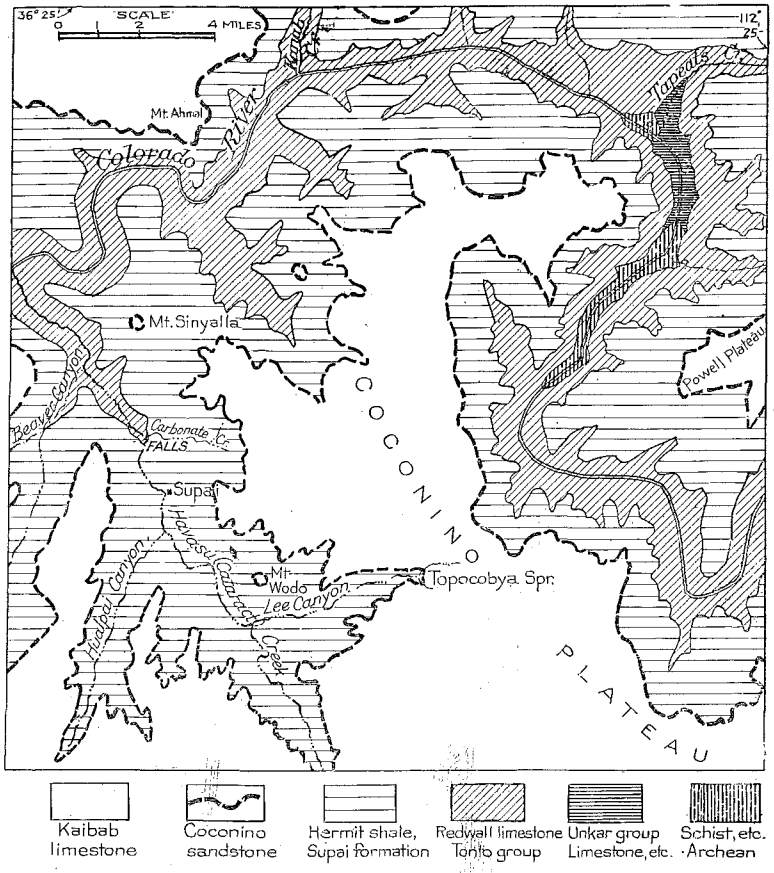


Fig. 15.—Geologic reconnaissance map of part of the Grand Canyon from Cataract (Havasu) Creek to Powell Plateau. By N. H. Darton.

of Chuar Butte is discernible in Plate 49a. Some details of this fault are shown in the following figure compiled from Walcott's section. The amount of displacement of the pre-Tonto movement is from 400 to 4,000 feet, which results in deep burial of the Chuar and Unkar strata along most of its eastern side. At Lava Butte the amount of displacement is 1,200 to 1,500 feet as indicated by the drop of the lava members of the upper Unkar. At the fault the strata of the Chuar group are flexed back at high angles. The old fault scarps were planed off in pre-Tonto time, for the sandstone of the Tonto group lies on a nearly smooth surface. The post-Paleozoic movements amount to a displacement of about 2,700 feet at most, including the uptilting of beds which is very marked. The fault dies out rapidly at either end.

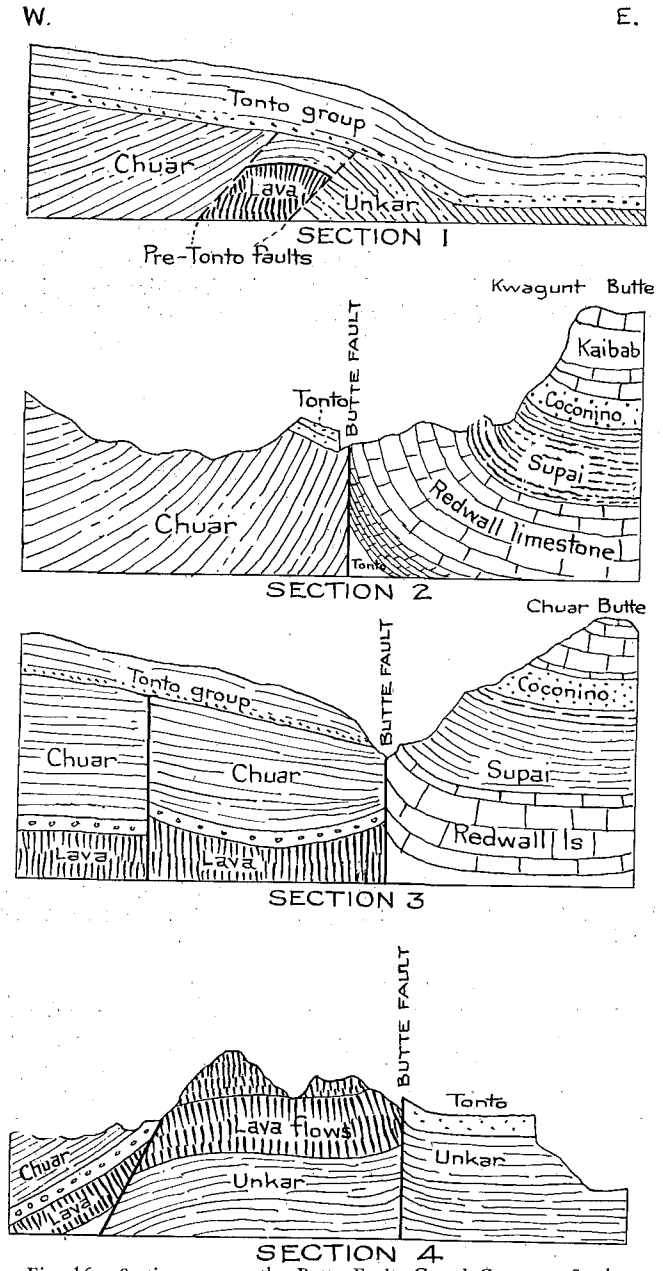


Fig. 16.—Sections across the Butte Fault, Grand Canyon: Section 1, on north side Nunkoweap Valley; Section 2, Kwagunt Butte; Section 3, at Chuar Butte; Section 4, through Chuar Lava Hill.

The lava beds in the upper part of the Unkar group vary in thickness, but at the Chuar Lava Hill they are 1,000 feet thick, including some interbedded sedimentary rocks. (See p. 26.) They have all the characteristics of lava flows, the upper portion being deeply vesicular. I have found that the 80-foot sheet of "dolerite" mentioned by Walcott (p. 516) opposite Congress Canyon (Red Canyon) is a sill of diabase intruded in Bass limestone 50 feet above the top of the old schists. It has altered some of the limestone to chrysotile (asbestos), as in the locality near Shinumo Creek and in the Mescal limestone of Gila County.

The stratigraphy and structural features in the Shinumo region about 20 miles northwest of El Tovar have been mapped and described in detail by Noble.[1] The map (Pl. 48) and the two cross sections (Fig. 17)

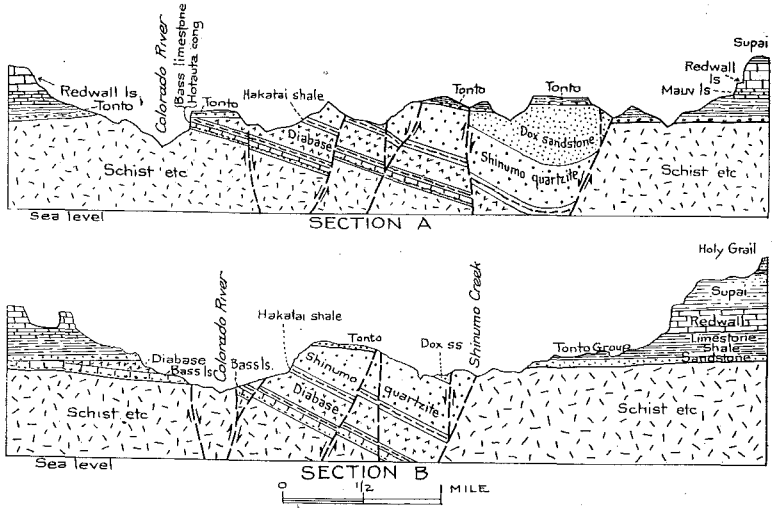


Fig. 17.—Cross sections showing relations of formations of the Unkar Group on and near Shinumo Creek, Grand Canyon. After Noble. On lines A and B, Plate 48.

are reduced from the map in his report on the Shinumo quadrangle. The stratigraphy in this region is summarized on page 26 of this bulletin, and several views (Pls. 3 and 49) further illustrate the principal features. Data as to the Archaen rocks are given on page 15. The Unkar succession consists of a basal arkosic conglomerate, in places 6 feet thick, overlain by Bass limestone, 335 feet thick, and the red Hakatai shale, 580 feet thick. The latter is invaded by thick sills of diabase, the principal plane of intrusion being near the middle of the

[1]Noble, L. F., The Shinumo Quadrangle, Grand Canyon District, Arizona: U. S. Geol. Surv., Bull. 549, 100 pages, map, plate, 1914, and a Section of the Paleozoic Formations of the Grand Canyon at the Bass Trail: U. S. Geol. Surv., Prof. Paper 131-b, pp. 23-73, Plates, 1922.

shale. The most prominent formation is the Shinumo quartzite, about 1,500 feet thick, which outcrops in high bluffs. Next above is the Dox sandstone, 2,300 feet thick, the top of which has been removed by erosion. The three formations of the Tonto group are well characterized, 600 to 700 feet thick, extending up to the great cliff of massive Redwall limestone. The faults are notable features. There were great displacements prior to the Paleozoic deposition, such as the ones shown in Plate 3, and also post-Paleozoic movements, in part on the old fault planes. Many small faults were also found by Noble, which are not mapped, and also various lines of movement with shattering of beds, and in most cases no displacement of the strata; these, however, have had great influence in shaping some of the topographic features in the Shinumo region, as well as in many other parts of the Grand Canyon province.

Aubrey Cliffs.—A reconnaissance of the Aubrey Cliffs, in the western part of Coconino County has yielded many new data as to distribution and relations of the formations. Two prominent faults were located, one a continuation of the Toroweap fault which extends up Prospect Valley and southward to Blue Mountain, and another fault which extends through Range 7. The Hurricane fault was observed near Colorado River, which it crosses near the mouth of Cold Spring Wash, but was not traced south of latitude 36°. The sections in Fig. 18 show the principal features observed from Grand Canyon to Seligman.

An outlier of Moenkopi formation remains on the plateau in T. 28 N., R. 8 West, largely covered by an old high-level gravel deposit, as shown in section B. The Kaibab limestone presents three principal members, two massive limestones separated by a thick succession of sandy, shaly, and gypsum beds. The Coconino sandstone is distinct throughout, but less than 100 feet thick. (See Pl. 21b.) It is underlain by Hermit shale, lying on massive sandstone of the Supai formation, which constitutes the wide "Esplanade" or inner bench of the canyon so characteristically developed in the western part of the canyon. In this region also the Redwall limestone is more than 1,500 feet thick, and its great cliff is continued down by Muav limestone and hard shale in the Tonto group to the bottom of the canyon, as shown in Plates 51 and 52. A recent boring at Pica Station is reported to have reached the granite at 1715 feet. As the hole began in the top of the Redwall limestone it shows that the strata thin to the southward.

Echo Cliffs and Vermilion Cliffs.—The long line of red cliffs of Jurassic sandstones extending across northern Arizona is known in part as Echo Cliffs and in part as Vermilion Cliffs, the latter finally crossing into Utah. Echo Cliffs extend from Moenkopi Wash to the Colorado River at the mouth of Glen Canyon. Their height gradually increases from about 500 feet northwest of Moenkopi to nearly 1,800 feet opposite Lees Ferry. In their higher part they mark a pronounced

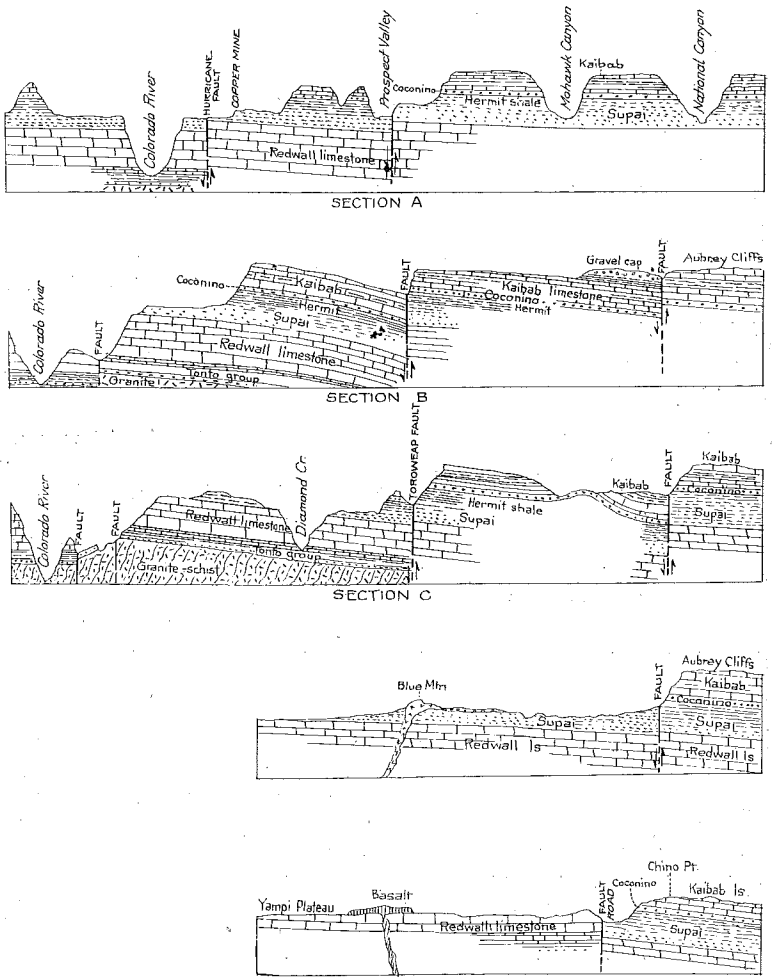


Fig. 18.—Sketch section of Aubrey Cliffs and associated features in the western part of Coconino County from Colorado River to Seligman.

flexure of the strata, details of which have been described by Gregory.[1] Near Tuba the dips are very low; east of Shinumo Altar they are about 10° and the amount increases somewhat to the north. According to Bryan, the monocline of the Echo Cliffs extends through Lees Ferry, where the dip is about 10 degrees, and dies out to the north. As shown in Plate 52, the flexure is a zone of increased dip on the general descent of the beds to the eastward. East and west of this zone the strata

[1]Gregory, H. E., *op. cit.*, pp. 114-115.

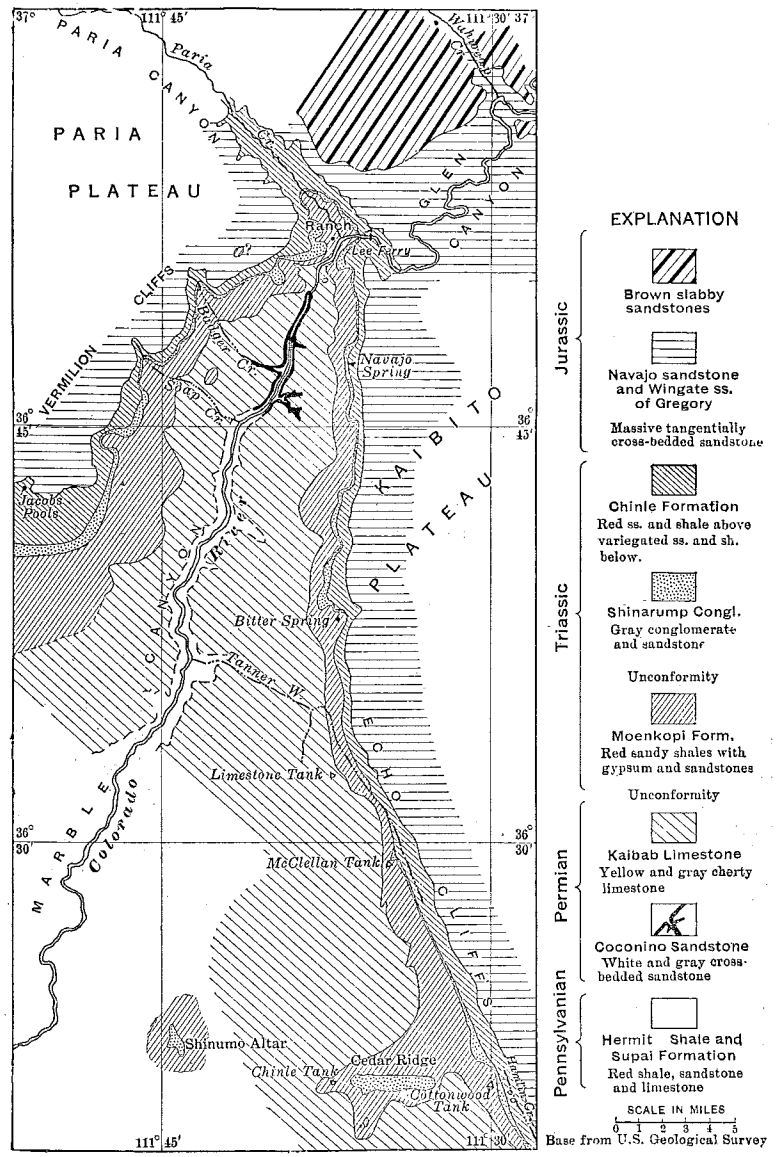


Fig. 19.—Geologic map of part of Marble Canyon and Echo Cliffs, by Kirk Bryan.

are nearly horizontal, and owing to the fold those to the west are from 1,000 to 2,000 feet higher than the corresponding beds on the east. To the west most of the beds are stripped off down to the Kaibab limestone. There is also a general tilt to the north, which is especially noticeable west of the Echo Cliff monocline. At the base of Vermilion Cliffs west of Lees Ferry the dip is 1° to the northward. The succession of rocks in these cliffs has been described by Bryan.[1]

SECTION NEAR LEES FERRY (BRYAN)

Formation	Feet
Navajo-Wingate—Cross-bedded, massive, red-buff sandstone, no parting, but upper one-half has lenses of dense gray limestone 6 inches to 3 feet thick at intervals. In Vermilion Cliffs the upper half is distinctly lighter color	1100–1200
Chinle—Blue, green, and red shale, white, gray, purple, and red sandstone; upper part heavy-bedded sandstone, and red shale. Wood in lower part	1000±
Shinarump—Gray conglomerate with sandstone and shale, much wood	0– 40
Moenkopi—Red sandy shale and thin-bedded sandstone with some gypsum. Local beds of red and gray sandstone, 2-6 feet thick, and in one place 12 feet of gypsiferous limestone; base generally 1-10 feet of cherty conglomerate	500
Kaibab—Yellow limestone, chert	500
Coconino—Gray cross-bedded massive sandstone	30
Supai—Red shale and red sandstone	500+

The Moenkopi to Navajo rocks are crossed by the Colorado River above Lees Ferry, and to the westward the latter constitute the Vermilion Cliffs, as shown in Plates 55 and 56. The upper massive sandstones make the very high, steep cliff, which has at its base the red sandstones and shales of the upper part of the Chinle formation. In general, however, the Chinle beds form badlands at the foot of the cliffs or are concealed by debris. The Shinarump conglomerate forms a distinct cliff, in most places surmounting irregular cliffs and slopes of the Moenkopi formation. The Kaibab limestone is bared to the southward, where the Colorado River cuts into and through it, forming the Marble Canyon, as shown in plates 54 and 55.

Kaibab Plateau. The plateau on the north side of the Grand Canyon between Kaibab Canyon and Marble Canyon is also known as Buckskin Plateau or Mountain, but the name Kaibab is preferable. It is a northern continuation of the Coconino plateau with its thick cover of Kaibab limestone and owes its elevation of more than 9,200 feet in places, to an upward arching of the strata. This feature is represented by contour lines on the diagram Plate 52, which also shows the structure or deformation of the entire High Plateau region of northern Arizona and the adjacent portion of New Mexico. Features of the dome

[1]Bryan, K., Discussion of Rock-fill Dam, Lees Ferry, Arizona: Am. Soc. Civ. Eng., Proc., vol. 48, pp. 1615-1627.

constituting the Kaibab plateau are the tilting of the strata plainly visible from Desert View (Navajo Point) east of El Tovar, and the steep easterly dips presented by the strata near the south end of the Marble Canyon. The steepness increases to the northward, notably in Pagump Valley (latitude (36° 26′) where erosion reveals the Redwall limestone on the steep slope of the flexure. Just east of this place the overlying strata descend into a local syncline, in which outliers of Moenkopi beds are preserved. Steep dips also continue far to the north along the west side of House Rock Valley.

The west side of the Kaibab dome is considerably faulted and also cut into by erosion so that Coconino sandstone and Supai formation are revealed. Some of the relations in this zone are especially well exposed on the road from Ryan to Big Spring, as shown in Fig. 20.

The structure west of this zone was not investigated, but apparently its principal feature is a long, west-sloping monocline of Kaibab limestone extending to the edge of the Kanab Canyon. This canyon for a large part of its course is cut deeply into the Redwall limestone. The Supai formation is prominent in canyons in this region, as shown in Fig. 20 and Plates 11b and 12b, but the Coconino sandstone is much thinner than in the walls of the Grand Canyon not far south.

San Francisco Mountains and other Volcanic Cones near Flagstaff and Williams.—In the south-central part of Coconino County the plateau bears a number of cones and ridges of volcanic rocks of which the San Francisco Mountains are the highest and most extensive. Kendrick Peak, Sitgreaves Mountain, and Bill Williams Mountain are other prominent peaks, and perhaps the more distant Picacho, Mount Floyd and Round Top should be regarded as members of the group. Much of the plateau surface in this area is covered by a sheet, or succession of sheets, of basalt with numerous cinder cones. One of the latter, known as Sunset Peak, is a conspicuous feature a few miles northeast of Flagstaff. These mountains all consist of lavas, the larger ones of very viscous flows, mostly in successions of various kinds. Two low mounds, Marble Hill and Slate Mountain, are, however, of laccolithic nature, and the Elden Mountain mass is partly laccolithic. The relations and character of the igneous rocks in the San Francisco Mountains and neighboring peaks have been described in admirable detail by Robinson.[1]

In Plate 57 is reproduced the larger scale map from Robinson's report with some small modifications mainly in boundaries of sedimentary rocks.

The general structure of the San Francisco Mountains is shown in the cross section, Fig. 21, based on detailed sections by Robinson.

It will be seen from the section that the mountain consists of a thick mass of latite on a platform of early basalt, largely covered by thick flows of dacite and andesite, the latter extending to the summit of the high peaks of the rim which nearly surrounds the deep central depres-

[1]Robinson, H. H., The San Francisco Volcanic Field, Arizona: U. S. Geol. Surv., Prof. Paper 76, 213 pages, pls., map, 1913.

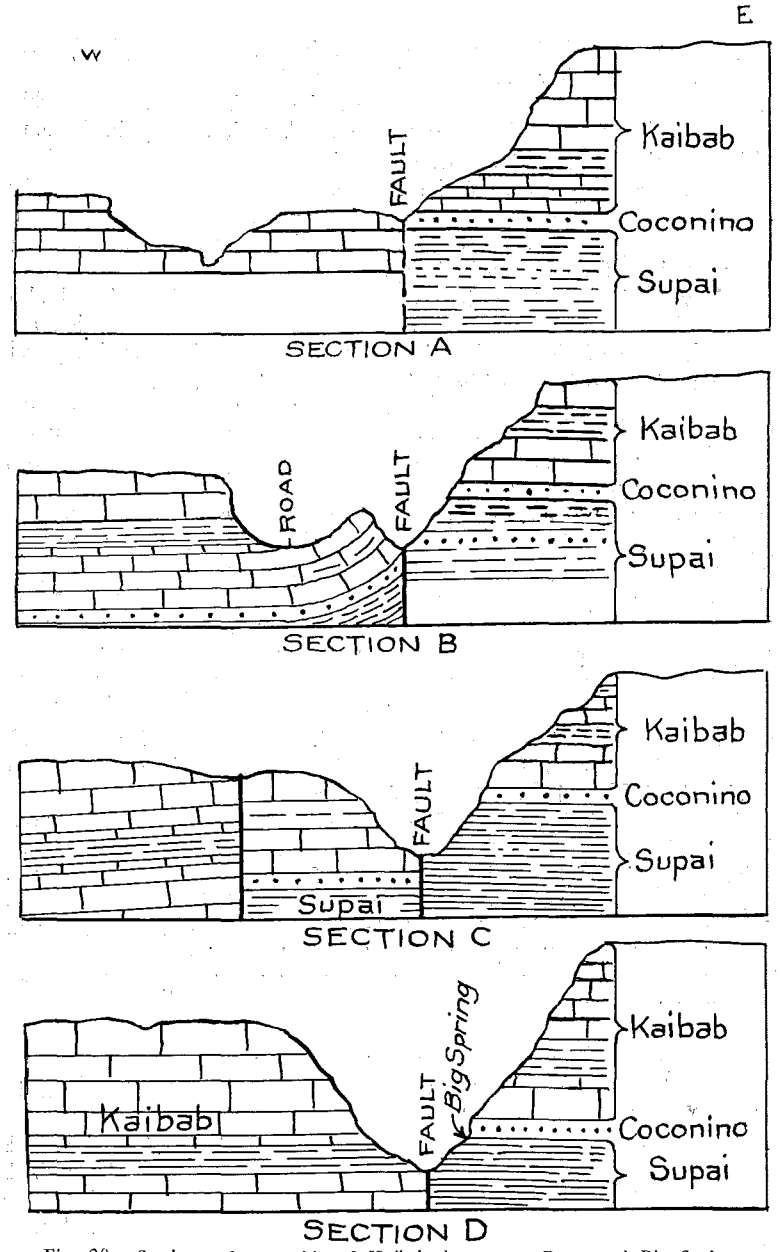


Fig. 20.—Sections of west side of Kaibab dome near Ryan and Big Spring. A, 1½ miles north of Ryan; B, ½ mile south of Ryan; C, 1¼ miles south of Ryan, and D, at Big Spring.

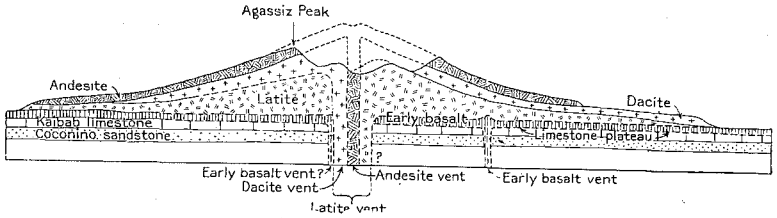


Fig. 21.—Section from northwest to southeast through San Francisco Mountain, after Robinson. Dotted portions eroded, broken lines hypothetical.

sion. In a ridge in the latter Robinson found stocks or vents which fed the flows of latite, hornblende dacite, pyroxene dacite, and andesite. There were also outflows on the flanks of the mountain, notably of rhyolite in Sugarloaf Hill and of dacite in Schultz Peak. Other eruptions not far distant resulted in O'Leary Peak, and in Dry Lake Hills and Elden Mountain. A large outflow of latite from Crater Hill cone constitutes the wide mesa just northwest of Flagstaff.

Kendrick Peak, a prominent cone 10 miles northwest of the San Francisco Mountains, consists mainly of a flow of rhyolite, but includes flows of dacite and andesite which were erupted in the order named. On its flanks are sheets of basalt erupted at a later stage from many small cones, some of them at considerable altitude. The section in Fig. 22 shows the principal features.

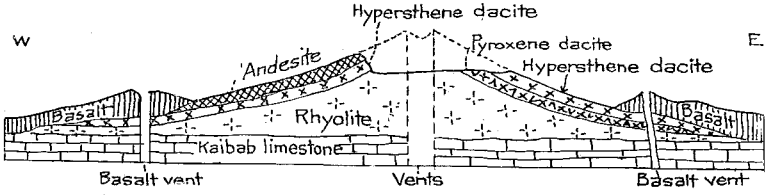


Fig. 22.—Section through Kendrick Peak, after Robinson.

Sitgreaves Peak, 10 miles northeast of Williams, consists entirely of rhyolite in one large cone and three small ones, and on the flank is a cone of recent basalt.

Bill Williams Mountain, just southwest of Williams, consists of lavas and breccias of two stages of eruption. The first is of andesite, which constitutes the thick central mass, and the second is of dacite, having the relations shown in Fig. 23. Both rocks are closely similar to the flows in San Francisco Peak.

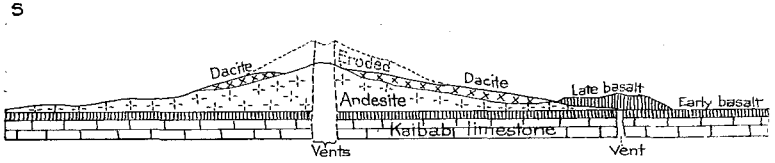


Fig. 23.—Section through Bill Williams Mountain near Williams (Robinson).

Mormon Mountain, 20 miles south of Flagstaff, consists largely of coalescing cones of short, thick flows of latite, but Robinson noted the presence also of some overlapping dacite.

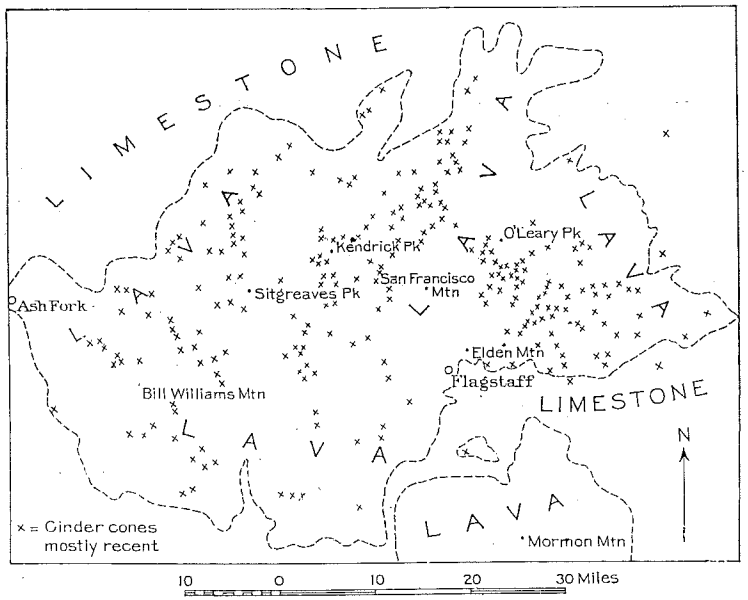


Fig. 24.—Map of lava fields in the San Francisco Mountains district, showing distribution of cinder cones marking vents of eruptives, most of them of the later period of basalt eruption (Robinson).

Red Mountain, at the head of Hull Wash, 25 miles north of Flagstaff, is a remarkable cinder cone deeply trenched by erosion so that its structure is visible. (See Pl. 59a.) It has been described by Atwood.[1]

The two laccolithic uplifts of Marble Hill, 14 miles north of Flagstaff and Slate Mountain, 25 miles northwest of Flagstaff, are of interest because of their special type of structure and because they reveal the formations which underlie the plateau. Elden Mountain is also in part laccolithic and it also exhibits uplifted strata.

Slate Mountain is about 1,000 feet high and occupies an area of nearly one square mile. The relations which I found are shown in Fig. 25. The igneous rock is rhyolite similar to that in Sitgreaves Peak and Marble Mountain. It cuts the Redwall limestone which is overlain by well-defined Supai formation consisting mostly of sandstone of dirty brown color, cross-bedded Coconino sandstone, considerably crushed, and cherty Kaibab limestone of which about 200 feet are exposed. The

[1]Atwood, W. W., Red Mountain, a Dissected Volcanic Cone, Jour. of Geol., vol. 14, pp. 138-146, 1906.

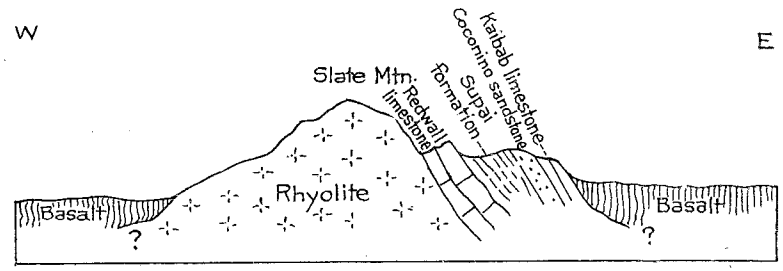


Fig. 25.—Section across Slate Mountain, 25 miles northwest of Flagstaff, Arizona.

mountain is flanked by late basalts and none of the earlier basalt is upturned.

Marble Hill is a nearly circular group of hills about one and one-half miles in diameter, of which the highest summit rises slightly more than 1,000 feet above the surrounding lava plains. The central cone, according to Robinson, is granite porphyry, which cuts the Redwall limestone steeply upturned in the central part of the hills. The overlying strata dip steeply away in all directions, but with many irregularities of dip and much faulting and crushing. The Supai beds, Coconino sandstone, and part of the Kaibab limestone are revealed. The latter is overlain by the older basalt which is upturned nearly all around the outer slope of the dome to angles mostly from 30 to 60 degrees. Robinson's section of this laccolith is copied in the following figure.

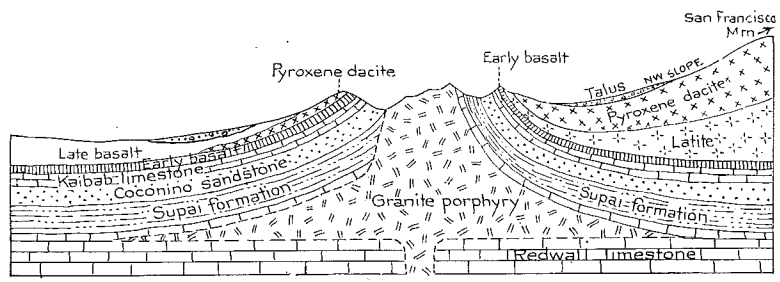


Fig. 26.—Section through laccolith of Marble Hill from northwest to southeast (Robinson).

The laccolith of Elden Mountain consists of a large mass of dacite which has uplifted portions of the sedimentary rocks of the plateau and apparently then welled up irregularly through the resulting opening. The upturned or uplifted strata are exposed on the northern and northeast slopes of the mountain. On the north side only the Kaibab limestone and Coconino sandstone are revealed, the former capped by the older basalt. On the east slope, however, about three miles north of Cliff station, there are extensive exposures. A section at this place

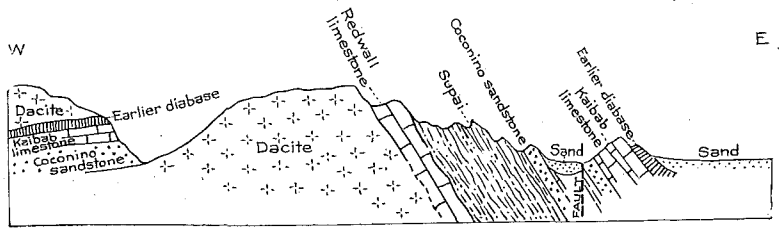


Fig. 27.—Section of the east side of Elden Mountain 3 miles north of Cliff.

is given in Fig. 27. The upturned Kaibab and Coconino rocks and earlier basalt appear in several small knobs east of the foot of the mountain, dipping steeply to the east. The upper part of the Redwall limestone is exposed in the higher slopes overlain by 1,000 feet or more of red beds of the Supai formation.

Crater Mound.—This remarkable crater with surrounding rim, long known as Coon Butte, is one of the most remarkable features in the plateau region. Many descriptions of it have been published,[1] and there

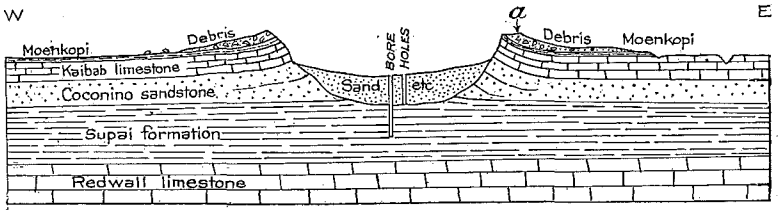


Fig. 28.—Generalized section across Crater Mound, 19 miles west of Winslow, Arizona.

has been considerable controversy as to its origin. Fig. 28 shows the principal features. It consists of a bowl-shaped crater, about 4,000 feet in diameter and nearly 600 feet deep, encircled by a narrow ridge or rim rising from 120 to 160 feet above the plateau surface. The rocks in the surrounding region lie nearly horizontal, but in the margin of the crater they are steeply upturned from 150 to 200 feet, with angles of dip averaging 30° but ranging from 10° to 80°. At one point the

[1]Gilbert, G. K., The Origin of Hypotheses Illustrated by the Discussion of a Topographic Problem: Geol. Soc. Washington, 1896. Science, N. S., vol. 3, pp. 1-13, 1896.

Barringer, D. M., and Tilghman, B. C., Coon Mountain and its Crater: Proc. Acad. Nat. Sci., Philadelphia, vol. 57, pp. 861-914, 1906.

Barringer, D. M., Meteor Crater of Northern Central Arizona: Nat. Acad. Sci., Nov. 16, 1909, 24 pp., pls.

Darton, N. H., A Reconnaissance of Parts of Northwestern New Mexico and Northern Arizona: U. S. Geol. Surv., Bull. 435, pp. 72-74, 1910, and Explosion Craters: Scientific Monthly, Nov., 1916, p. 430.

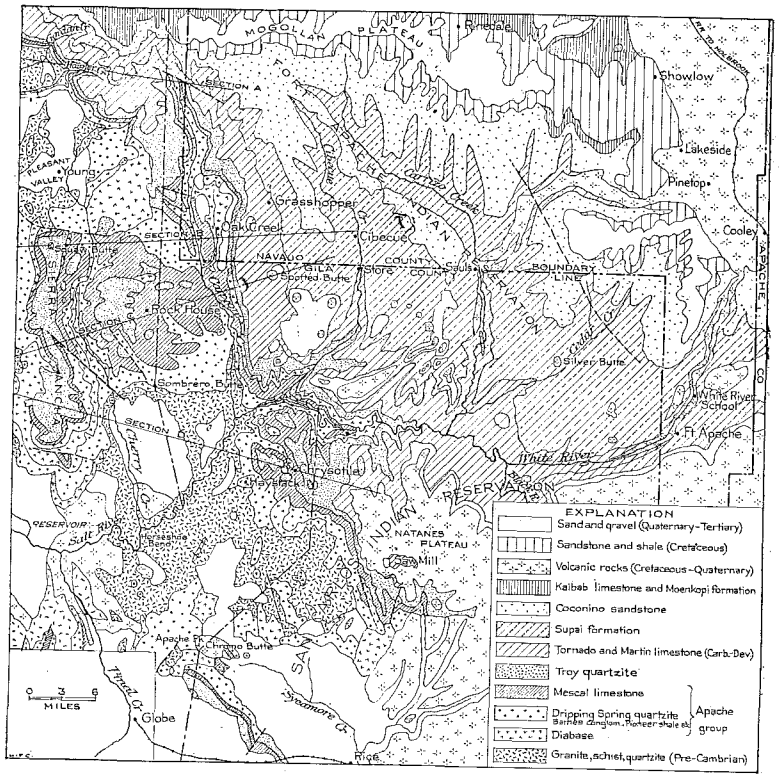


Plate 65. Geologic map of upper part of the Salt River Basin. By N. H. Darton.

beds are slightly overturned. There is local faulting and lateral crushing. The rocks upturned are basal Moenkopi, about 25 feet thick, Kaibab limestone, 200 to 300 feet, and the Coconino sandstone, of undetermined thickness, but probably about 500 feet. The sandstone is greatly crushed under the limestone, and talus hides the relations at its base. The rim consists of an irregular ridge thickly capped by detritus from the crater, consisting of limestone and sandstone ranging from masses 30 feet in diameter to fine dust. The coarser material is predominantly Kaibab limestone, and there is a very large amount of nearly pure silica or "rock flour" at the base of the deposit. The rim is about one-fifth of a mile wide, but a thin sheet of fragmental material extends much farther; a block of limestone 10 feet in diameter is half a mile from the crest. The bottom of the crater is about 1,800 feet across and nearly flat. Several borings, one 1,100 feet deep, have found wash and pond deposits lying on broken rock and rock flour. Solid rock entered

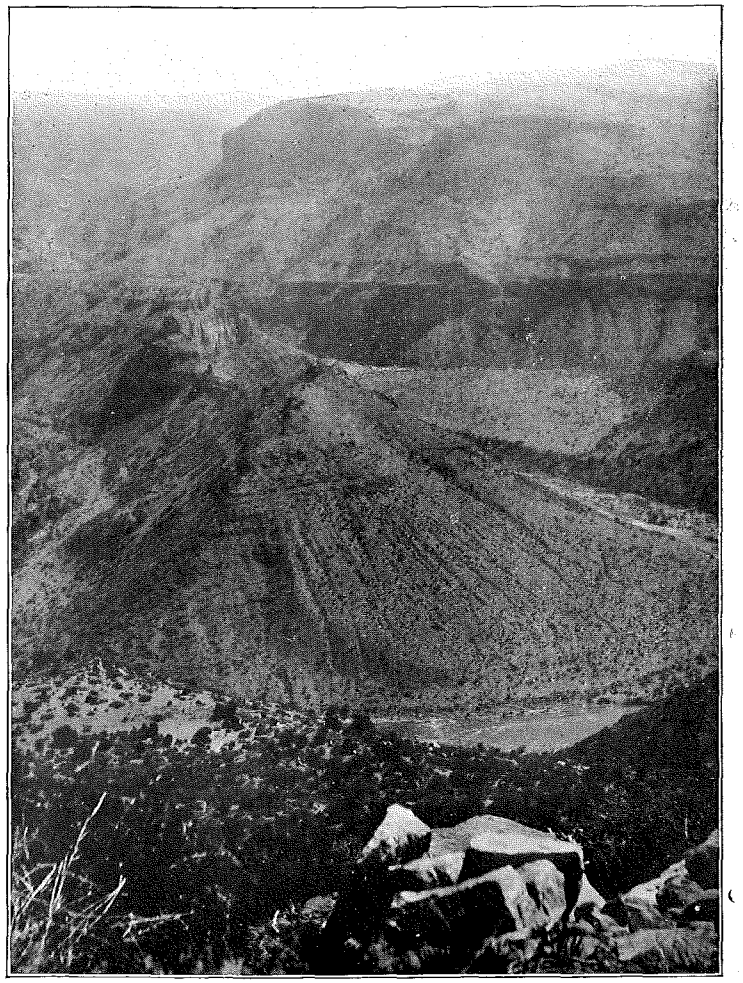


Plate 66a. Canyon of Salt River at mouth of Cibeque Creek. Looking north up Cibeque Valley. Cliffs of Dripping Spring and Troy quartzites and thick sills of diabase. Mescal limestone in slopes in middle ground.

820 to 870 feet below the floor is yellow to red sandstone (Supai). Apparently it lies horizontal and presents no evidence of disturbance. The position of the Coconino-Supai contact is not known. Gilbert estimated that the capacity of the crater is 82 million cubic yards and that the amount of loose material on the rim and beyond is about the same.

After several examinations of the crater, and consideration of all that has been written, the suggestion of Gilbert that the crater and rim were produced by a volcanic steam explosion in the Coconino sandstone appears to me much more likely than the hypothesis that it was caused by the impact of a great meteorite, as urged by Barringer, Merrill,[1] Fairchild,[2] and others. It is agreed that if it was a meteor it must have been at least 500 feet in diameter. Various drill holes and a detailed magnetic survey have failed to reveal any meteor excepting small fragments, such as have been found over a wide area in the surrounding

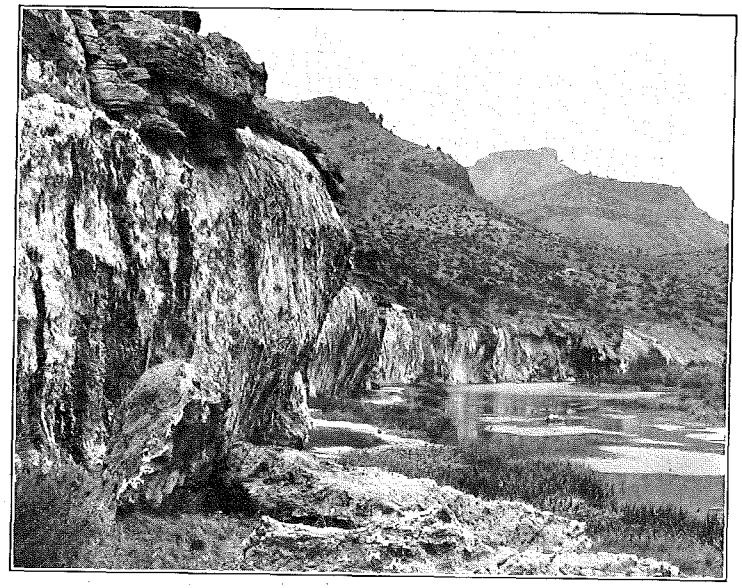


Plate 66b. Salt Springs and deposits at Salt Banks on the Salt River, 30 miles northeast of Globe, Arizona. Photo by U. S. Reclamation Service.

plateau. Another deep hole at "a," Fig. 28, at a place where the rim is notably bulged upward was finally abandoned late in 1924. The suggestion of Merrill that the meteor may have been wholly or partly volatilized by the heat of the concussion and its residue blown out of the crater is difficult to accept. As the feature is in the *midst* of a volcanic region, with many recent cones at no great distance, and the crater of

[1]Merrill, G. P., The Meteor Crater of Canon Diablo, Arizona: Smithsonian Misc. Col., vol. 50, pt. 4, pp. 461-498, 1908, and A Retrospective View of the Origin of Meteor Crater, Arizona: Astron. Soc. of the Pac., Pub. No. 189, Oct., 1920.

[2]Fairchild, H. L., Origin of Meteor Crater (Coon Butte), Arizona: Geol. Soc. Am., Bull., vol. 18, pp. 493-504, 3 pls., 1907.

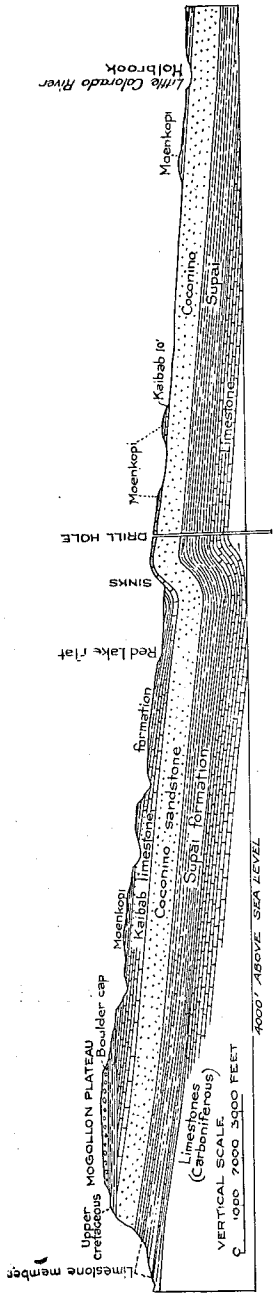


Fig. 29.—Sketch section from the Little Colorado Valley near Holbrook across the Mogollon Plateau at Pinedale.

Zuni Salt Lake, which is closely similar, *and has cinder cones in the center*, is not far southeast near the western margin of New Mexico, it appears to me that there is strong probability of volcanic origin.

NAVAJO COUNTY

Plateau south of Holbrook — Mogollon Plateau.—There is a general rise of the strata south of Holbrook into the wide cuesta known as the Mogollon Plateau, and in this slope there is also a local upward doming of the strata in an oval area of considerable size. The larger features of this structure are shown in the diagram, Plate 52, and the general relations of the strata are shown in the cross section, Fig. 29.

The principal formations presented in this region are the red shale and sandstone of the Moenkopi formation, the Kaibab limestone which thins out to the northeastward, and the Coconino sandstone which is extensively bared on the dome. The Mogollon Plateau is capped by Upper Cretaceous coal measures mantled by a heavy boulder deposit. Under the Coconino sandstone are the red beds of the Supai formation, and the Carboniferous limestone succession is revealed by borings. The region has been of great interest to geologists in late years because the dome has been bored into for oil at various localities, so far without encouraging results. Considerable information was received as to local geology, especially as to the thinning of the Kaibab formation, from Mr. C. E. Major and Mr. Dorsey Hager, who have prepared reports for oil companies. The following records of the two deepest borings on the dome afford important data as to the thickness and succession of beds; I have grouped some of the strata reported and added the correlation.

RECORD OF ADAMANA BORE HOLE, SEC. 4, T. 14, R. 20, SOUTHWEST OF HOLBROOK, ARIZONA

Feet	*Material*	*Formation*
0– 60	Red shale	Moenkopi
60– 80	Limestone, yellow, very sandy	Kaibab
80– 394	Sandstone, yellow	Coconino
394– 439	Shale, white	Coconino
439– 549	Sandstone, mostly buff, some reddish	Coconino
549– 680	Sandstone, white	Coconino
680– 692	"Limestone", hard	Supai
692– 855	Red shale, some gypsum and salt	Supai
855–1040	Shale, brown	Supai
1040–1050	Lime, blue	Supai
1050–1090	Shale, brown, and salt	Supai
1090–1745	Shale, blue and brown, salt	Supai
1745–1950	Limestone, blue	Redwall
1950–2040	Sandstone and salt	Redwall
2040–2150	Shale, brown	Redwall
2150–2345	Limestone, some shale	Redwall

This record was to the end of January, 1921. A year later the depth was 350 feet greater, and soft, brown beds were being penetrated. In February, 1923, the depth was about 3,000 feet and the material was black shale. The Supai formation appears to be about 1,065 feet thick in this hole, but there is some uncertainty as to its lower limit.

RECORD OF HOPI BORING, IN SEC. 21, T. 15 N., R. 19 E., SOUTHWEST OF HOLBROOK, ARIZONA

Feet	*Material*	*Formation*
0– 465	Sandstone, hard, cross-bedded, gray to buff	Coconino
465– 625	Sandstone, red	Supai
629– 697	Limestone, sandy, red	Supai
697– 710	Sandstone, gray	Supai
710–1075	Shale, etc., red	Supai
1075–1200	Sandy shale, black	Supai
1200–1725	Sandstone, red, with salt beds, (limestone, 1550–1590 feet)	Supai
1725–1788	Limestone, very hard, black on blue	Redwall
1788–1875	Sandstone	Redwall
1875–2175	Red sandstone with salt in upper half	Redwall
2175–2355	Limestone, red, sandy, hard	Redwall
2355–2400	Sandstone, buff	Redwall
2400–2420	Sandy limestone and sandstone, red	Redwall

Another record gives red sand and shale 2196 to 2235 feet, lime and shale, 2235 to 2505 feet, and white "lime," 2505 to 2520 feet. Possibly the base of the Supai was at 1725 feet, but red material occurs in underlying strata.

Early in 1925 the Taylor-Fuller boring penetrated arkosic sandstone 3685-3870 feet, limestone 3870-3994 and red and brown hard sandstone 3994-4112 feet, possibly strata of the Apache group which outcrop on Canyon Creek 60 miles southwest.

The Holbrook boring (No. 1) about three miles west of the Hopi hole is reported to have entered red shale at 511 feet, which continued to 935 feet, interrupted by limestone from 680 to 692 feet and by gypsum at intervals from 692 to 865 feet and some salt from 855 to 935 feet. Apparently there are local salt basins in Permian and Pennsylvanian strata in this region.

The westernmost bore hole, which is at the Black Canyon claim in Section 20, T. 16, R. 17, was sunk 476 feet with diamond drill. The cores were nearly all light colored sandstone (Coconino). Some layers were found to contain considerable calcium carbonate and a few thin layers of shale were penetrated. The mesa at this place is capped by the thin Kaibab limestone, the upper part very sandy. A boring for water at Winslow had reached a depth of 965 feet late in 1924 all in Coconino sandstone below 100 feet. The overlying Kaibab was thin.

The thinning of the Kaibab limestone in the plateau south of Holbrook is an interesting feature which has been described in considerable detail on a previous page. It results in the disappearance of the formation at Holbrook, although its thin edge is well characterized a short distance south of that place and near Winslow and Snowflake. It is absent in the basin northeast of Holbrook and in the Defiance uplift where the Moenkopi formation, and to the northward the Shinarump conglomerate, lies on the Coconino sandstone.

As shown in Plate 52, the dome of the Holbrook region trends northwest and finally flattens out in the monocline southeast of Winslow. It is broad and flat to the southeast along the Little Colorado River, which cuts a canyon across it, mostly with walls of Coconino sandstone, from near Snowflake to Holbrook. Woodruff Butte consists of Moenkopi, Chinle, and Shinarump beds in a shallow basin, capped by basalt (See Pl. 60a.) Possibly the vent from which this latter rock came is in the butte. Just east of Taylor there is a small local dome in which the Coconino sandstone is revealed overlain by yellow sandy Kaibab limestone only a few feet thick.

The Sinks are on the south slope of the large dome, about 10 miles northwest of Snowflake. There are 30 or 40 of them, ranging from a few yards to 100 yards in diameter, in an area about a mile in length, and all near or on the steep dip to the south. Most of them expose sandstone of Coconino aspect (see Pl. 60b), overlain by Kaibab limestone, here 20 or 30 feet thick. Undoubtedly this sandstone is underlain by a limestone member which has been removed in places by solution in underground waters passing into the valley of Dry Lake to the southward.

This latter valley is a syncline filled with Moenkopi formation, as shown in the cross section (Fig. 28), which extends nearly to Chevlon Canyon. In the center of the basin, southwest of the Sinks, are two buttes capped by Shinarump conglomerate.

The Moenkopi extends far up the slopes south of Dry Lake Valley, and on an irregular surface of this formation and in places overlapping on to the Kaibab limestone, is the cap of Upper Cretaceous strata which

extends from west to east across the country on the top of the plateau. To the south and west it is mantled by an old boulder cap and to the east by the igneous rocks of the White Mountain region.

The Cretaceous strata on the higher part of the Mogollon Plateau, which is at its southern edge, consist mostly of shale and sandstone. A section at the head of Carrizo Creek and the north fork of Phoenix Wash shows about 300 feet of strata under the heavy boulder cap. The upper half is shale and sandstone with a 2-foot bed of coal and coaly shale at base. Under this are 3 feet of white clay, 30 feet of sandstone, 6 feet of fire clay, and 30 feet of sandstone which may be top Kaibab. Next below are 50 feet of limestone, probably Kaibab, lying on a thick mass of Coconino sandstone.

South of Turkey Springs, 12 miles south-southwest of Heber, the section is similar to the one given above. The gravel cap, 40 feet thick, lies on sandy shales with sandstone layers. The coal horizon is represented by 2 feet of coaly shale, which lies on gray fire clay, in turn underlain by 6 feet of white sandstone. Brown to gray sandstones below, about 20 feet thick, may be at the top of the Coconino which is extensively exposed in the canyon below. In Adair Wash, 3 miles northwest of Showlow, the upper beds are shale with fossil-bearing concretions, in all 30 feet thick. This lies on 33 feet of soft sandstones, white near base, underlain by red beds of the Moenkopi formation. In the slopes northwest of Lakeside there is at top, under the lava, pale red massive sandstone grading down into slabby sandstone and shale, with concretions, and then limestone carrying Cretaceous fossils. At base are sandstones and shales lying on Kaibab limestone, here only about 50 feet thick.

Fort Apache Reservation.—This large Indian Reservation was crossed in various places and many new data were obtained as to the geologic relations. The districts adjacent to Canyon Creek and Salt Creek have been described on previous pages in this report, as they exhibit mainly the formations of the Apache group. The plateau region north of Salt Creek presents a wide area of the red shales and sandstones with interbedded limestones, of the Supai formation, the stratigraphic features of which are described on page 84. These strata lie nearly horizontal, but have various low undulations of dip. On the ridges and slopes heading north to the Mogollon Plateau is the overlying Coconino sandstone, capped in the high slopes by Kaibab limestone and Cretaceous beds. East of longitude 110° the Mogollon plateau is thickly mantled by Tertiary igneous rocks extending from the great centers of eruption constituting the White Mountains. Lava flows, probably of Quaternary age, extend down the valleys of Corduroy and Forestdale creeks and of White River. The source of the flow in the valley of Forestdale Creek was the large crater at Pine Top, and the White River flow probably came from Cooley Mountain or some nearby cone. Many peaks of igneous rocks occur on the east, in greater part on the outcrop area of the Supai formation. They are mostly plugs or stocks, in part feeders of basalt flows, and

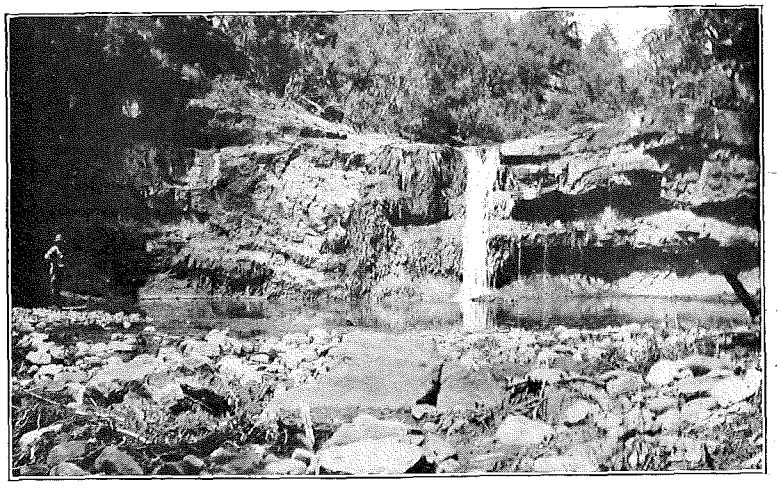


Plate 67a. Mescal limestone on Haigler Creek 10 miles north-northeast of Young P. O., Gila County.

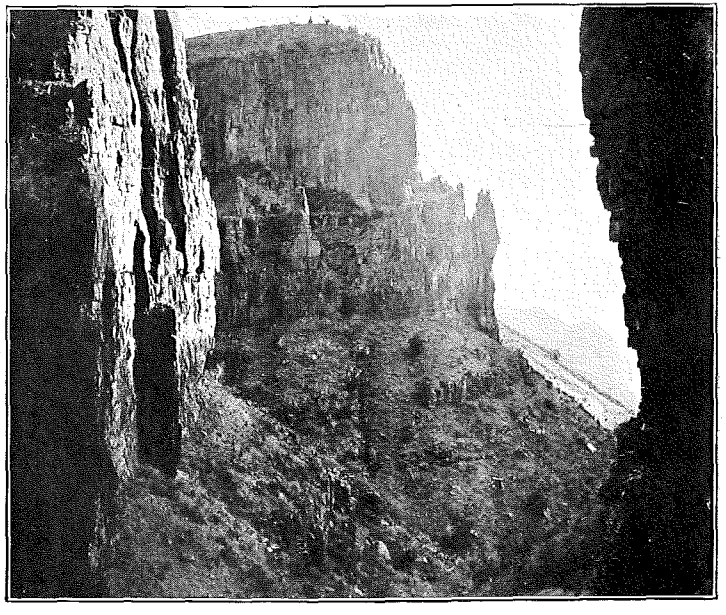


Plate 67b. Dripping Spring quartzite on sill of diabase at Natural Corral, north side of valley of the Salt River, 9 miles northeast of Roosevelt Dam. Looking east.

in part other rocks. Between Cibeque Creek and Carrizo Creek there are several remnants of old lavas from these sources, which cap mesas of various sizes and in most cases lie on deposits of gravel and sand. Silver Butte, on the west side of Cedar Creek, is a large mass of igneous rock, apparently a stock.

Monument Valley to Moonlight Creek.—In the dome north of Kayenta the Moenkopi formation and overlying sandstones are bared by erosion, and northward in Utah the San Juan Valley is deeply excavated into still older red beds and limestones of Pennsylvanian age.[1] After tracing the Coconino sandstone northward to Canyon de Chelly on the Defiance uplift, where the Kaibab limestone and Moenkopi formation are absent, it was interesting to find the Coconino sandstone extensively exposed on Moonlight Creek in Utah and along the east side of the Monument Valley region in Arizona. (See Pls. 17 and 61a.) The Moenkopi formation is present throughout this region, consisting of the usual red sandy shale and sandstone, but including near its middle a conspicuous sandstone member which caps many of the monuments or presents a buff cliff in their higher slopes. This sandstone is moderately compact and somewhat cross-bedded, but differs materially in character and aspect from the hard cross-bedded, dirty-buff Coconino sandstone, outcropping in the deeper valleys and along the west slope of Comb Ridge. It is part of the "Oljeto sandstone member" of Woodruff[2]. Probably Kaibab limestone, 4 feet thick, was found on Moonlight Creek about 6 miles north of the Arizona boundary line. It lies on typical Coconino sandstone, contains Permian fossils, and is overlain by about 150 feet of red shale (Moenkopi) extending to the base of the sandstone of the monuments. This sandstone is overlain by 31 to 40 feet of red sandy shale constituting the top member of the Moenkopi and is capped by characteristic Shinarump conglomerate.

APACHE COUNTY

Defiance uplift—Canyon de Chelly.—In the eastern part of the northern half of Apache County the strata are extensively arched in an anticline which has been designated the Defiance uplift. In its larger features it extends from the Santa Fe Railroad near Houck nearly to the Utah State line. The general structure is shown in Plate 52. The strata steeply upturned along its eastern side comprise beds from the Supai formation to the Mesaverde coal measures, the latter rising out of the Gallup coal basin to the southeastward. As noted by Gregory, the pre-Cambrian quartzite is exposed in the center of the uplift in a

[1]These are described by Longwell, C. R., Miser, H. D., Moore, R. C., Bryan, K., and Paige, Sidney, Rock Formations in the Colorado Plateau of Southeastern Utah and Northern Arizona: U. S. Geol. Surv., Prof. Paper 132a, 1923.

[2]Woodruff, E. G., Geology of the San Juan Oil Field, Utah: U. S. Geol. Surv., Bull. 471, p. 87, 1912.

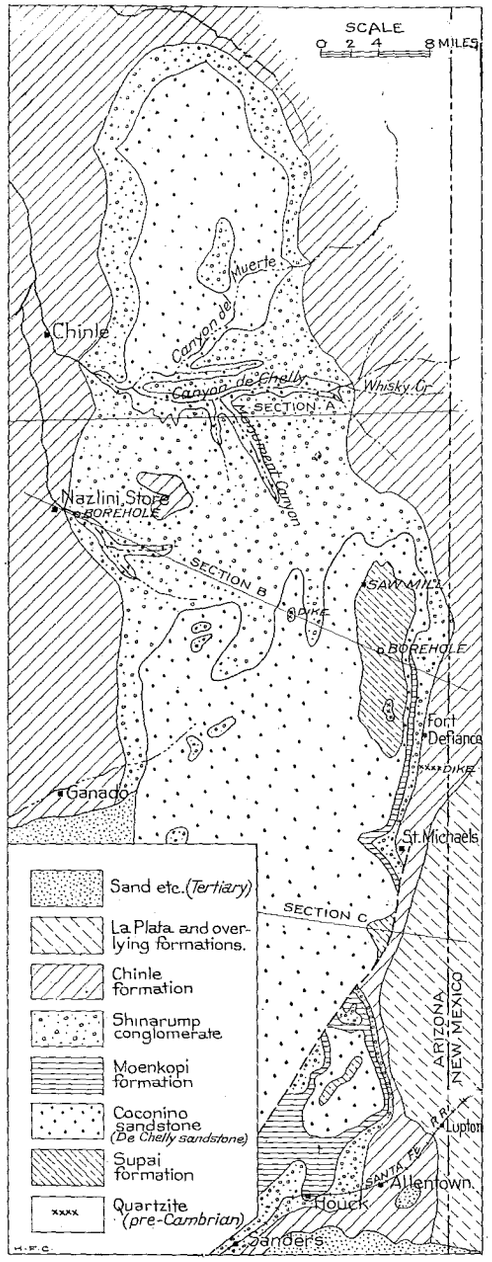


Fig. 30.—Defiance uplift, Apache County, Arizona, by N. H. Darton.

small area along Quartzite Canyon, 3 miles northwest of Fort Defiance. I find that the red beds overlying it are of Supai age, presenting the same relations to the old pre-Cambrian basement as in the Zuni Mountains in New Mexico, not many miles southeastward, where red beds (Permian), regarded as of corresponding age, with a fossiliferous limestone member near their base lie on granite. Granite has also been found recently under the Supai in bore holes northwest of Fort Defiance and south of Chinle. Fossil plants of Permian age were found in these red beds of the Defiance uplift by Gregory. (See p. 88.) These relations indicate that in this region a ridge of the basement rocks probably persisted through Cambrian, Ordovician, Silurian, Devonian, Mississippian and Pennsylvanian time, but was finally buried beneath the red deposits of Supai time. It must, however, be suggested that deposits may have been laid down in some part of this long interval and removed by erosion prior to the Permian.

The distribution of formations in the Defiance uplift is shown in

Fig. 30, and some of the relations are represented in the section in Fig. 31. A notable feature in the stratigraphy of the region beside the

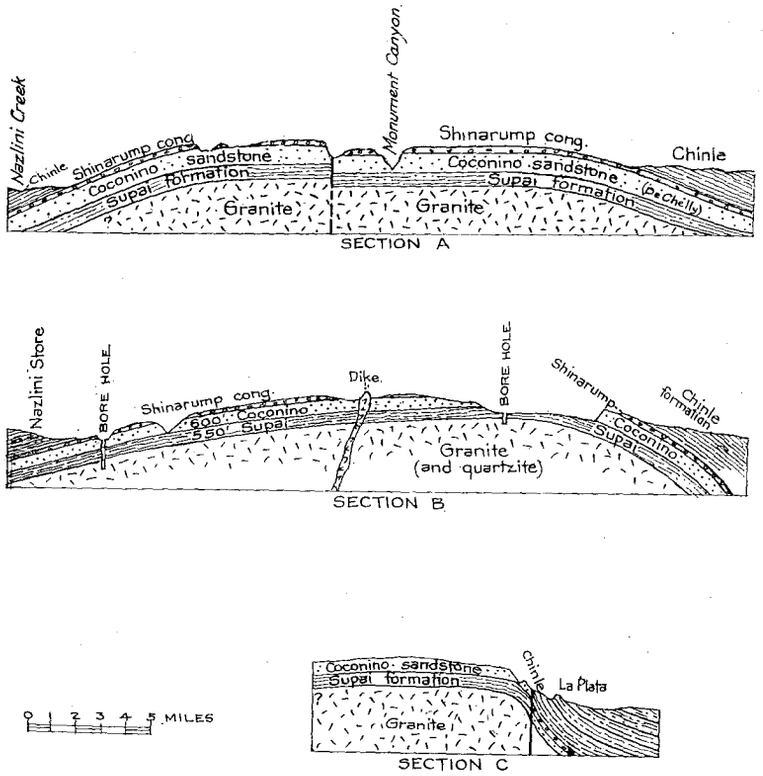


Fig. 31.—Sketch sections across the central part of the Defiance uplift along lines shown in Fig. 30.

overlap of the Supai formation on granite and quartzite is the absence of the Kaibab limestone and the thinning out of the Moenkopi formation to the northward. These facts were first brought to my attention by Mr. Dorsey Hager, who investigated prospects for oil in the region. The red shale and sandstone of the Moenkopi formation are well characterized near the Santa Fe Railroad, and they were traced northward past St. Michaels and Fort Defiance (see Pl. 25b), finally thinning out not far north of the latter place. On the northwest side and north end of the uplift distinctive Shinarump conglomerate lies directly on Coconino sandstone. This feature, with unconformity and channeling, is well exhibited on the mesa slopes adjoining Canyon de Chelly just east

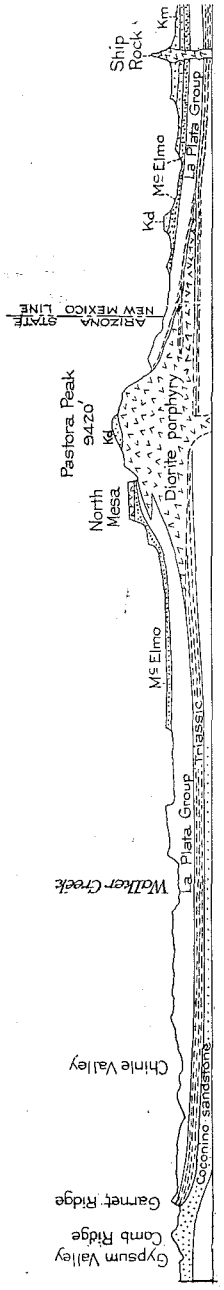


Fig. 32.—Section east and west through Carrizo Mountain, after Gregory and Emery.

of Chinle, as shown in Plate 26b. In all exposures the Coconino sandstone presents its very distinctive features similar to those exhibited in the Holbrook region and southward. It is superbly exposed in the great walls of Canyon de Chelly, Canyon del Muerto, Monument Canyon and Nazlini Canyon. Its relations to the Supai formation are visible in high cliffs a short distance west of Fort Defiance, where there is a fairly strong break between the red beds and the overlying coarse, cross-bedded sandstone of the Coconino. To the northward in these cliffs, however, the distinction is lost somewhat by the development of beds of coarser, lighter color in the upper part of the Supai, suggesting transition. If this relation continues northward the upper part, at least, of the Supai may not be distinguishable from the Coconino and with this character it may be present in the lower part of the sections in Canyon de Chelly and Canyon del Muerto, where about 800 feet of sandstone is exposed. Nazlini Canyon is cut only into the upper part of the succession, but samples from the diamond drill hole in the bottom of the canyon showed at least 600 feet of strata of typical Supai aspect lying on the granite. For a record of the hole see page 86.

Carrizo Mountain to Comb Ridge and westward.—Carrizo Mountain is an isolated mass rising about 2,500 feet above the surrounding hilly country in the northeastern corner of Apache County. It is due to a laccolith intruded mainly at the base of the Wingate sandstone and uplifting these strata and overlying beds several thousand feet. The structure as determined by Gregory[1] and Emery[2] is shown in the following cross section:

The igneous rock of the laccolith and its branches is diorite porphyry. Dacite occurs in dikes on the northeast slope of the mountain and as a volcanic neck in Walker Peak and some other knobs some distance south. The rocks exposed in the country adjoining Carrizo Mountain are Navajo sandstone overlain by supposed McElmo sandstone. Small

[1]Gregory, H. E., *op. cit.*, Prof. Paper 93.

[2]Emery, W. B., The Igneous Geology of Carrizo Mountain, Arizona: Am. Jour. Sci., 4th ser., vol. 42, pp. 349-363, 1916.

areas of Cretaceous rocks also cap nearby mesas and an outlier of sandstone, presumably Dakota, constitutes the summit of the mountain.

YAVAPAI COUNTY

Jerome Region.—The Jerome district is on the slope of a general rise of the strata toward the Prescott district, but there is considerable local uplift and faulting, the latter having brought the great ore bodies to the surface. The Redwall and associated limestones are extensively exposed, and the pre-Cambrian floor of schist and granite is bared to the west and south. Basalt covers many of the slopes and the higher summits, including the high mesas of Woodschute and Mingus mountains west and south of Jerome. The map (Fig. 33), the sketch section (Fig. 34), which I have constructed from the map, and the following facts regarding the geology are from observations by Reber[1] and mapping for the Arizona Bureau of Mines by O. P. Jenkins and E. D. Wilson.

The basal formation, of pre-Cambrian age, is a great greenstone complex, probably of volcanic origin, invaded by large bodies of quartz porphyry and augite diorite and by small later dikes of diorite and andesite. These older rocks are extensively exposed in the slopes south of Jerome. The schists which overlie the greenstone complex are correlated with the Yavapai schist. They are closely folded and comprise many kinds of rocks from fine-grained schist and quartzite to thick-bedded conglomerate. Just southwest of Jerome a volcanic agglomerate appears to lie between the schist and the main porphyry mass. The basal sandstone of the Paleozoic is classed as Tapeats. It is of maroon color, about 100 feet thick, locally conglomeratic, and is overlain in most places by 10 to 20 feet of shale. Next above are limestones, some of which are sandy. They contain Upper Devonian fossils[2] about 350 feet above the base. The Redwall limestone outcrops in massive ledges presenting 250 feet or more of beds, capped by the lower red sandstone of the Supai formation which on Woodschute Mountain is protected by the heavy lava cap. It also outcrops extensively in the slopes north and northeast of Jerome. Wilson[3] has described the occurrence and relations of pre-Cambrian quartzite in the slopes southeast of Del Rio. The map showing this feature is reproduced in Fig. 35.

Bradshaw Mountains.—The geology of this range and the adjoining ridges and mesas between latitude 34° and 34° 30′ has been mapped and described in detail by Jaggar and Palache.[4] Some of the salient

[1]Reber, Louis E., Jr., Geology and Ore Deposits of the Jerome District: Am. Inst. Min. Eng., Trans., vol. 66, pp. 3-26, 1922.

[2]Ransome, *op. cit.*, Prof. Paper 98 (k), p. 161.

[3]Wilson, E. D., Proterozoic Mazatzal Quartzite of Arizona: Pan. Am. Geol., vol. 38, pp. 299-312, 1922.

[4]Jaggar, T. A., and Palache, Charles, U. S. Geol. Surv. Atlas, Bradshaw Mountains folio (No. 126), 1905.

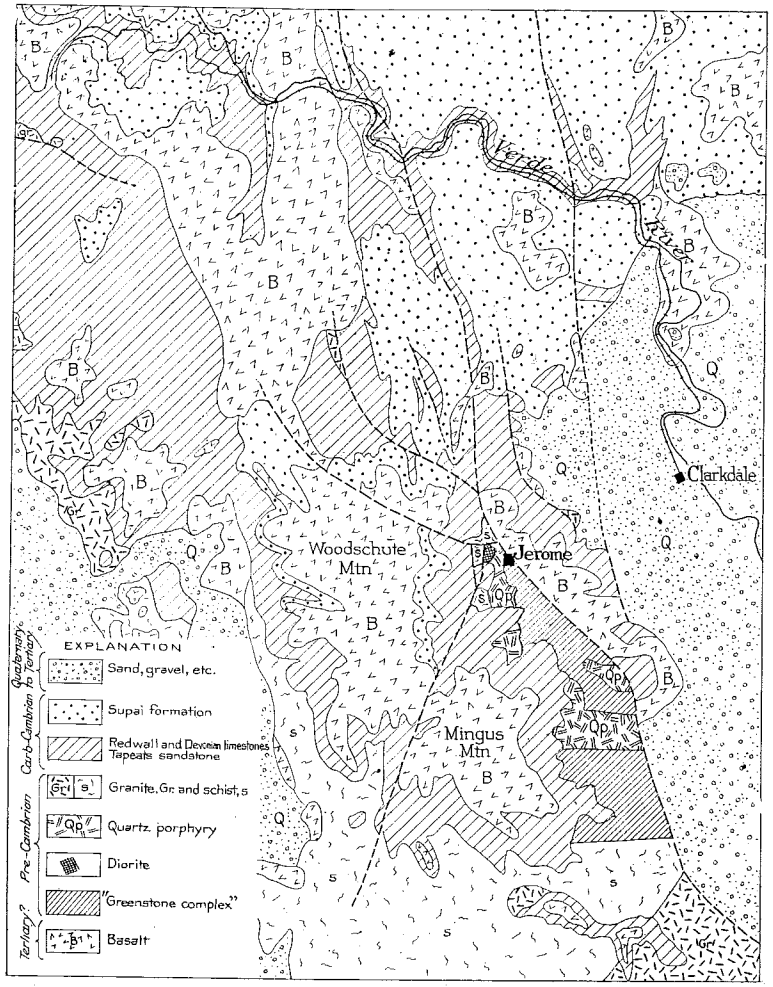


Fig. 33.—Geologic map of the Jerome district.

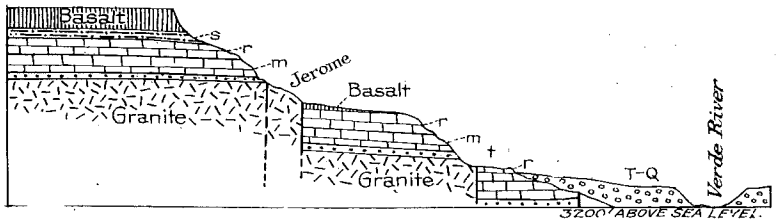


Fig. 34.—Sketch section showing relations at Jerome.

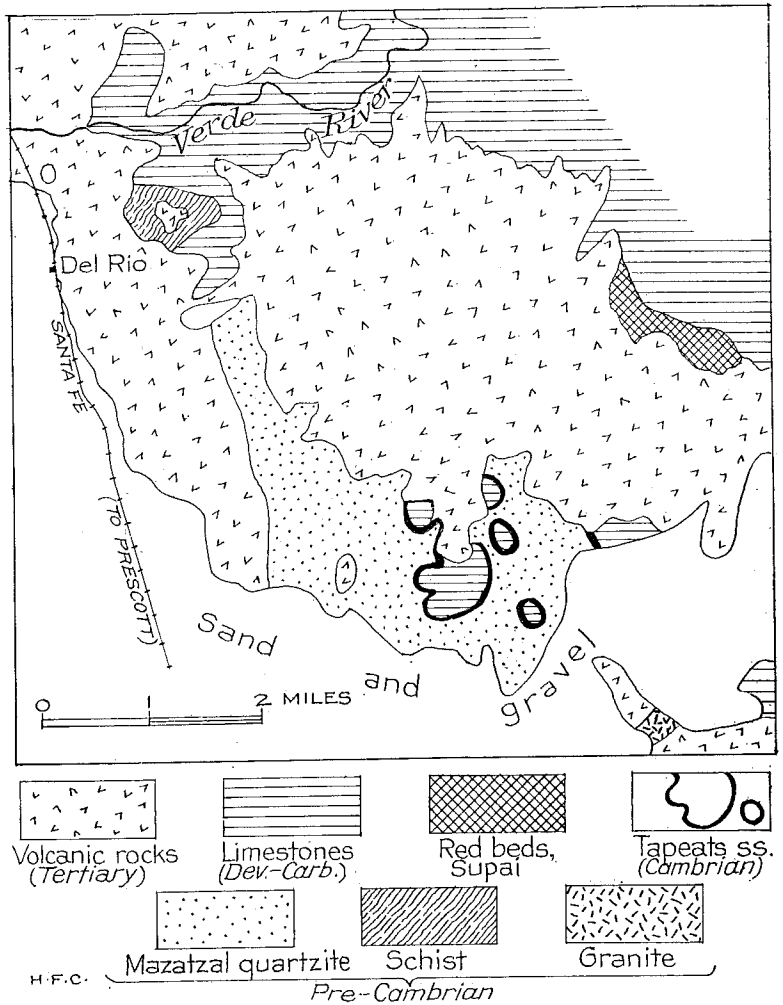


Fig. 35.—Geologic map of pre-Cambrian quartzite area near Del Rio, by E. D. Wilson.

features are shown in the sections (Fig. 36) which cross the quadrangle from west to east.

The Bradshaw Mountains consist mainly of granite and diorites of pre-Cambrian age which are intruded into Algonkian schists of various kinds. On the adjoining mesas are accumulations of volcanic agglomerate of supposed Tertiary age, mantled in large part by extensive flows of basalt, which in places are from 200 to 500 feet thick. To the south-

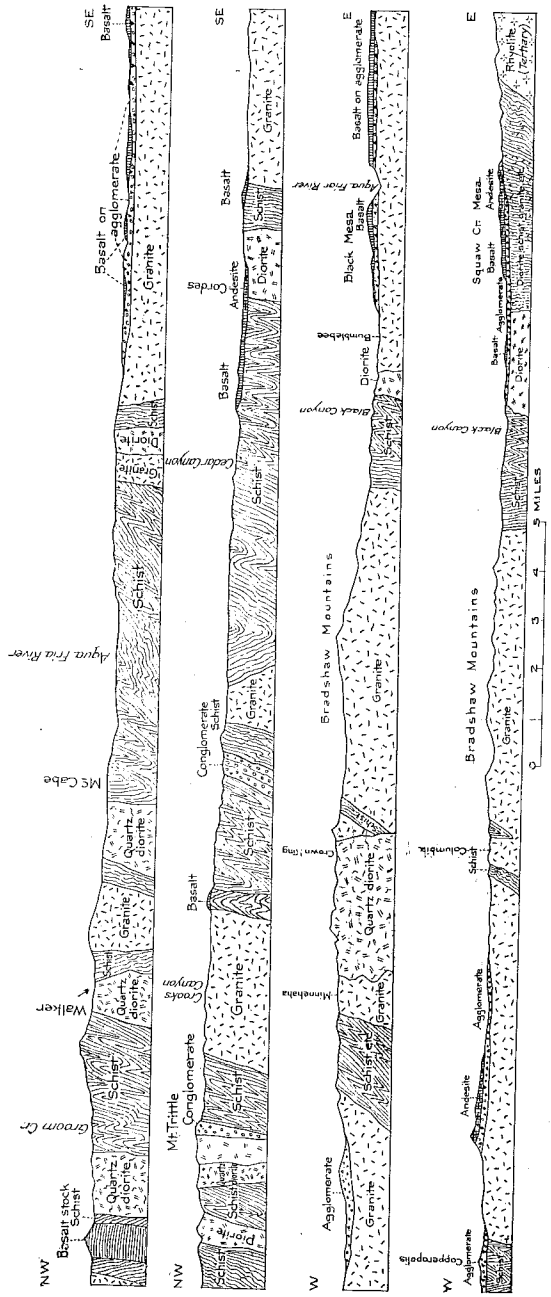


Fig. 36.—Sections across the Bradshaw quadrangle, after Jaggar and Palache.

westward the agglomerate is mantled by flows of andesite. These lavas are classed as probable Tertiary. Some features of the metamorphic and volcanic rocks of the region are described on page 18 of this bulletin.

YUMA COUNTY

Buckskin Mountains.—The Buckskin Mountains extend nearly across the northern part of Yuma County. Williams River flows along the foot of their north side and the wide flats of Cactus Plain and Butler Valley lie south. Bancroft[1] has described the rocks and their relations at various mining camps in the central and western part of the range, and Blanchard[2] has presented many interesting details regarding the western part. During 1922 I visited one of the western extensions of the range near the Billy Mack mine, a few miles northeast of Parker, and discovered Carboniferous fossils in the limestone.

Bancroft found that the Buckskin Mountains consist in greater part of schist, presumably of pre-Cambrian age, with some masses of limestone, mostly in the form of marble, which he classed also as pre-Cambrian. The western part is covered more or less thickly by an extensive sheet of basalt of probable early Quaternary age, for, as shown by Blanchard, it lies in part on Temple Bar conglomerate and gravels.

According to Bancroft, the rocks about Planet, where copper has been mined extensively, are granite gneiss overlain by limestone and marble, with interbedded amphibolite in its lower part and at the top a series of fine-grained mica schists, apparently a metamorphosed sandy shale. A cross section at this place is reproduced in Fig. 37. The basal contact

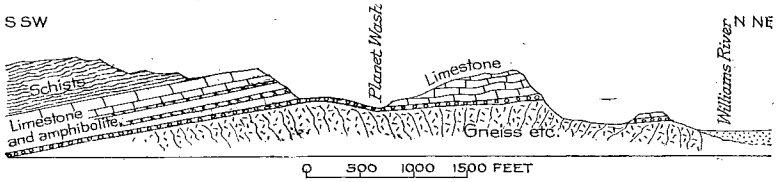


Fig. 37.—Section near Planet, after Bancroft.

of the strata on gneiss is said to be very irregular and with limestone conglomerate in places. The thickness of strata is about 900 feet near Planet, where the lower 200 feet consists of thin members of limestone intercalated with amphibolites. The latter are believed to be metamorphosed igneous rocks. The basal conglomerate, which is 20 feet thick locally, is composed of boulders of limestone, quartz and gneiss. On the lower limestone series lies a more massive limestone, 100 feet thick in

[1]Bancroft, Howland, Reconnaissance of the Ore Deposits in Northern Yuma County, Arizona: U. S. Geol. Surv., Bull. 451, 1911.

[2]Blanchard, R. C., The Geology of the Western Buckskin Mountains, Yuma County, Arizona, 80 pages, privately published, 1913.

places. At Mineral Hill, 3 miles west of Planet, there is a basal series of argillite overlain unconformably by mica schists, with a small amount of impure limestone, both cut by an intrusive rock which has been metamorphosed to schist. About the Signal Mine the country rock is granitic gneiss, clearly of igneous origin and classed as pre-Cambrian. Southwest of the mine it is overlain uncomformably by dark brown massive limestone 100 feet thick in places, with layers of amphibolite. The limestone is also cut by diabase dikes. In the vicinity of the Clara Mine there is a thin body of limestone which in the higher ridges adjoining is capped by ash and andesite of the Tertiary volcanic series. The relations at these places are shown in the following figure:

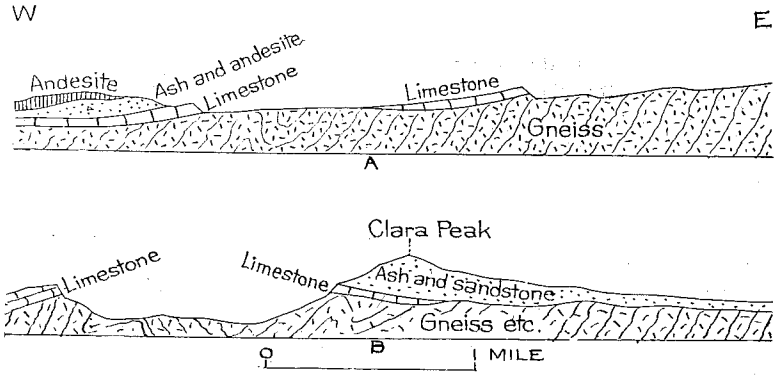


Fig. 38.—Sketch sections at Swansea, Arizona, after Bancroft: A, Section south and west of Signal Mine; B, Section from Clara Mine through Clara Peak.

Blanchard described many structural and petrographic features of the rocks in the western half of the Buckskin Range. He regarded the limestone, schist, and porphyry as pre-Cambrian as well as the gneiss, although in one of the masses of metamorphosed limestone he found organic remains that are almost certainly crinoid stems. The map and cross section in Fig. 39 show the principal features of the area.

The gneisses were found to be associated with schists and apparently to grade into granite. Quartzite is also mentioned, but its relations are not described. Numerous dikes occur including pegmatites, aplites, quartz porphyries and diabase all of which are more or less metamorphosed. Some of the limestone is included in the gneiss. The largest area of limestone noted is on Brown Mountain, where there are also many smaller masses, lying on gneiss but supposed to be separated by faults. Some interesting facts were given regarding the Temple Bar conglomerate, which lies on an irregular floor of gneiss and is mostly tilted. It is cut by dikes and capped by flows of basalt 400 to 800 feet thick which in most places lie on a bed of rhyolite tuff 5 to 50 feet thick. An earlier basalt also occurs in the detrital beds below. A sheet of

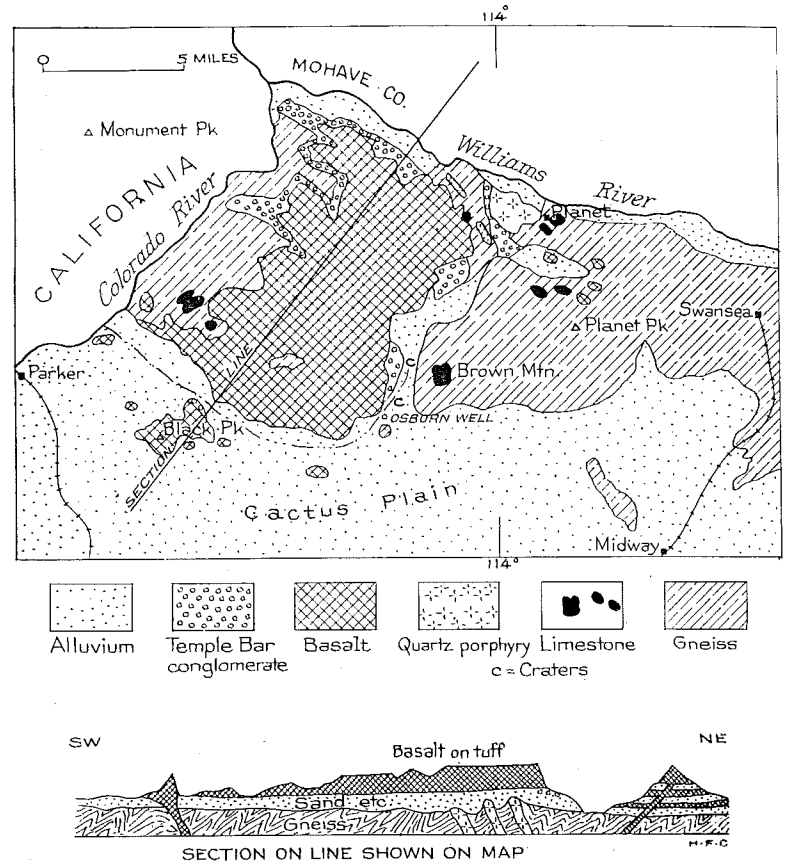


Fig. 39.—Geologic map and cross section of the western part of the Buckskin Mountains, northern Yuma County, Arizona, after Blanchard.

rhyolite porphyry of Quaternary age extends along the Williams River, especially on the south side, where, at one place, it is 3 miles wide. It appears to be intruded and lies on quartz porphyry and gneiss. It is not shown on the map. Blanchard discovered fossils in the tuff on Osborn Wash which were determined by Dall as *Bittium* and a probable young *Corbicula*, regarded as Pliocene or possibly earlier in the Tertiary. The tuff, which is about 4 feet thick, is included in the upper part of the Temple Bar conglomerate 30 to 40 feet below the top which is capped by basalt from Black Peak. Further details regarding this fossiliferous bed have been given by Ross[1] who found that most of the rock was

[1]Ross, C. P., *op. cit.*, p. 189.

limestone and that it grades into calcareous conglomerate. The most notable exposures were 8 miles west of Osborn well on the road to Parker.

In the vicinity of the Billy Mack Mine northeast of Parker, I found a thick succession of limestone and shale, largely metamorphosed into marble and schist. These strata are penetrated by igneous rock, mainly granitic. The general structural relations are as shown in the following section:

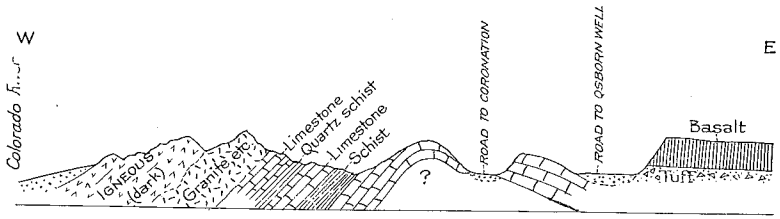


Fig. 40.—Sketch section of ridges at the Billy Mack Mine northeast of Parker, Arizona.

A few fragments of fossils, mainly crinoid stems, were found in the less altered limestone in ledges north and south of the mine, which are not determinable specifically but undoubtedly are of Carboniferous age.

Jones[1] has given a section of a succession of volcanic ash, basalt flows and conglomerate in Sec. 21, T. 11 N., R. 11 W., in connection with an occurrence of manganese.

Plomosa Mountains.—This range with its various outlying knobs and ridges consists largely of granite and other crystalline rocks overlain by a thick body of Tertiary volcanic rocks. Black Mesa at the southern end of the range appears to have a heavy cap of basalt. A few data regarding the rocks have been given by Bancroft[2] and Ross.[3] On the southwestern slope of the range there were noted a mass of grayish-green, fine-grained rock, in part schistose and probably an old volcanic extrusive quartz biotite schist and coarse gneiss. Near the Guadalupe mine, 10 miles east of Quartzite, the rocks under a cap of Tertiary andesite are schistose basic rock probably dioritic and of volcanic origin, quartzite and limestone. About 500 feet of the latter is exposed for a short distance, apparently lying on the quartzite with limestone conglomerate intervening at one place. Some of the limestone has been metamorphosed to marble, but other portions are not so greatly altered and closely resemble strata in which Carboniferous fossils were found in ranges east and north. A similar limestone is well exposed on the west slope of the range on the road from Bouse to Quartzsite, having

[1]Jones, E. L., Jr., *op. cit.*, Bull. 710d, p. 183.
[2]Bancroft, H., *op. cit.*
[3]Ross, C. P., *op. cit.*

the relations shown in Fig. 41, and it outcrops at intervals along the east slope from near Ibex Mountain northward to a point 7 miles south-

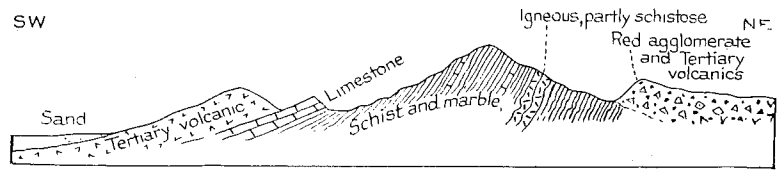


Fig. 41.—Section across the northern end of the Plomosa Range on the road from Bouse to Quartzsite, 10 miles southwest of Bouse.

west of Bouse, in most places being underlain by quartzite. Schists and gneissic rocks cut by granites, aplite, and diabase constitute most of this part of the range. At the Iron Mine, 8 miles southwest of Bouse, the limestone dips to the southwest at angles from 50° to 90° and lies on or against biotite granite. In the Little Butte district at the north end of the range, about 5 miles northwest of Bouse, there is a considerable variety of rocks, including a thick succession of red shale which includes limestone beds, rather suggesting the Supai formation, but more likely of Cretaceous age. These strata lie on or are cut by granite which is penetrated by dikes of diabase. In a small knoll north of the main automobile road I found limestone conglomerate, the limestone closely resembling Carboniferous strata.

I am informed by Mr. Carl Lausen[1] that he has found strata of supposed Lower Cretaceous age on the south end of the Plomosa Range. The rocks are chiefly hard, red shales with layers of coarse and fine sandstones and some quartzite. There are also included some layers, up to 6 inches thick, of dense, thin-bedded limestones of dark color. No fossils were observed, but the strata are thought to be of fresh water origin.

Dome Rock and La Paz mountains and ridges north.—According to Ross[2] the Dome Rock Mountains "consist almost exclusively of rock of the basal complex," but felsitic intrusive rocks of Tertiary age and possibly some lavas occur. The portion of La Paz Mountain in the Colorado Indian Reservation was examined by Jones,[3] who found much greenish-gray to black schistose porphyritic rock, probably a metamorphosed quartz monzonite, a quartz diorite porphyry, and amphibolite and biotite schist probably derived from diabase and diorite. A light colored granitic rock was also noted intruding the schists. The ridges north of Tyson Wash consist of schists with intercalated thin beds of marble, cut by granite-gneiss, amphibolite schist, quartz epidote schist

[1]Personal communication.
[2]Ross, C. P., *op. cit.*, p. 195.
[3]Jones, E. L., Jr., *op. cit.*, Bull. 620, pp. 47-48, 55-57.

and granite. In the northernmost ridge of this range, about the Valenzuella Mine, Bancroft[1] found that the prevailing rocks were coarse-grained schists, apparently mostly metamorphosed sediments. One included lens of marble 12 feet thick was noted, and this rock was reported in one of the mine workings. There are also dikes of quartz porphyry and aplite, which are mostly metamorphosed to schist. Later pegmatites, diabase, and minette also occur as dikes. In general the schists dip away from a gneissic granite which appears south of Tyson Wash and is probably the oldest rock in the region. West of Quartzsite the rocks are mainly quartz mica schist, apparently intruded by granites or quartz

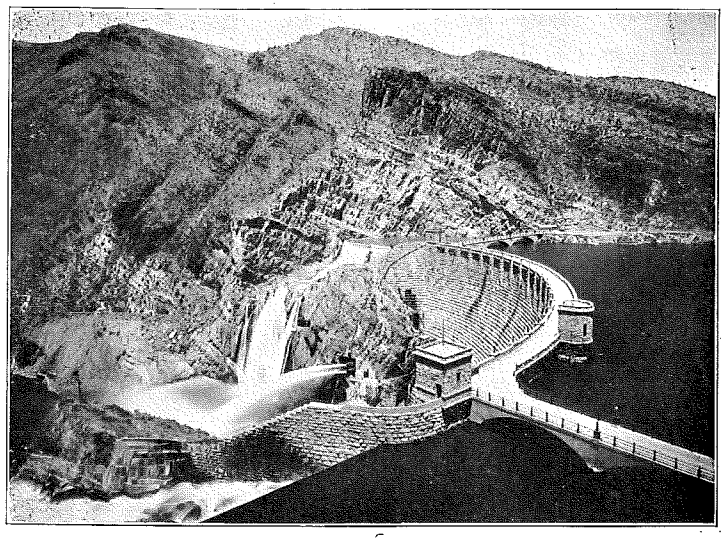


Plate 68a. Apache group at Roosevelt Dam on the Salt River at south end of the Mazatzal Mountains. Looking north. Photo by U. S. Reclamation Service.

monzonite. Schist also predominates at the Cinnabar Mines about 8 miles southwest of Quartzsite, where it contains much magnetite in scattered crystals. The schist about 1½ miles west of the Cinnabar Mines contains two prominent layers of impure limestone.

I visited the Bowyer Mine northwest of Quartzsite, where I found limestones and quartzites penetrated by igneous rocks. At one point near the shaft a marbleized limestone contains some thin sheets of flaky asbestos quite different in character and mode of occurrence from the chrysotile of Gila County. The section at this place is shown in the section of Fig. 42. Part of the limestone is altered to marble and it

[1]Bancroft H., *op. cit.*, p. 80.

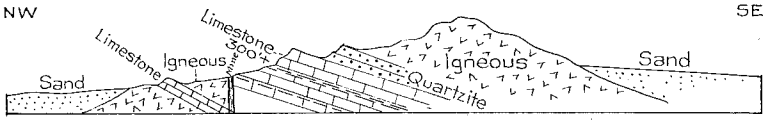


Fig. 42.—Section across outlying ridge of La Paz Mountain, 5 miles northwest of Quartzsite.

contains some shaly members, but the less altered portions closely resemble the limestone containing Carboniferous fossils in other parts of Yuma County. I believe it is Redwall or younger.

Harquahala Mountains.—The very prominent range of the Harquahala Mountains consists largely of crystalline rocks probably in greater part of pre-Cambrian age but including some metamorphosed Paleozoic rocks. In the flanking limestone south of Martin Peak and near Socorro Mine, I found fossils of Carboniferous age. Bancroft[1] has given details regarding rocks at various mining districts in the western part of this range, and classes all the rocks as Pre-Cambrian excepting some late intrusions. A basal granite was noted at the Bonanza Mine, but where best exposed a mile or so farther north, it is cut off from the strata by a fault. At this mine there are quartzite and shale dipping north, and south of

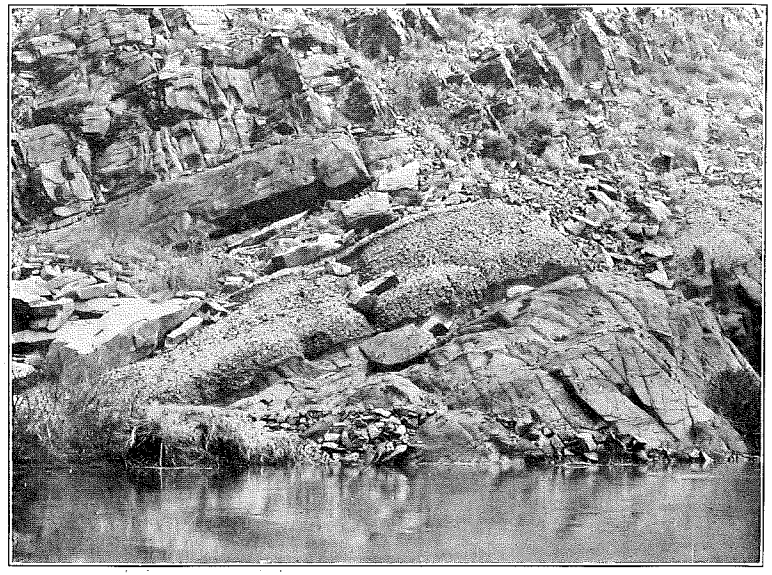


Plate 68b. Conglomerate at base of Apache group lying on granite in canyon of the Salt River below Roosevelt Dam. Looking south. Photo by W. T. Lee.

[1]Bancroft, H., *op. cit.*, pp. 104-115, map.

the mine is a thick mass of limestone in large part altered to marble, constituting Martin Peak and some other knobs to the south. In the higher strata nearly a mile south of the mine, I found fossils of Carboniferous age; a section of Martin Peak made on a very brief visit is shown in Fig. 43. Part of the limestone is dolomite according to analyses

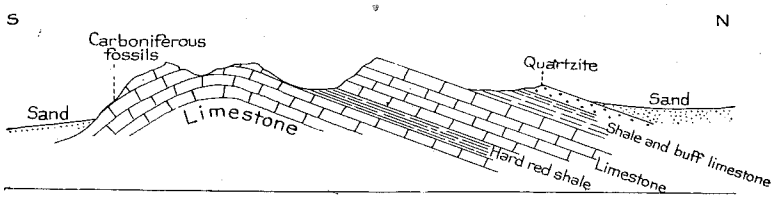


Fig. 43.—Section near the Bonanza Mine.

quoted by Bancroft. The limestone outcrop trends northeast from Martin Peak and crossing the auto road near Tolladay Wells 5 miles south of Wenden extends to and beyond Socorro mine. The limestone lies on or against coarse gray granite with 20 to 60 feet or more of quartzite intervening in places. Some of the basal part of the quartzite is conglomeratic and it appears to lie on an old shore of granite. The dip is southwest. A section just east of the Socorro Mine is shown in Fig. 44.

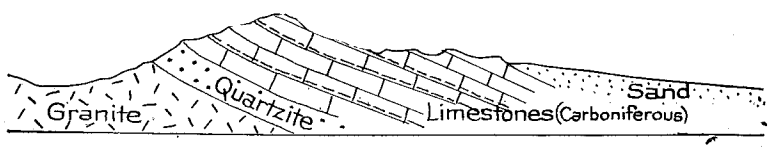


Fig. 44.—Section of limestone hill east of the Socorro Mine, 10 miles southeast of Wenden, Arizona.

The limestone is mostly altered to marble from white to a blue-gray color, but some portions are less altered than others. Several shale members are included which are in greater part altered to slate. In shaly limestone layers, about a half mile east of the mine, some fragments of fossils were found which are undoubtedly Carboniferous. Limestone also occurs at intervals along the south slope of the range and in some outlying ridges. In one of the latter 2 miles south of the foot of the Harquahala Mountains, near the center of T. 4 N., R. 11 W., there are extensive exposures of about 500 feet of limestone conglomerate, in massive beds dipping steeply northeast. The boulders are mostly blue limestone, but some are granite and quartzite. In the limestone boulders are many fossils of late Carboniferous age. This conglomerate, however, is probably much younger than Paleozoic and has derived its materials from ledges along the front of the Harquahala Mountain range. Ledges of this kind occur extensively on the southeast slope of the mountain 13 miles south-southwest of Aguila in a locality about a mile west of the

El Tigre mine. About 500 feet of the limestone is exposed at this place, dipping east and mostly changed to marble. It is flanked on both sides by granite and schist and includes some members of silicious schist which was undoubtedly originally shale. This limestone again appears in two knobs 6 miles farther south-southwest, where one of the less altered beds yielded some fragments of Carboniferous fossils. The dip here is northeast at an angle of about 50 degrees.

Bancroft mentions the occurrence of a limestone-shale-quartzite succession at Hercules Mine on the north slope of the range 3 miles south of Wenden. The strata are cut by diorite and much schistosity is developed in this rock and the beds which it cuts. Considerable mica schist is present also, which perhaps is of pre-Cambrian age. At the San Marcos Mine 4 miles southeast of Wenden, Bancroft found granites, in part massive, in part schistose, of probable pre-Cambrian age; they have been intruded by basic dikes which are sheared and altered, and by aplites which show no schistosity.

Huarcuvar Mountain.—This range consists largely of schist, apparently in greater part of pre-Cambrian age, penetrated by large masses of granites, some of which Bancroft[1] and Ross[2] regard as probable Mesozoic. One of these forms Huarcuvar Peak. Numerous dikes of aplite and vogesite were noted, and some masses of later lava constitute Bullard Peak and some flanking ridges at the east end of the mountain, north of Aguila. Jones[3] found that one outlying spur north of Aguila consists of red sandstone of probable late Tertiary age, containing scattered pebbles of granitic rocks. Limestone occurs in connection with schist and quartzite at several places in the western part of the range. Most of it is highly altered and while it is classed as pre-Cambrian by Bancroft, I believe there is some likelihood that it is Paleozoic. A great thickness of shales, schists, and phyllites was noted at the Desert Mine, 2 miles north of Vicksburg.

Eagle Tail Mountains.—This narrow but prominent ridge with its picturesque peaks known as "Eagle Tail" and "Court House Rock," presents a fine succession of the Tertiary volcanic rocks.

Cemetery Hills and Clanton Hills.—These hills in the central-eastern part of Yuma County present a variety of rocks. There is a basement of pre-Cambrian granite and schist, irregularly overlain by Tertiary volcanic rocks. Schist was found in the center of the Cemetery Hills. According to Ross,[4] the Clanton Hills "consist almost exclusively of flat-lying, gray, cherty, fine-grained limestone with numerous concretions, some of which resemble fossils." In these strata replacements of small Cypridian crustaceans were discovered. "At the west end of the hills is exposed a bed of reddish sandstone." These limestone beds have been

[1] *Op. cit.* Bull. 451, pp. 23, 24, 25, 29, 95-104.
[2] *Op. cit.* Prof. Paper, plate XLV.
[3] Jones, E. L., *op. cit.* Bul. 710-d, p. 137.
[4] Ross, C. P., *op. cit.*, p. 188.

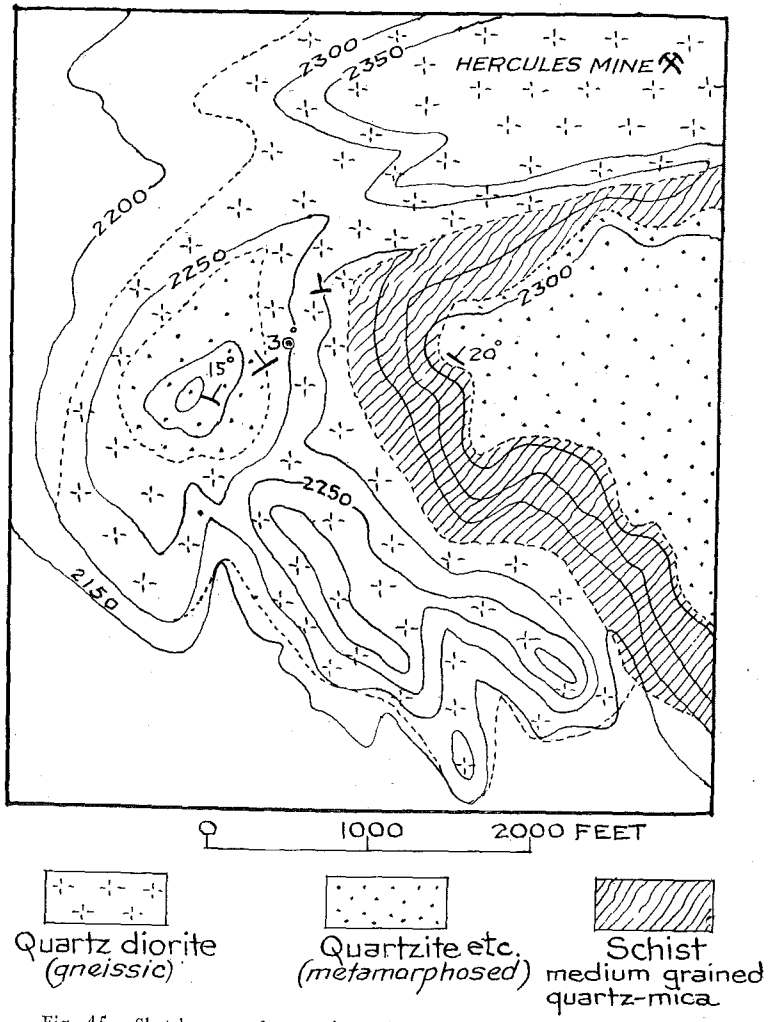


Fig. 45.—Sketch map of area about the Hercules Mine south of Wenden, by Bancroft.

found to be intercalated in the Tertiary volcanic series, having rhyolite flows and tuff below them.

Trigo Mountains.—While the Trigo Mountains consist largely of Tertiary volcanic rocks, the underlying granites and schist appear in the southern and southeastern parts of the range, the schist extending to and along the banks of the Colorado River for some distance.

Kofa Mountains.—This range, known also as the S. H. or Stone

House Mountain, consists of a thick body of Tertiary volcanic rocks lying on an eroded surface of old crystalline rocks which appear in places along its base. Its western end and part of its southern slope present very high cliffs of massive rhyolite and other volcanic rocks. The only published data relating to the range are those given by Jones[1] for the Kofa-Polaris Mining District on the western slope, and the Alamo District on the northeastern slope. He notes rhyolites and andesites with tuffs, breccias, and local thin beds of sand and gravel capped by basalt, the latter 300 feet thick. The succession amounts to at least 2,000 feet. An intrusive mass of granite is exposed west of Cemitosa Tanks, cut by diorite dikes. About Polaris schists of various kinds appear, cut in places by narrow dikes of monzonite porphyry.

Gila Mountains—Tinajas Altas Mountains.—This prominent range extends from northwest to southeast across the southwestern part of Yuma County south of the Gila River. The two mountains are separated by a gap. According to mapping by Kirk Bryan,[2] the rocks are gneiss and granite. Blake[3] has given a few details regarding the features near the Fortuna Mine and northward. Granite appears near the railroad, but gneiss preponderates to the south. The mica schist and "hornblende slate" contain intercalated beds of quartzite. Near the mine the very marked planes of schistosity dip south and southwest at angles of about 45°. Dikes of white feldspathic rocks cut the schist, and some of the higher peaks are pink granite which has been intruded in large bodies.

Antelope Hill.—This butte rises prominently above Gila River about 10 miles east of Welton. According to Ross[4] it consists of grayish arkose composed largely of granite debris. The beds dip south at a low angle and about 500 feet are exposed. They are classed as Tertiary because of their close association with the volcanic series.

Baker Peaks.—Gneiss of pre-Cambrian age has been noted by Bryan[5] in Baker Peaks.

Cabeza Prieta and Tule Mountains.—The various ridges of this group consist of pre-Cambrian granite and gneiss, overlain in places to the southward by older lava and masses of conglomerate. Bryan[6] gives the section Fig. 46 showing some of the relations.

On the west side of the range a thick body of lava and lava conglomerate 750 feet thick dips under the Lechuguilla Desert, as shown in Fig. 47. On its east side this lava rests on a very uneven surface of gneiss with irregularities several hundred feet high. Bryan mentions granites of supposed Mesozoic age in the Tule Mountains.[7]

[1]Jones, E. L., Jr., A Reconnaissance in the Kofa Mountains, Arizona: U. S. Geol. Surv., Bull. 620, pp. 155-164, 1916.
[2]Bryan, K., *op. cit.*, Bull. 730 (b.).
[3]Blake, W. P., Report of the Governor of Arizona, 1899, pp. 58-59, 1899.
[4]Ross, C. P., *op. cit.*, p. 188.
[5]Bryan, K., *op. cit.*, p. 22.
[6]Bryan, K., *op. cit.*, p. 35.
[7]Bryan, K., *op. cit.*, p. 25.

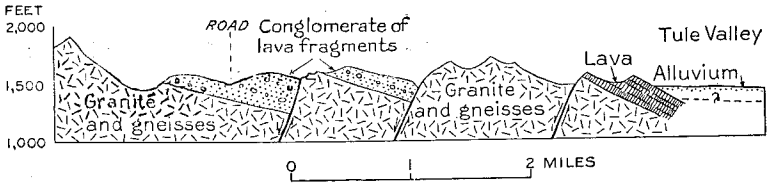


Fig. 46.—Section across part of the Tule Mountains, Arizona. (K. Bryan.)

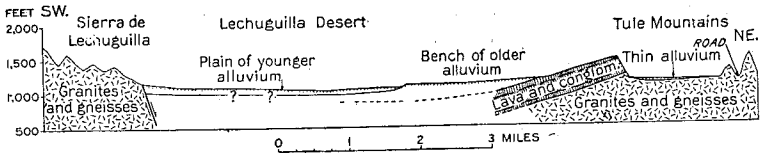


Fig. 47.—Section from the Tule Mountains to Sierre de Lechuguilla. (K. Bryan.)

Pinta Mountains and O'Neil Hills.—This long narrow range consists of granite which in the O'Neil Hills at least, Bryan[1] regards as probably of Mesozoic age.

Pinacate lava field.—This very recent flow of lava extends across the International boundary line at longitude 113° 30′. According to facts presented by Bryan,[2] MacDougal[3] and Sykes, the sheet of lava is from 50 to 100 feet thick, with sharply defined margins and many small craters on its surface. The Indians of the region have legends that their ancestors witnessed the outflow of the lava.

MARICOPA COUNTY

Vulture Mountains.—This range of hills, ridges and peaks southwest of Wickenburg consists of a variety of rocks, including extensive areas of granite and schist, probably of pre-Cambrian age. The famous old Vulture Mine is in schist cut by diabase. According to Purington,[4] the schist is exposed for about a mile east and west with strike N. 75° W., and dip 35° N. On the northern, eastern, and western sides of the mountain are overlying masses of Tertiary volcanic rocks. Vulture Peak appears to consist of a thick body of agglomerate. Tuff of light cream color occurs on the northern slope overlying agglomerates in a thick succession which dips north and includes flows of igneous rocks. Granite is prominent in the ridges east of Forepaugh, and schist in the foothills south of that place.

Gila Bend Mountains.—This irregular series of high ridges, buttes, and mesas in the western central part of Maricopa County has not been

[1]Bryan, K., *op. cit.*, p. 25.
[2]Bryan, K., *op. cit.*, p. 33.
[3]MacDougal, D. T., Across Papagueria: Am. Geog. Soc. Bull., vol. 40, pp. 705-725, 1908; Hornaday, W. T., Campfires on Desert and Lava, map, 1908.
[4]Purington, C. W., Min. and Sci. Press, vol. 94, pp. 308-310.

studied in detail. The western and southeastern ends were found to consist of granite, possibly with some gneiss and schist, and most of the central area consists of Tertiary volcanic rocks which in Woolsey Peak attain considerable thickness. On the flanks of the range are remnantal mesas capped by basalt at several levels; one of the highest and most extensive is Yellow Medicine Butte; others on the south side of the range extend in a long slope to the bank of the Gila River. At the Dixie Mine, which is on the north slope, about 15 miles northwest of Woolsey Peak, I found a succession of shales and andesite agglomerate cut by quartz monzonite porphyry(?) probably of Tertiary or possibly of Cretaceous age.

Bighorn Mountains.—Jones[1] in describing manganese mines states that the Bighorn Mountains are composed of pre-Cambrian granite, gneiss and schist overlain by Tertiary lava flows which, in the northern part of the range, are mostly red biotite andesite. He states that Black Butte, which is 20 miles S. 70° W., from Wickenburg, consists of white rhyolite tuff and pink flow-banded rhyolite, in part glassy or felsitic, overlain by black basalt and probably some rhyolite. Small seams of manganese ore occur in shear zones in the rhyolite.

Sand Tank Mountains.—These mountains consist of many ridges, buttes and mesas, in part of granite and gneiss and in part of an overlying succession of Tertiary volcanic rocks which in places are fully 2,000 feet thick. The principal features in the western part of the range, as set forth by Bryan, are shown in the cross sections Fig. 48.

Bryan mentions that in this range there are chloritic schists which have been feldspathized and there are many transitions from schist to gneiss. Fine-grained biotite granite and phyllite occur also.

Sauceda Mountains.—This range, extending into the northern part of Pima County, consists of a thick succession of Tertiary volcanic rocks locally overlain or flanked by basalts possibly of Quaternary age. Hat Mountain, a very prominent summit east of Midway, was found to be capped by a basalt remnant of this character.

Estrella Mountains.—This very rugged mountain range extends for about 25 miles, with a northwest-southeast course, along the south side of the Salt River Valley southwest of Phoenix. Its average width is 3 miles, and it rises very steeply about 3,000 feet above the plain. Its highest point is Moctexuma[2] Peak, which has an elevation of about 4,500 feet. The northeastern front is very steep. According to Schrader[3] the range consists of granite and schist cut by later granitoid rocks. Conspicuous among the latter in the southern part of the range is a biotite granite. A granitic aplite occupies an area of 5 or 6 square miles between North Peak and the Webb Mine. Coarse-grained granite or pegmatite occurs in large dikes. Diabase dikes were also noted.

[1]Jones E. L., Jr., *op. cit.*, Bull. 710d, p. 137.
[2]The original or Mexican spelling is here followed.
[3]Schrader, F. C., Manuscript Report on the Gila River Indian Reservation, in U. S. Geological Survey.

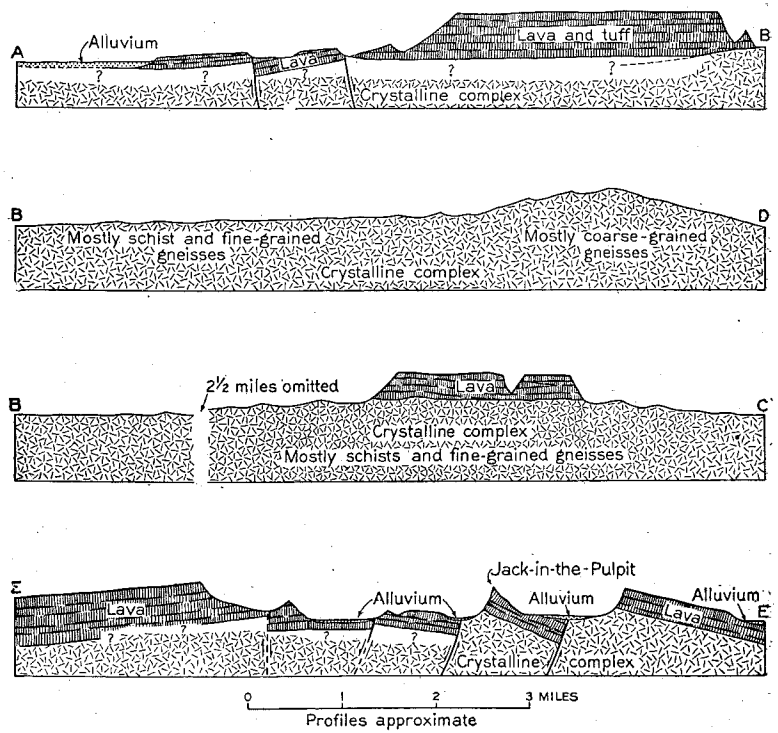


Fig. 48.—Sections across the western part of the Sand Tank Mountains. Section A-B is north to south and E-E crosses it at right angles. B-D extends northwest from B of the section A-B and B-D extends northeast from B of the section A-B.

GILA COUNTY

Sierra Ancha—Salt River Region.—The high and very rugged mesa known as the Sierra Ancha is one of the most prominent topographic features in the central part of the State. Its highest point, Aztec Peak, has an altitude of about 7,400 feet. The sierra consists largely of a thick succession of the formations of the Apache group lying nearly horizontal. Large bodies of diabase are intruded in the strata at various horizons. It presents a very steep front to the Tonto Valley on the west and to the Salt River Valley on the south. Cherry Creek has cut a canyon about 4,000 feet deep along its east side, separating it from another high, rugged plateau which culminates in Sombrero Butte. Farther east this plateau is deeply trenched by Canyon Creek in a canyon nearly as deep as that of Cherry Creek. Sections showing some of the features of this region are given in Fig. 49, and the distribution of formations is shown in the map in Plate 65.

The basement rocks in the region are pre-Cambrian granite, schist

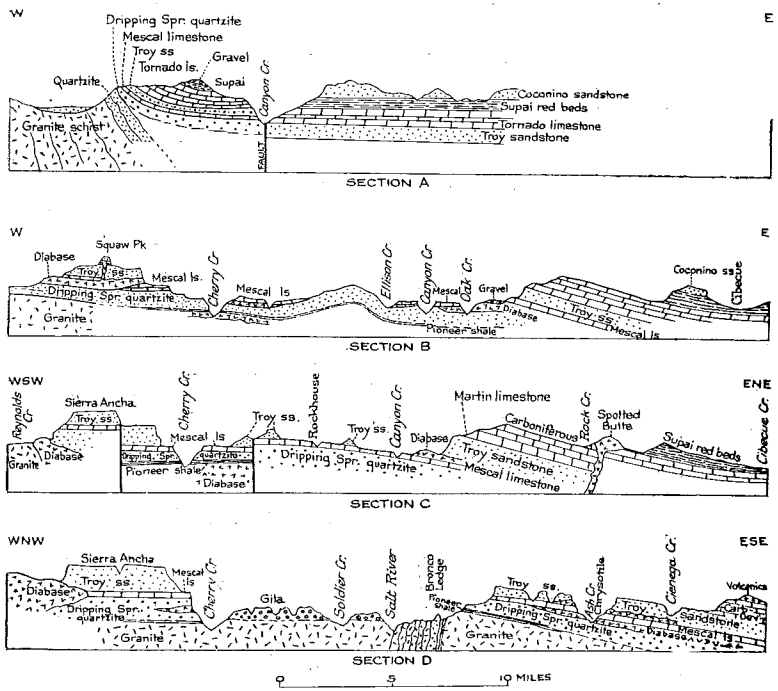


Fig. 49.—Sections across the Sierra Ancha—Canyon Creek district in Gila and Coconino counties, Arizona, along lines shown on map, Plate 65.

and quartzite, the first greatly predominating. Exposures are extensive in the valley of the Salt River from Pinal Creek to a mile or two above Canyon Creek and extending up the latter for about 7 miles, also in the Pleasant Valley area about Young and in the deeper valleys of the Tonto drainage north of that place. Schist outcrops on the south side of the Salt River and south and north of Young. Quartzite is a notable feature in the great "Broncho Ledge" (Q to Q) near the Salt River and in a ridge extending from Q to Q north of Young. The Broncho Ledge was examined west of Haystack Butte, where I found the relation shown in Fig. 50. It is a very prominent ledge of white quartzite dipping steeply to the east and extends from Butte Creek to beyond Horseshoe Bend, finally disappearing beneath volcanic rocks. This quartzite is part of a succession included in the Pinal schist.

The rocks of the Apache group constitute the great mesas of the Sierra Ancha, the wide plateau to the east of that sierra, the walls of the deep canyons of Cherry, Canyon and Ash creeks, Salt River Canyon above the mouth of Canyon Creek, the western front of Natanes Plateau, and the Timber Camp and Seven Mile Mountains. The strata dip at angles that are mostly low and to the eastward. They are faulted

to some extent and invaded by much diabase mainly in the form of thick sills, with stocks and great local thickenings. One of the latter constitutes Haystack Butte as shown in Fig. 50. The several formations are well defined in most parts of the area, comprising Scanlan conglom-

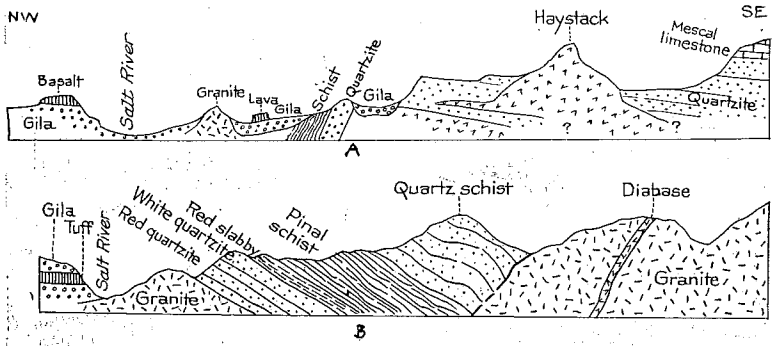


Fig. 50.—Sections of Broncho Ledge west of Haystack Butte. Section A, through Haystack Butte; section B, about 2 miles south of section A.

erate, Pioneer shale, Barnes conglomerate, Dripping Spring quartzite, Mescal limestone, and Troy quartzite. In many places certain thin layers of the Mescal limestone have been converted into asbestos (chrysotile) in connection with the great diabase intrusions. This mineral has been mined extensively at Chrysotile, on the south front of the Sierra Ancha, and on the Salt River near the mouth of Cibecue Creek. Many small prospects have been opened along Salt River and Cherry Creek and its branches, and on Bear Creek 20 miles north-northeast of Rice. Some relations of the chrysotile deposits on the south end of the Sierra Ancha have been described by Diller[1] and Bateman [2] and a brief description of the rocks has been given by Ransome.[3]

I found that the Mescal limestone extends northward up the valley of Canyon Creek and is also present on the head of Cherry Creek, and westward to Haigler Creek and Gordon Canyon, where, however, it is thin, highly siliceous and in part locally replaced by iron ore. The formations of the Apache group were examined at various points in the valley of Cherry Creek, where they constitute high canyon walls and many ridges and buttes. Some of the relations are shown in sections B, C, and D, of Fig. 49. Above the great fault west of Sombrero Butte the Mescal limestone constitutes prominent terraces on both sides of the canyon, where it has been extensively prospected for asbestos. It is in-

[1]Diller, J. S., Asbestos in 1917: U. S. Geol. Surv. Mineral Resources of United States 1917, Pt. 2, pp. 198-199, 1918.

[2]Bateman, A., An Arizona Asbestos Deposit, Econ. Geol., vol. 18, pp. 663-683, 1924, with discussion by E. Sampson, Ibid., vol. 19, pp. 386-388.

[3]Ransome, F. L., *op. cit.*, pp. 153-154.

vaded by sills of diabase and locally overlain by a vesicular basalt flow of Apache age. The Troy and Dripping Spring quartzites are great cliff makers, and the latter is underlain by Barnes conglomerate and Pioneer shale and invaded by large sills of diabase.

The southern end of the Sierra Ancha presents to the south a line of high cliffs, high up in which there is a conspicuous white streak due to the refuse from the asbestos mines. These mines are in the ledges of Mescal limestone uplifted by thick sills of diabase and overlain by a flow of basalt. The sections in Fig. 51 show some of the relations in this vicinity.

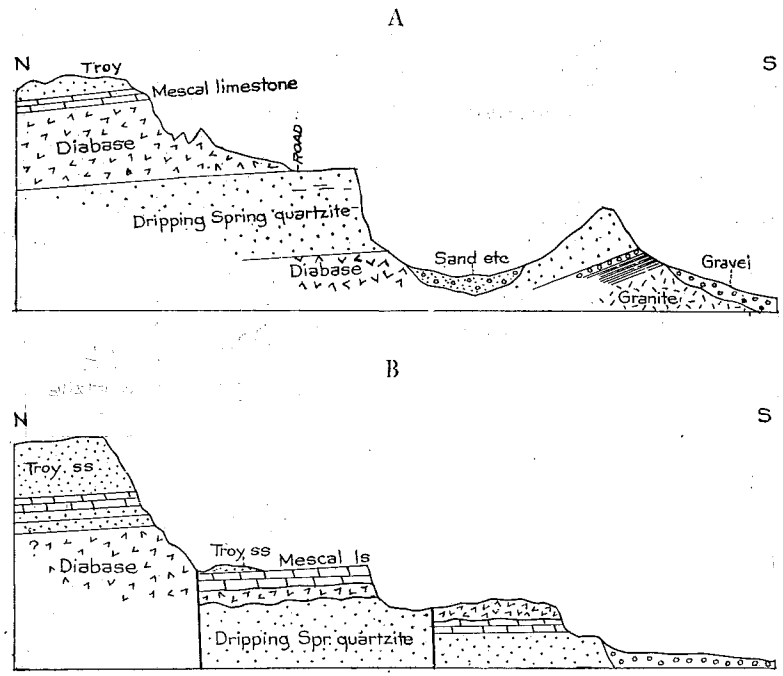


Fig. 51.—Sketch sections in the southern end of the Sierra Ancha, 30 miles northwest of Globe, Arizona. Section A, through asbestos workings; Section B, through faulted blocks 1 to 2 miles east of the asbestos workings. Note: A sheet of basalt (lava) separates the Mescal and Troy in these exposures.

In the central part of the Sierra Ancha there are great masses of diabase mostly intruded in or at the top of the Dripping Spring quartzite. This diabase extends continuously through the range to the foot of the rise to Juniper Flats north of Carr's Ranch. In this vicinity and northward to Pleasant Valley the rocks of the Apache group have the relations shown in Fig. 52.

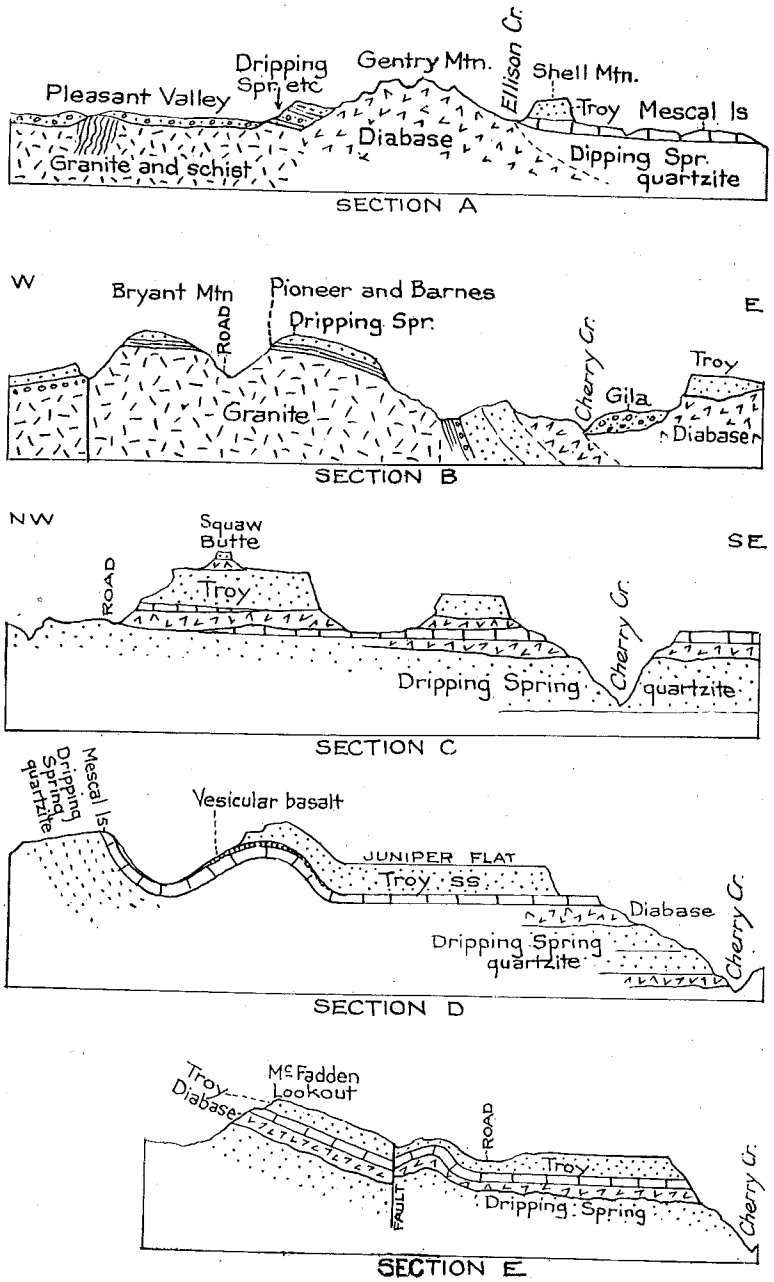


Fig. 52.—Sketch sections in the central part of the Sierra Ancha. A, Pleasant Valley to Shell Mountain; B, through Bryant Mountain; C, through Squaw

Plate 69a. The great canyon of the Gila River through the Mescal Mountains. Looking south-southwest from a point 1 mile southwest of Mescal Spring. Cliffs are Dripping Spring and Troy quartzites. Foreground, granite; distant mountains, Tornado limestone.

It will be seen from these sections that there is considerable complexity in the structure, due to faulting and igneous intrusion. The Mescal limestone outcrops at many places, extensively overlain by the flow of vesicular basalt. Barnes conglomerate and Pioneer shale appear in many sections, the latter in part represented by arkosic sandstone. The

relations of the formations of the Apache group in the region north of Pleasant Valley were examined with considerable care. It was found that from near Haigler Creek northwestward they lie on or abut against a massive quartzite believed to be of pre-Cambrian age. The Mescal limestone is thin and highly siliceous, but exposures of characteristic beds were found on the head of Cherry Creek, on Haigler Creek, at the falls of Colcord Creek (see Pl. 67a), and in Gordon Canyon. The Troy quartzite is conspicuous, but considerably thinner than in the region south. The upper part of the Dripping Spring quartzite is a slabby sandstone mostly of dark brown or dark gray color. The Pioneer

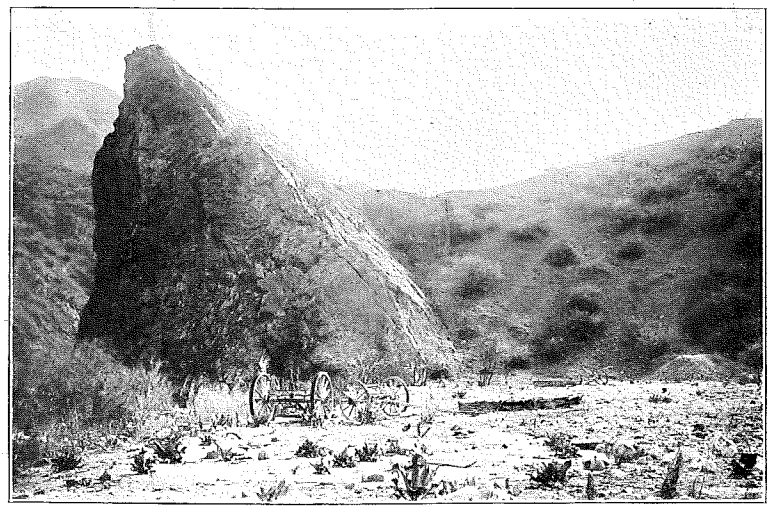


Plate 69b. Fault on west side of Mineral Creek ½ mile south of Ray, in which Pinal schist is thrust up on Dripping Spring quartzite. Looking south. Photo by Ransome.

shale and Barnes conglomerate are well exposed in buttes and arroyos 4 miles north of Young.

In Gordon Canyon the Mescal consists of siliceous limestone alternating with massive shale and many silica layers, in all about 100 feet thick. It is separated from the overlying sandstone by a thick sill of diabase, which is coarsely crystalline up to the contact. It is not unlikely that this sandstone is Tapeats and lies unconformably on the diabase, etc. This idea is strongly suggested by relations on the ridge south of the mouth of the canyon of Haigler Creek, where the sandstone, only 30 feet thick, dips at a lower angle than the underlying Mescal, which also is thinner than elsewhere, apparently by erosion of its top. Similar overlap is suggested in ridges on either side of Gordon Canyon.

On Haigler Creek the lower quartzite is seen lying on the granite on

an erosion plane dipping east at an angle of about 40°. The lower half consists of coarse conglomerate of round and subangular boulders of quartzite up to 6 inches, and a few of them are 3 feet in diameter, grading up into 150 feet of hard gray quartzite which constitutes an upper member. The dip is about 30°. On this quartzite lie slabby beds

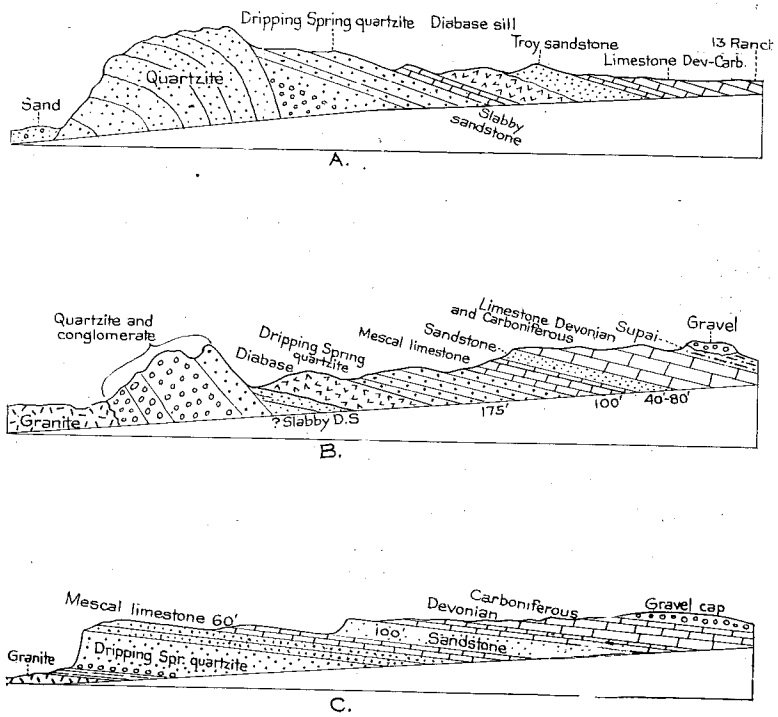


Fig. 53.—Sections showing relations of formations of Apache group from Gordon Canyon to the upper valley of Cherry Creek. A, Gordon Canyon; B, Haigler Canyon; C, upper valley of Cherry Creek.

of sandstone of Dripping Spring aspect, dipping about 12°. The contact apparently shows an irregular erosion surface, but there is very little notably coarse material in the overlying beds. The sill of diabase is thick and irregular and is overlain by typical upper members of the Dripping Spring. The Mescal limestone, 100 feet or more thick, makes a falls in Colcord Creek (see Pl. 67a) not far above the junction with Haigler Creek. The limestone consists of characteristic alternations of thin beds of limestone and silica, and has a member of red shale and

fine sandstone in its middle. The overlying sandstone (Troy or Tapeats) is only 30 feet thick and is succeeded by Devonian (probable) and Carboniferous limestones.

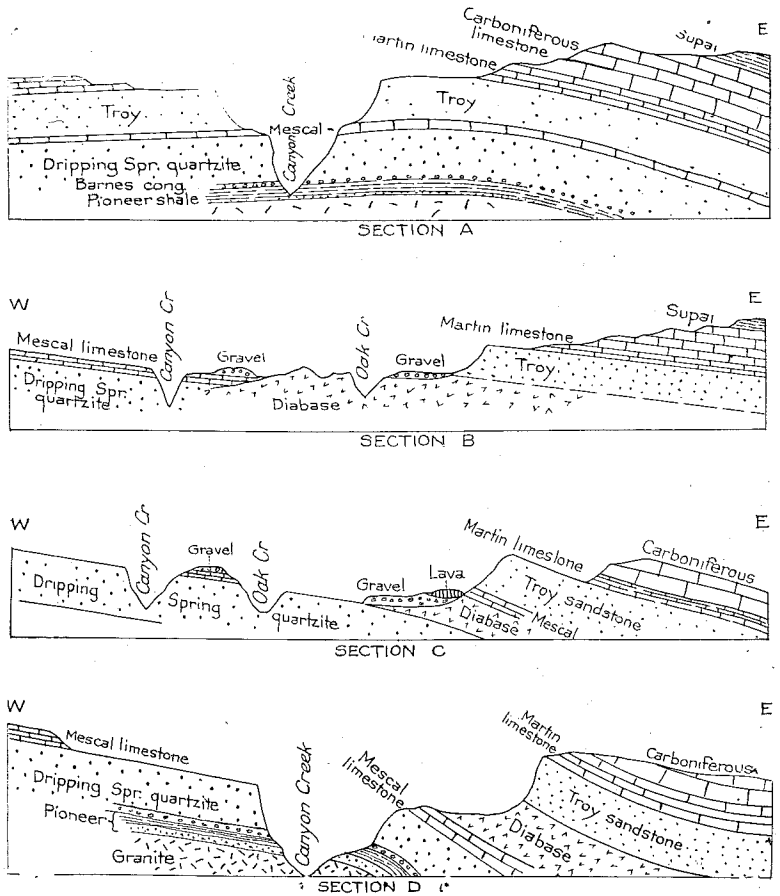


Fig. 54.—Sketch sections across the valley of Canyon Creek. A, about 5 miles northwest of Oak Creek Indian Village; B, near Oak Creek Indian Village; C, near Coconino-Gila County line; D, ten miles northeast of Sombrero Butte.

Canyon Creek cuts deeply into the formations of the Apache group for many miles, finally in the last seven miles of its course trenching the underlying granite. The principal relations are shown in the three upper sections of Fig. 54. At a point near where the creek reaches the granite the section is as shown in Fig. 49. The Mescal limestone forms a shelf, mostly cut into detached knobs, all along the

east side of the canyon, but in the region northeast of Rock House it forms the valley floor for a short distance. Much diabase is intruded, at one place to a thickness of 300 feet, and the easterly dips are steep for some distance. In this region and farther up the valleys of Canyon and Oak creeks there are many remnants of gravel and boulder terraces, in a few cases overlain by basalt of Quaternary age. Near the Indian villages on Oak Creek the intrusive masses of diabase thicken greatly and have considerable prominence topographically, as shown in section B, Fig. 54. In this region and southward considerable iron ore develops in the upper part of the Mescal limestone, which has been prospected to some extent. The upper part of the formation is highly siliceous and hard, so that it spreads out widely on some of the mesas. At a point 5 miles northwest of the Oak Creek Indian Settlement the canyon deepens greatly, mainly because of a cross fault, and also of a rise of the strata to the northward, which finally reveal an excellent section of Barnes conglomerate and Pioneer shale, as shown in section A, Fig. 54. The shale is red and purplish-red with characteristic white spots. About 100 feet are exposed down to a massive hard sandstone member, probably not far above the base. The underlying pre-Cambrian rocks are not exposed, but a sill of diabase appearing in the base of the Dripping Spring quartzite at one point in the canyon might easily be mistaken for a schist. The Mescal limestone, 60 feet thick, is very siliceous, scarcely any limestone remaining in it, but the characteristic cherty layers continue. In the Troy quartzite not far above its base is a conspicuous member of white sandstone which appears in many canyon walls in this general region and notably on Shell Mountain, a prominent butte about 10 miles east-southeast of Young. A fault, which crosses Canyon Creek about 15 miles northeast of Young, or less than 2 miles below Ramer (now Wallace) Ranch, cuts off the formations of the Apache group with relations shown in section A in Fig. 49. At one point the fault passes along the east slope of the canyon and the Mescal limestone with its iron ore bed is in contact with the Martin limestone. A short distance south of this place, or down the valley, about 20 feet of the top beds of the Troy are revealed below the Martin limestone on the down-dropped block on the east side of the fault. This limestone about 60 feet thick is overlain by about 230 feet of gray limestones and shales with abundant Pennsylvanian fossils, which extend to the base of the red beds of the Supai formation at Ramer Ranch. No Mississippian was found here and apparently it is also absent or very thin in the head of the Tonto basin to the west.

Chrysotile region.—The exposures of Mescal limestone in Ash Creek near Chrysotile, and on Salt River and its branches near the mouth of Cibecue Creek, show about 200 feet of beds, mostly massive gray to blue-gray limestone, penetrated by sills of diabase. Near Chrysotile the overlying flow of vesicular basalt is thick and extensive. Some of the relations at this place are shown in Fig. 55. A widespread mantle of

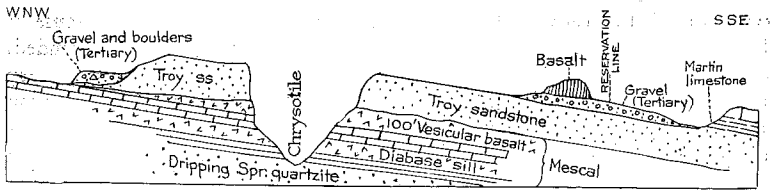


Fig. 55.—Sketch sections across Ash Creek and southeastward at Chrysotile.

gravel overlies the Troy quartzite in this vicinity and remnants of it occur on many of the high lands adjoining the Salt River, Cibecue and Carrizo canyons, part of them preserved by flows of basalt. A large mass of the gravel constitutes the summit of a notably high butte on the ridge on the south side of Salt River a short distance above the mouth of Canyon Creek. This gravel deposit also exists in places under the great igneous flows of Natanes Plateau. Near the Regal mine, on the south side of the deep gorge of Salt River just below the mouth of Cibeque Creek, the formations of the Apache group present the features shown in Fig. 56.

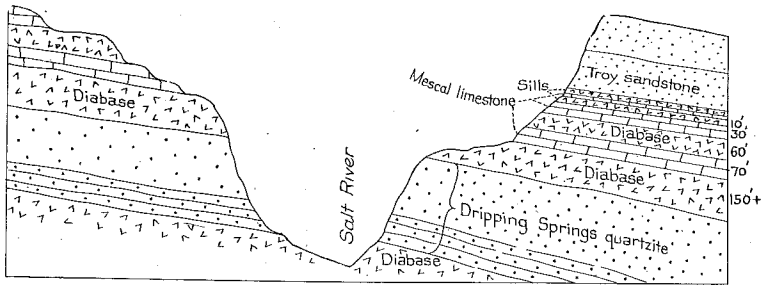


Fig. 56.—Sketch section across Salt River Canyon near the Regal Mine, 6 miles north-northeast of Chrysotile, Arizona. Looking east.

Western part of Sierra Ancha.—Ransome[1] examined various portions of the western slope of the Sierra Ancha and obtained many data as to the relations of the formations of the Apache group. In a section measured on Workman Creek on the west slope of Sierra Ancha, a few miles northeast of Carr's Ranch, he found that the great sill of diabase at the latter place was overlain by about 250 feet of limestone (Mescal), capped by about 50 feet of vesicular basalt. The strata in this section are represented in Fig. 57. In Greenback Valley, about 9 miles west-

[1]Ransome, F. L., *op. cit.*, Prof. Paper 98-K, pp. 153-157.

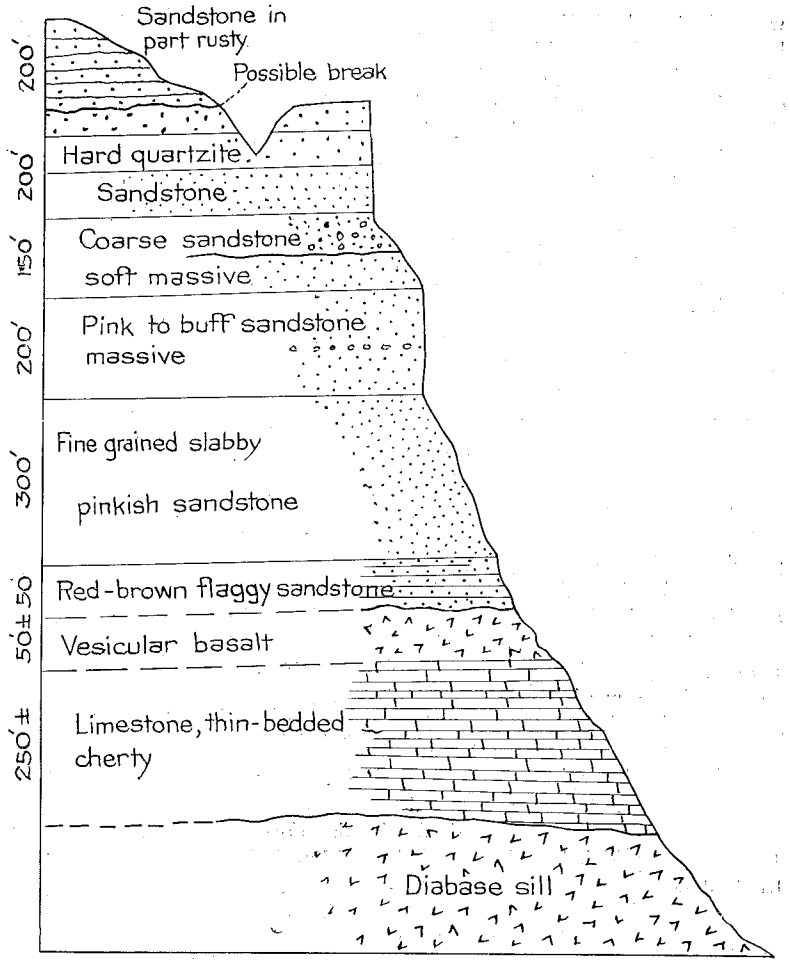


Fig. 57.—Columnar section of rocks on west slope of Sierra Ancha on Workman Creek, after Ransome. The limestone is Mescal.

northwest of Carr's Ranch, Ransome found Dripping Spring quartzite invaded by many sills of diabase. The deep gorge of Sallymay Creek exposes the basal beds lying on coarse granite. They consist of coarse Scanlan conglomerate, 6 feet thick, overlain by 150 feet or more of quartzitic arkose with thin shale partings believed to represent the Pioneer. A diabase sill at the top of these beds interrupts the section. The summit of Greenback Mountain is capped by Mescal limestone, and conglomerate like Barnes was observed on the north slope of Chubb Mountain. On the northwestern part of the range, 4 miles north-north-

west of Greenback Valley, many faults were noted in beds lying nearly horizontal and comprising Scanlan conglomerate, 5 to 6 feet, Pioneer shale and interbedded quartzite, probably 200 feet, and Dripping Spring quartzite 500 feet. The underlying granite is exposed in places and there are many sills of diabase. Some of the high plateau remnants are capped by cherty limestone (Mescal).

In Delshay Basin near latitude 34°, at the northwestern end of the Sierra Ancha, Ransome found an area of sericitic and greenstone schists cut by dikes of granite porphyry and rhyolite, a bold ridge of schistose rhyolite forming the west wall of the basin. Pre-Cambrian quartzite occurs, including a large lens of magnetitic quartzite, and lying southeast of it is a zone of schistose conglomerate containing much schist material and apparently underlain by granite. The rocks of the Apache group consist of the following strata: A capping of Mescal limestone, with much shale, rusty sandstone and chert, possibly 225 feet in all; Dripping Spring quartzite, in part slabby, about 400 feet; probable Barnes conglomerate 2 feet; Pioneer shale represented by red and brown sandstone with layers of spotted red shale in its lower part, 400 feet; and basal conglomerate (Scanlan), 3 feet or more, lying on granite.

Globe Hills and Apache Mountains.—The Apache Mountains are a prominent ridge constituting a portion of the high divide between the Gila and the Salt River drainage, lying north and east of Pinal Creek. Apache Peak is the culminating summit with altitude of about 6,100 feet, and Chromo Butte, altitude about 5,700 feet, is another notable feature. The Globe Hills are a group of irregular ridges and knobs on the slope toward Pinal Creek. They are well known because of the great deposits of copper ore which are worked in mines in the northern part of Globe. The geologic features of the mineral district have been described in detail by Ransome,[1] and the following brief statement is from his report.

Some of the relations are shown in the greatly generalized section, (Fig. 58) to which have been added the Mescal limestone and overlying basalt flow.

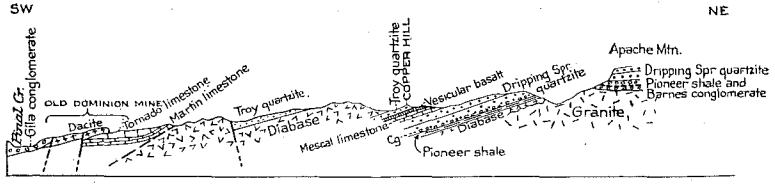


Fig. 58.—Generalized sketch section through the Globe Hills north of Globe, Arizona.

[1]Ransome, F. L., Geology of the Globe District, Arizona: U. S. Geol. Surv., Prof. Paper 12, 168 pages, plates, maps, 1903, and U. S. Geol. Surv., Folio 111, 1904.

The oldest sedimentary rocks exposed in the area mapped by Ransome are the formations of the Apache group, but a short distance north on the slopes of Apache Mountain the underlying granite appears. The Apache group consists of 800 feet of sandstone and shale with large intrusive sills of diabase. Later observations have shown that the Mescal limestone, with its overlying sheet of vesicular basalt, have the relations shown in Fig. 58. The overlying Troy sandstone is present and also the succession of Dripping Spring quartzite, Barnes conglomerate, Pioneer shale, and the basal Scanlan conglomerate, but their continuity is broken by numerous faults. In places near Copper Gulch and adjoining ridges the Martin limestone and Tornado limestone appear in small areas, also delimited by faults. A small wedge-shaped mass of these limestones occurs along the great fault a short distance south of Richmond Basin. Much Gila conglomerate extends along the lower slopes and through some of the higher divide saddles up to an altitude of about 4,800 feet. Along the slopes north and east of Globe are flows of dacite with more or less tuff, of Tertiary age. The formations are remarkably uniform in their characteristics through this area but there are variations in thickness, and the lower part of the Pioneer consists of 150 feet or more of

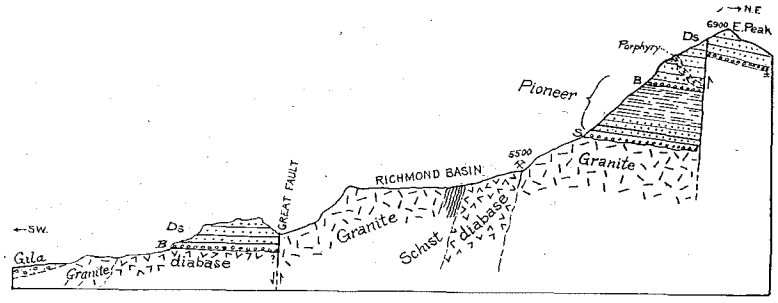


Fig. 59.—Section from Apache Peak southwestward. Ds, Dripping Spring quartzite; B, Barnes conglomerate; S, Scanlan conglomerate. By N. H. Darton.

quartzite. The typical red shale is about 200 feet thick, and is overlain by about 15 feet of Barnes conglomerate. These features are well exhibited near Apache Peak, as shown in Fig. 59. The Dripping Spring and Troy quartzites here are less thick than in the Dripping Spring Mountains, the Sierra Ancha and on the Salt River.

I found a fine exposure of the Mescal limestone and about 100 feet of overlying vesicular basalt in the railroad cut and nearby slopes a short distance northeast of Copper Hill. The basalt is overlain by Troy quartzite, at the base of which is a conglomerate containing fragments and pebbles of underlying basalt, cherty limestone and quartzite.

Chromo Butte, on the eastern extension of the Apache Mountains, is an outlying mass of Tertiary igneous rocks. A branch ridge, extending

southeast and finally reaching the railroad in Aliso Creek valley, 13 miles east of Globe, consists of rocks of the Apache group, in places overlain by Martin and higher limestones. These rocks are well exposed near and north of the railroad and automobile road 1½ miles east of Gilson, where I found the relations shown in Fig. 60.

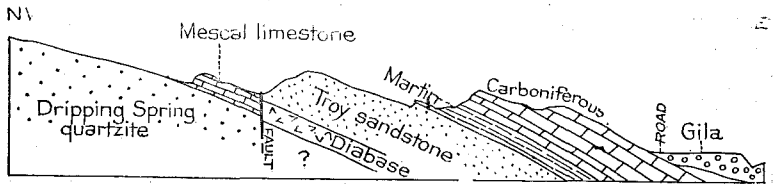


Fig. 60.—Section of ridge northeast of Gilson, east of Globe, Arizona.

The Mescal limestone is exposed in regular succession at two points on the east side of Chromo Butte. Its thickness is about 200 feet, and while part of it presents alternations of thin silica layers and limestone, other parts are massive blue limestone. A section in the arroyo just above the old Champion Mill, or about one mile southeast of Chromo Butte, has features shown in Fig. 61. This section is somewhat incom-

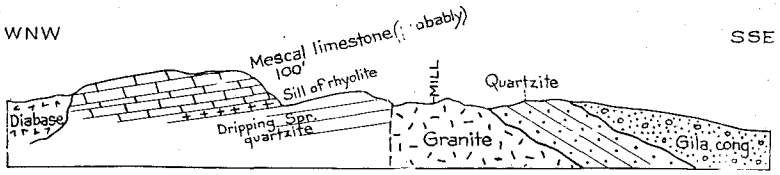


Fig. 61.—Sketch section along Champion Arroyo 10 miles northeast of Globe, Arizona.

plete, probably owing to faulting. In the deep gorge about 3 miles northeast of Chromo Butte, on slopes of Seven Mile Mountain, and northward along the western margin of the San Carlos Indian Reservation, there are exposures of Scanlan conglomerate, Pioneer shale, Barnes conglomerate, and Dripping Spring quartzite. There is more or less arkose at the base of the Pioneer shale and some thin beds of sandstone are included in the red shale. The easternmost ridge of Timber Camp Mountain near the reservation boundary line, about 5 miles southeast of Chrysotile, presents the structure shown in Fig. 62.

Natanes Plateau.—The wide divide lying south of the valley of the Blue River in the eastern part of Gila County and northern part of Graham County is known as the Natanes Plateau. It consists of a thick succession of lavas which flowed from outlets in the White Mountains. Under these lavas to the westward appear the Carboniferous and Devonian

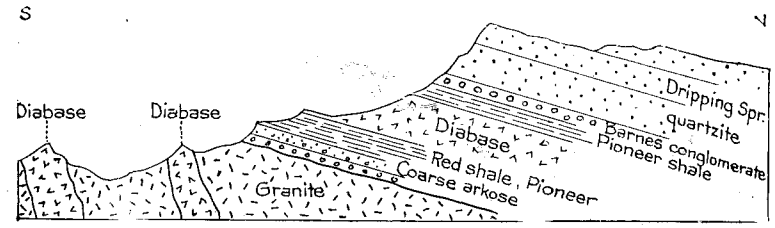


Fig. 62.—Sketch section of the eastern ridge of Timber Camp Mountain, 5 miles southeast of Chrysotile.

limestones and underlying Apache group. The limestones are conspicuous on the north side in the Black River Valley, and the Apache rocks appear extensively on the west front of the plateau from Blue Creek to Sycamore Canyon and extending thence northward to Salt River. A few features of the south front of the plateau are shown in the sections in Fig. 63.

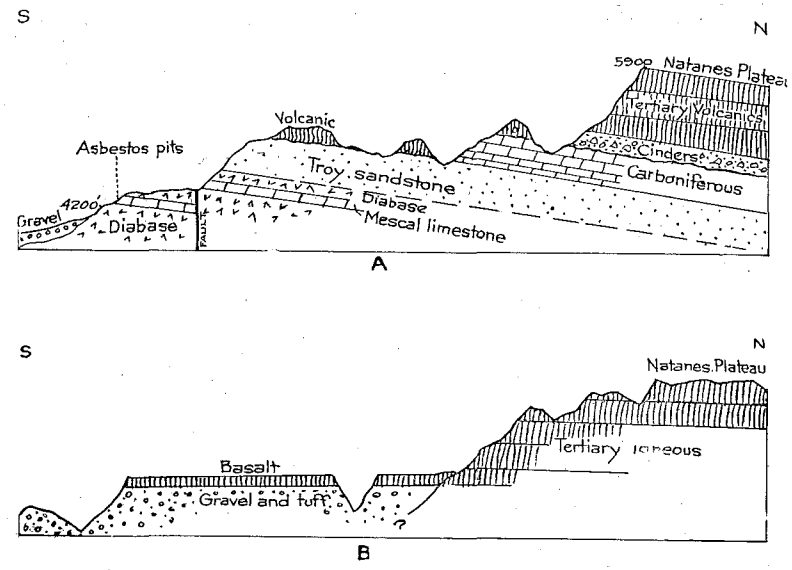


Fig. 63.—Sketch sections of the south front of Natanes Plateau north of Rice. A, near Bear Creek; B, north from the San Carlos River, northeast of Rice.

At the place where the south face of the plateau is traversed by the automobile road from White River Agency to Rice, the Troy quartzite and overlying limestone are well exposed, broken by a prominent fault, as shown in Fig. 64.

This section also shows the abrupt descent to the valley of Sycamore

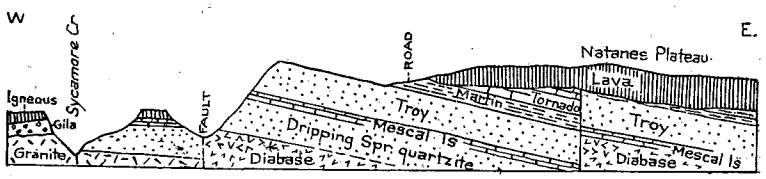


Fig. 64.—Sketch section of the west front of Natanes Plateau south of the Sawmill, on the road to Rice.

Creek, where there is another fault, also with downthrow on the west side.

Pinal Mountains.—This range extends northward from Pinal Creek east of Pinal Peak to the Salt River Canyon west of the mouth of Pinal Creek. The very important mining district about Miami lies in its central part. The geology of the greater part of this range has been described by Ransome.[1] The principal structural feature of the central area are represented in sections A and B of Fig. 66, copied from Plate 2 of Professional Paper 12.

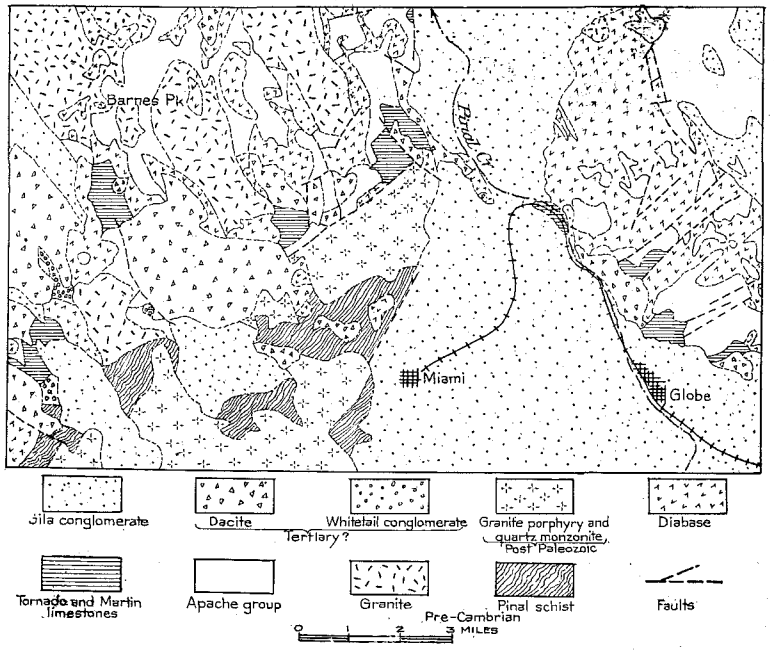


Fig. 65.—Geologic map of part of the Pinal Mountains and the Globe Hills, after Ransome.

[1]Ransome, F. L., *op. cit.*, Prof. Paper 12, folio 111, and Prof. Paper 115.

The higher southern part of Pinal Mountain consists of great bodies of granite and quartz mica diorite of pre-Cambrian age, penetrating the Pinal schist. Both Mt. Madera and Pinal Peak are diorite. As shown in the cross sections, the sedimentary rocks are mostly of the various formations of the Apache group, penetrated by huge sills of diabase and overlain by limestones of Devonian and Carboniferous age. Considerable dacite of Tertiary age occurs and on the flanks of the ridges is much Gila conglomerate. There is extensive faulting so that the formations occur in blocks of various sizes. A few miles north of Miami the beds are cut by some large bodies of granite and quartz monzonite now believed to be of Mesozoic age. The formations of the Apache group are well exposed at many places. The section in Fig. 67 passing through Barnes Peak shows the relations of beds up to the Mescal. At this place the Scanlan conglomerate is 1 to 6 feet thick, the Pioneer shale 200 feet, the Barnes conglomerate (type locality) 10 to 15 feet, the lower massively-bedded member of the Dripping Spring quartzite 150 feet, and the upper, more slabby member 275 feet. The Troy quartzite and Mescal limestone were not separately mapped in this area.

The northern end of the Pinal Mountains was examined near the Globe to Phoenix automobile road ("Apache Trail"), which crosses the range from the valley of Pinal Creek. The sections in Fig. 68 show the principal features in this region, as well as the

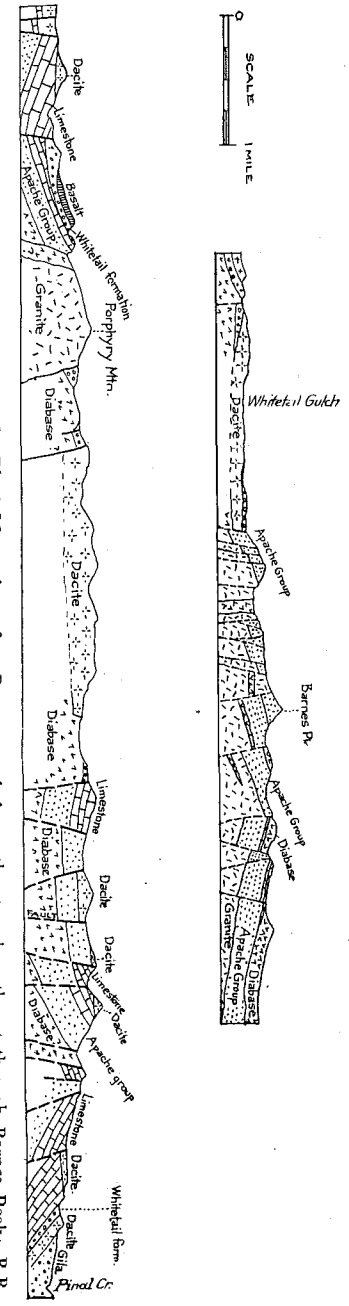


Fig. 66.—Sections across the central part of the Pinal Mountains, after Ransome. A-A, northeast and southwest through Barnes Peak; B-B, northeast and southwest through Porphyry Mountain and near Sleeping Beauty Peak.

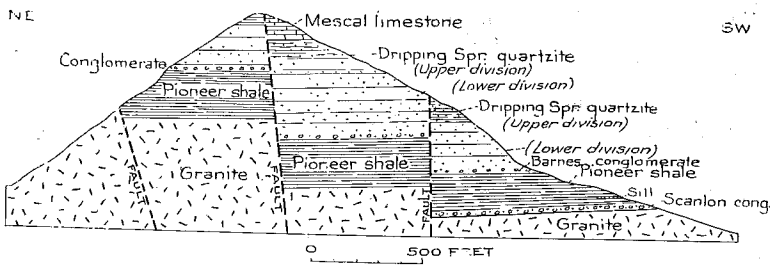


Fig. 67.—Section northeast to southwest through Barnes Peak; 7 miles northwest of Miami, Arizona, after Ransome.

relations of volcanic rocks on the east side of Pinal Creek. The exposure of rocks of the Apache group is extensive and many of the features are visible on the north side of the canyon by which the road ascends from Pinal Creek. The red Pioneer shale is well characterized, overlain by typical Barnes conglomerate. The Mescal limestone is at least 150 feet thick and there is present about the same amount of Troy quartzite overlain by Martin shale containing Devonian fossils.

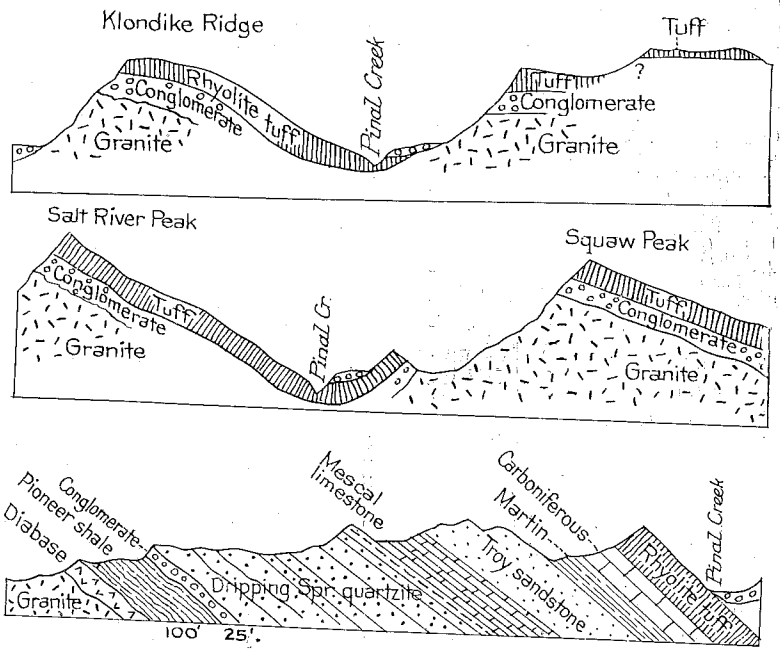


Fig. 68.—Sections of the northern end of the Pinal Mountains (north of the Globe-Phoenix road). Section 1, through Klondike Ridge. Section 2, through Salt River Peak. Section 3, near the main road.

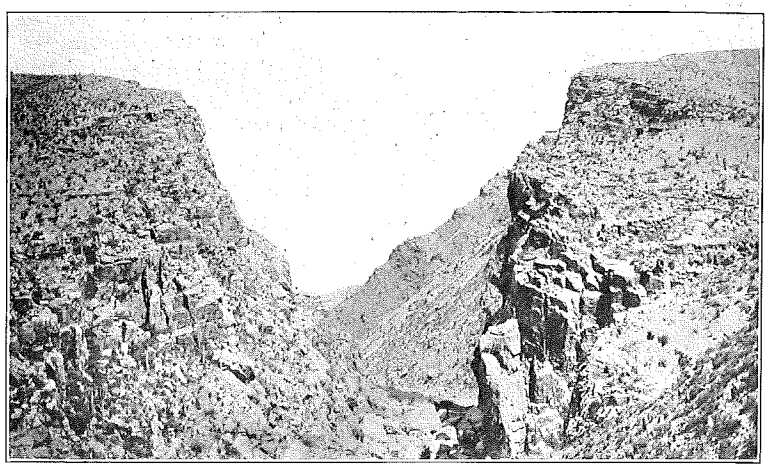


Plate 70a. Ledge of Troy quartzite at Needle's Eye, canyon of the Gila River 23 miles southeast of Globe, Arizona. Looking east to ledges of underlying Mescal limestone and Dripping Spring quartzite.

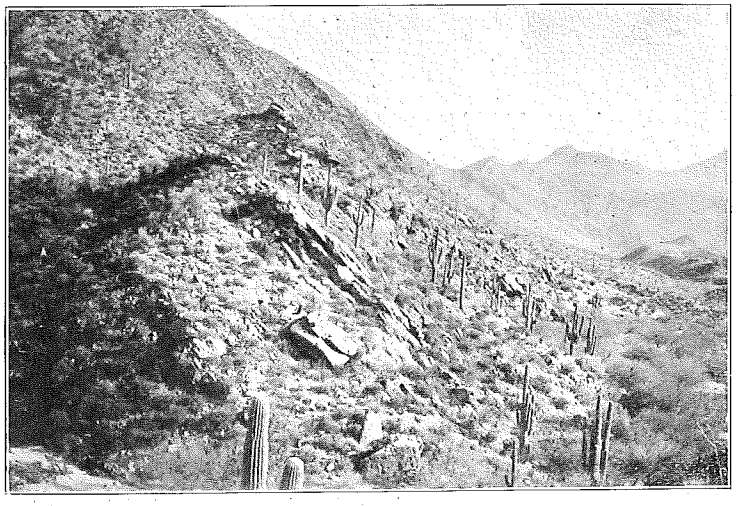


Plate 70b. Limestone conglomerate on Tornado limestone 3 miles north of Tuttle Ranch, Christmas Quadrangle. Looking north.

Mazatzal Mountains.—This prominent ridge extends for 40 miles with nearly due north-to-south course along the western boundary of Gila County. The great Roosevelt Dam on the Salt River is in the deep gorge at the south end of the mountain. South of this gorge Two Bar Ridge, a mountain with the same structure, continues southward. Data as to the geology of the range have been recorded by Ransome[1] and by Wilson.[2] Ransome states that Four Peaks consists in part of a medium grained, gneissic, quartz-mica diorite, and northward for some distance the rocks are mostly granitic. The prevailing rock along Sycamore Creek, on the west side of the range, is rather coarse porphyritic granite believed to be pre-Cambrian in age. In many flat-topped buttes this granite is overlain by tuff capped by lava, principally basalt, and there are also dark dikes apparently of the same material. On the north slope of Mount Ord the granite is succeeded by a belt about 5 miles wide of schistose and slaty rocks trending northeast-southwest and crossing the range obliquely. To the southeast, in Tonto Basin and north of the north end of the Sierra Ancha, this area of schistose rock is probably at least 15 miles wide. To the southwest the schists are exposed for only a mile or two beyond Sycamore Creek, where they are overlapped by Tertiary lavas. The line between schist and granite passes a short distance north of Mount Ord and crosses Tonto Creek near the mouth of Gun Creek. Some schistose rhyolite is included. The northward boundary crosses the Mazatzal range just south of the quartzsite area of Mazatzal Peak. This quartzite is accompanied by some conglomerate and shale and makes up the northern part of the range. Some of the quartzite is infolded with the schist, but the conglomerate associated with the larger bodies such as make up Mazatzal Peak contains flakes of schist showing that it at least is younger than the schist. On the Middle Fork of Deer Creek, on the east slope of Mazatzal Peak, this conglomerate is 87 feet thick and lies on rhyolite oxidized to a red color probably a part of the schist complex and having the same N. 33° E. strike. The conglomerate grades up into quartzite which appears to be more than 1,400 feet thick. On the North Fork of Deer Creek were found the features shown in Fig. 69.

The quartzite on the east side appears to be flexed into an arch and faulted against shale to the west. This shale, of which about 1,000 feet is exposed, is somewhat dolomitic and near the top grades into quartzite, pebbly at base, which extends to the summit of the mountain.

Wilson[3] gives further details regarding the quartzite and proposes for it the name Mazatzal. Its area in the northern part of the range is about 40 square miles, and other outcrops occur near Natural Bridge

[1]Ransome, F. L., Quicksilver Deposits of the Mazatzal Range, Arizona: U. S. Geol. Surv., Bull. 620-f, pp. 111-112.

———, Some Paleozoic Sections in Arizona and their Correlation: U. S. Geol. Surv., Prof. Paper 98-k, pp. 157-158, 1916.

[2]Wilson, E. D., Proterozoic Mazatzal Quartzite of Arizona: Pan Amer. Geol., vol. 38, pp. 299-312, 1922.

[3]Wilson, E. D., *op. cit.*, pp. 301-305.

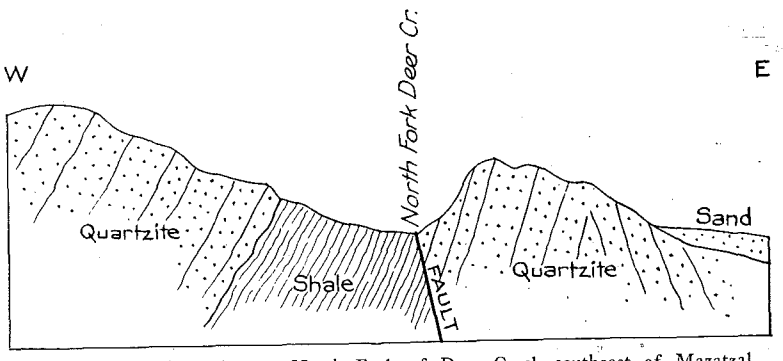


Fig. 69.—Sketch section on North Fork of Deer Creek southeast of Mazatzal Peak. (Ransome.)

and Del Rio. A map which is reproduced in Fig. 70 shows some of the relations. The following section is given at North Peak:

SECTION OF MAZATZAL QUARTZITE AT NORTH PEAK, MAZATZAL MOUNTAINS

	Feet
Quartzite, white to gray, mostly fine-grained, with some beds coarser and cross-bedded	100
Conglomerate, with pebbles up to 1 inch, quartz, jasper, feldspar, granite, schist, etc.	1
Quartzite, gray, coarser than the overlying bed	140
Conglomerate	3
Quartzite, gray, massive	100
Quartzite, brown, massive	25
Quartzite, reddish, pebbly, largely cross bedded	80
Quartzite, reddish, glassy, fine, slabby, ripple marked	250
Quartzite, pale brown, glassy, massive, cross-bedded	150
Quartzite, red, massive, with layers of spotted maroon colored hard shale. (Lies on pre-Cambrian schist)	100
Total	950

Ransome[1] has called attention to the occurrences of pre-Cambrian quartzite on Pine Creek northwest of Payson. At the Natural Bridge he found the relations shown in Fig. 71. The basal granitic conglomerate contains boulders up to 2 feet in diameter. It was noted that the quartzite is an old ridge against which the Tapeats and overlying strata abut and it was traced about 4 miles north-northeast of the Natural Bridge to a point east of Pine. An exposure is mentioned 2½ miles southeast of Pine in which the nearly horizontal Tapeats sandstone is in contact with the older quartzite and contains angular fragments of it. Wilson[2] has mapped the rocks in this vicinity. (See Fig. 70.) He found that

[1]Ransome, F. L., *op. cit.*, pp. 158-159.

[2]Wilson, E. D., *op. cit.*, pp. 305-306.

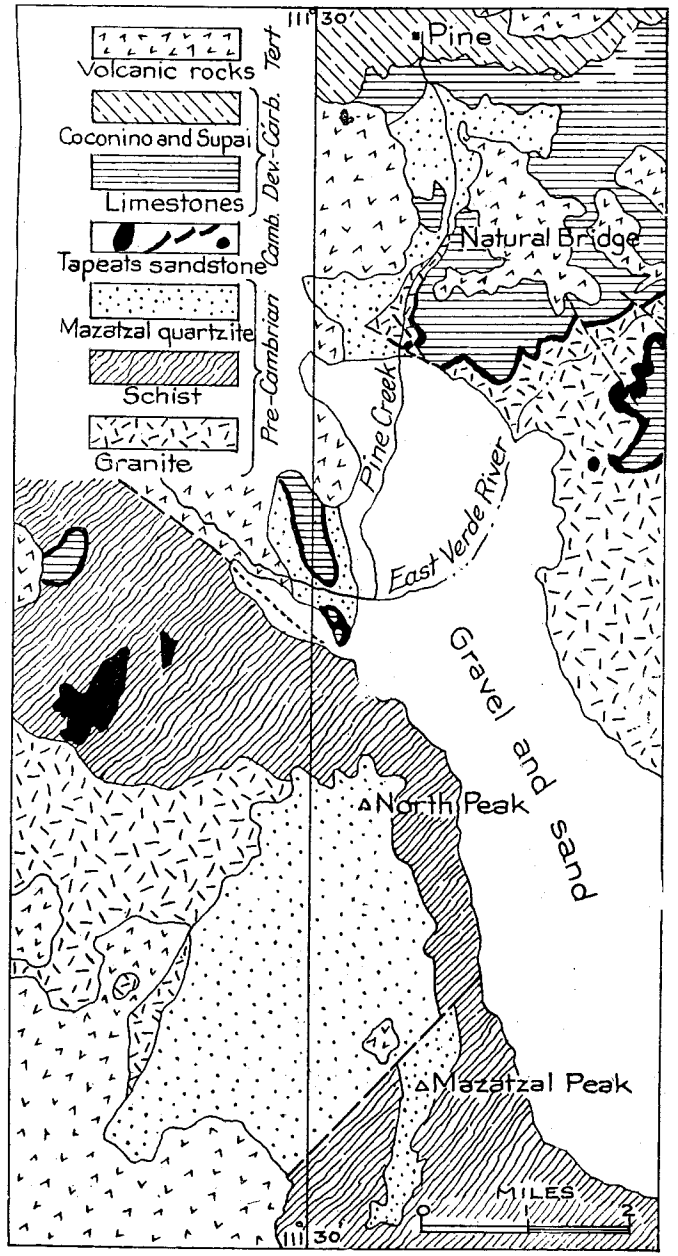


Fig. 70.—Map showing relations of Mazatzal quartzite in Mazatzal Mountains-Natural Bridge-Pine region, after Wilson.

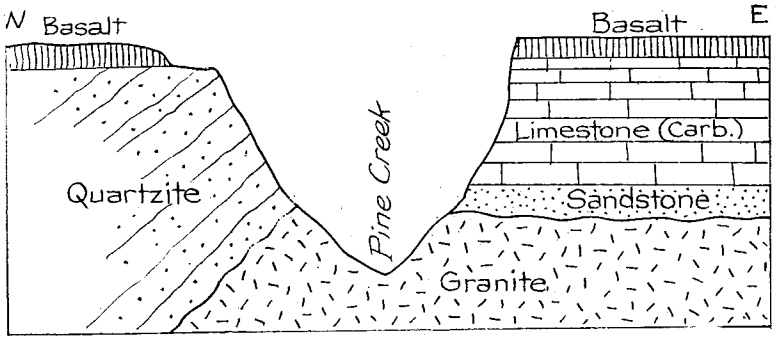


Fig. 71.—Diagrammatic section across Pine Creek at Natural Bridge, northwest of Payson, Arizona.

1,150 feet of the quartzite are exposed at the Natural Bridge with basal conglomerate 300 feet thick, and 2,500 feet of beds were noted south and southeast of Pine.

A very fine section of the formations of the Apache group is exposed in the walls of the deep canyon of Salt River at Roosevelt Dam. Ransome[1] has described this exposure and reproduced a cross section by Lee.[2] Some features at this place are shown in Plate 68a, and the basal contact in Plate 68b. The following section which I made at the dam agrees closely with the section by Lee and descriptions by Ransome.

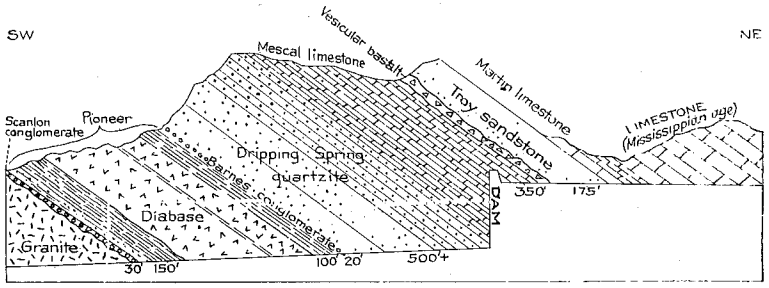


Fig. 72.—Sketch section of formations of Apache group, etc., at Roosevelt Dam.

The Scanlan conglomerate includes many boulders and lies on a notably irregular erosion surface on the old granite. The lower part of the Pioneer shale below the great diabase sill is partly sandstone with some pebbly layers, but the portion above the sill is the typical hard maroon shale with light colored spots. Characteristic Barnes conglomerate is overlain by fully 500 feet of Dripping Spring quartzite, mostly

[1]Ransome, F. L., *op. cit.*, Prof. Paper 98-k, pp. 149-152.
[2]Lee, W. T., *op. cit.*, W. S. Paper 136, pp. 96-98.

of reddish-brown color and with slabby bedding in its upper part. The Mescal limestone, which dips NE. 25°, is a hard, compact, light colored rock in moderately massive beds, on weathered surfaces showing thin layers of silica. It is overlain by a flow of vesicular basalt which separates it from Troy quartzite. (See Pl. 5b.) The latter, about 175 feet thick, has a thin basal member of dark shale grading up into coarse sandstone, in all about 60 feet thick, and a top member of hard massive sandstone, thin-bedded in its upper part. The Martin limestone is well represented by fossiliferous beds (see p. 62), and there is a considerable thickness of Carboniferous limestone, on which lies Gila conglomerate.

Mescal Mountains.—The high southeasterly continuation of the Pinal Mountains, known as the Mescal Mountains, extends across the southern end of Gila County into the northeastern corner of Pinal County. It is cut across by the canyon of the Gila River, which in places is 2,200 feet deep, with very steep walls.

The rocks in the higher parts of the range are mainly pre-Cambrian granite, diorite and schist, the formations of the Apache group, and the Martin and Tornado limestones. On the flanks are Gila conglomerate and various Cretaceous and Quarternary volcanic rocks, and in Deer Creek basin to the south, an area of coal-bearing sandstones and igneous rocks of Cretaceous age.

The general structure of the Mescal Mountains is a highly arched anticline broken by many faults. In the Porphyry Gulch region there is local doming caused by the intrusion of a laccolith of diorite in the Tornado limestone. The general distribution of the rocks in the Mescal Mountains is shown on the map in Plate 72, and by sections A to F in Figs. 73 and 74. The data for the region west of longitude 110° 45′ are from maps and reports by F. L. Ransome; the data east of that meridian are the results of my reconnaissance surveys in 1919 to 1922.

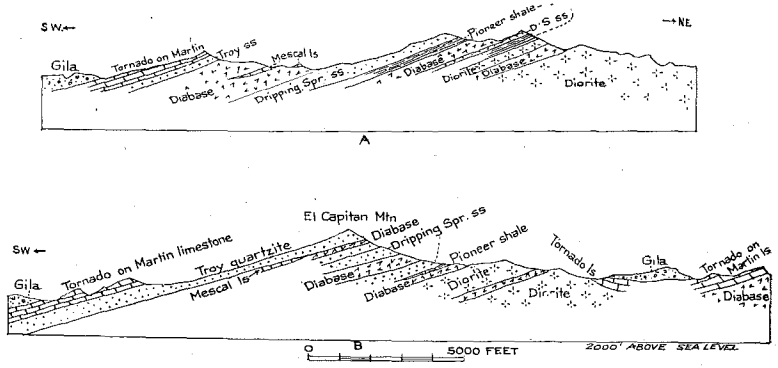


Fig. 73.—Sections across the western part of the Mescal Mountains, after Ransome. Along lines shown on map Plate 72.

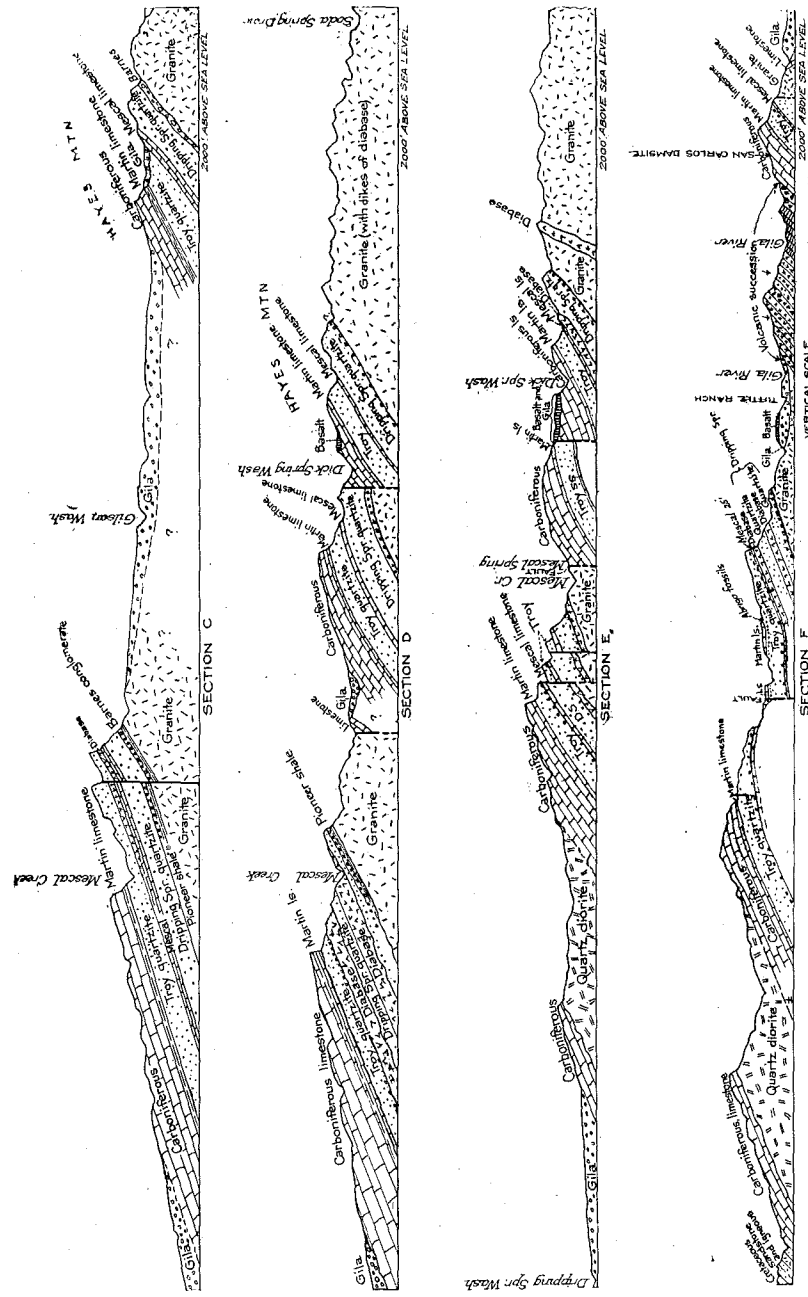


Fig. 74.—Sections across the central and eastern parts of the Mescal Mountains and Hayes Mountain, along lines shown on map Plate 72.

The rocks of the Apache group and of the overlying formations in the western part of the range, as described by Ransome,[1] comprise the following formations:

ROCKS OF THE MESCAL MOUNTAINS (RANSOME)

		Feet
Early Pennsylvanian and Early Mississippian	Tornado limestone, mostly massive beds, light gray	1000
Later Devonian	Martin limestone, mostly thin-bedded, gritty at base, shaly at top	325
Apache group	Troy quartzite, cross-bedded, pebbly; shaly rusty beds with worm casts at top	400
	Vesicular basalt flow	25–75
	Mescal limestone, somewhat dolomitic with cherty layers	225
	Dripping Spring quartzite — arkosic quartzite, mostly with dark red or gray banding; ripple marks	450
	Barnes conglomerate	10–55
	Pioneer shale, maroon; arkosic and quartzitic near base	150
	Scanlan conglomerate	0–15
Pre-Cambrian	Pinal schist granite and quartz diorite.	

These formations present some local variations, mainly in thickness and minor components. The vesicular basalt flow lying on the Mescal limestone is not present everywhere to the eastward. A notable exposure, showing its relations, is on the west slope of the range on the new automobile road from Globe to Dripping Spring Valley. The Troy quartzite lies on a somewhat uneven surface and in places where the old lava flow is lacking its absence may be due either to original irregularities of distribution or to erosion. The presence of great sills of diabase is a notable feature throughout the region. They occur largely at the horizons of the Pioneer shale, Dripping Spring quartzite, and Mescal limestone. Ransome mentions that the Martin and Tornado limestones are cut by a few small bodies of diabase, but I am sure that these are not the same intrusions as the sills and dikes in the Apache group but feeders of some of the Tertiary or Quaternary basalts. One of these in Steamboat Mountain, 6 miles east of Kelvin was examined by me and Mr. Lausen and found to be clearly of that nature. In other portions of the region I have found that the diabase invades mainly the strata older than Troy but in

[1]Ransome, F. L., The Copper Deposits of Ray and Miami, Arizona: U. S. Geol. Surv. Prof. Paper 115.

some instances the lower part of the quartzite is invaded. The aspect of some of the Troy quartzite is shown in Plate 7a.

In the Gila River region I found very extensive exposures of the rocks of the Apache group, which continue eastward along the north front of the mountain to near longitude 110° 30′, where the Tertiary volcanic rocks overlap across them. The Mescal limestone diminishes greatly in thickness, being only about 25 feet thick at the Needle's Eye, a constriction in the canyon of the Gila River 2½ miles southwest of Tuttle Ranch. A section at this place is given in Fig. 75. The Mescal

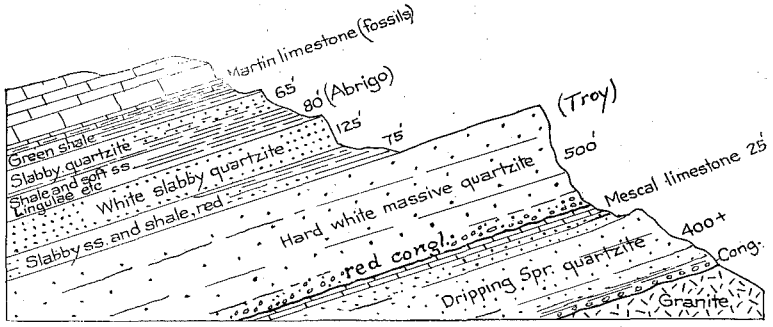


Fig. 75.—Section near Needle's Eye on the Gila River. Looking west.

beds in the region are nearly all silica, but exhibit the very characteristic alternation of harder and softer bands. In the mountain slope 3 miles south of Tuttle Ranch the Mescal formation is not more than 6 feet thick, and in a section 2 miles north of Needle's Eye it is absent. Its eastern margin is near longitude 110° 34′, east of which the Troy quartzite lies unconformably on the Dripping Spring quartzite (see also A, Fig. 76) and near longitude 110° 33′ the latter also thins out and the Troy quartzite to the east lies directly on the granite.

At the Needle's Eye the Troy quartzite consists of a very massive, white member about 500 feet thick, with overlying members of 75 feet of slabby, reddish sandstone and sandy shale, all rather soft, and a cliff-making, partly slabby, white quartzite 125 feet thick. On this lie brown to greenish-gray shales and soft, earthy sandstone in which were discovered many lingulae and other organic remains, affording a satisfactory basis for correlation with the Abrigo, and therefore indicating that all the underlying beds are pre-Abrigo. Next above the Abrigo is hard, slabby sandstone or quartzite, 65 feet thick, extending to the base of shales and impure limestone which yielded Devonian (Martin) fossils. These fossil-bearing Abrigo beds were also found eastward of the river along the north slope of the Mescal Mountains.

Near longitude 110° 43′, on the north slope of the Mescal Mountains the Troy quartzite has been removed by pre-Martin erosion, and for a distance of a half-mile Martin limestone, including huge masses of

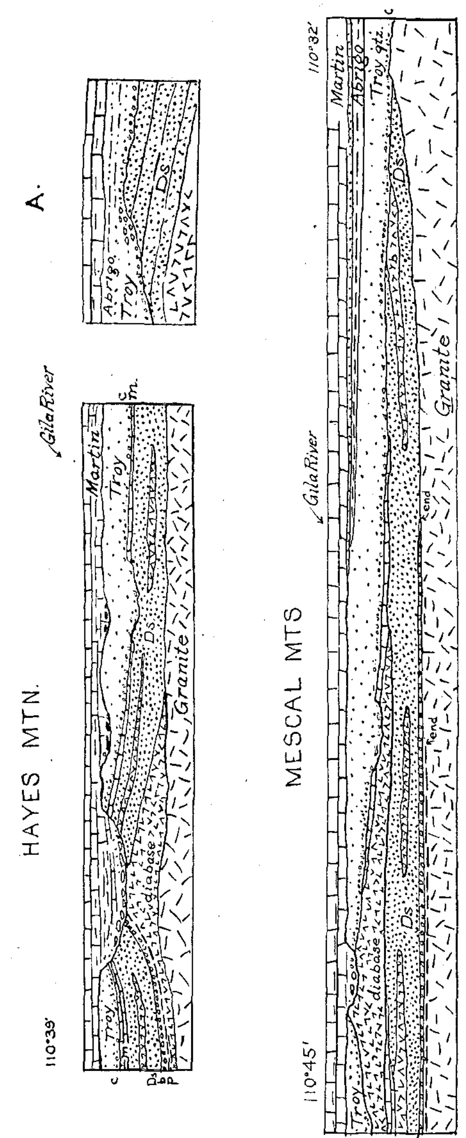


Fig. 76.—Diagrammatic sections showing stratigraphic relations in the Mescal and Hayes mountains. M, Mescal limestone; b, Barnes conglomerate; p, Pioneer shale; Ds, Dripping Spring quartzite; c, Basal Troy conglomerate. A, section on north slope of the Mescal Mountains near longitude 110° 32½', showing a mound of slightly tilted Dripping Spring beds, against which the Troy has been deposited. Coarse local conglomerate intervenes at places.

the quartzite, lies on the eroded surface of the thick sill of diabase intruded into or above the Mescal horizon.

Hayes Mountain, a northern spur of the Mescal Mountains, consists of a large area of granite flanked on the south by Apache group, and limestones of Devonian and Carboniferous ages. Many large sills of diabase are intruded in the Mescal and underlying strata. The section in Fig. 77 shows the general relations near latitude 33° 15', southwest of Rice. In places along the south slope of this range the base of the Martin limestone lies unconformably on coarse-grained diabase, Barnes

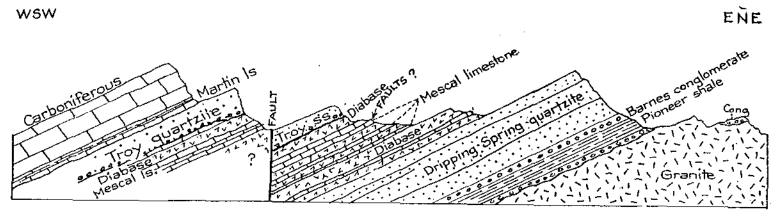


Fig. 77.—Section of Hayes Mountain 12 miles southwest of Rice.

conglomerate, Dripping Spring quartzite, Mescal limestone, and Troy quartzite. At one point near longitude 110° 38', on this slope the Martin limestone has a basal member consisting of very large boulders of materials from these various formations. (See Fig. 76.)

Dripping Spring Mountains.—The range of high ridges constituting the Dripping Spring Mountains extends from Mineral Creek north of Ray, southeastward across the eastern margin of Pinal County to the canyon of the Gila River near Christmas below the mouth of Dripping Spring Valley. The latter valley borders the north side of the range whose southern slope descends to the Gila River. The very important mining district of Ray is near the west end of the range. The geology has been explored in detail by Ransome.[1] Some of the principal features are shown on the map in Fig. 78, and cross sections in Fig. 79, reduced from plates in Ransome's report. The most conspicuous features in the range are many summits and buttes of the Troy quartzite and other formations of the Apache group. The Mescal limestone, with its many cherty layers (see Pl. 6a), appears in numerous outcrops. At this horizon and to a less extent at other horizons in the group, are great sills of diabase. Dikes of dark rock cutting Devonian and Carboniferous limestones were of later age. In Troy Basin a large intrusive mass of granite porphyry is exposed and dikes of this rock cut the strata at other places in the range. Faults are numerous, breaking the

[1]Ransome, F. L., The Copper Deposits of Ray and Miami, Arizona: U. S. Geol. Surv., Prof. Paper 115, 1919.

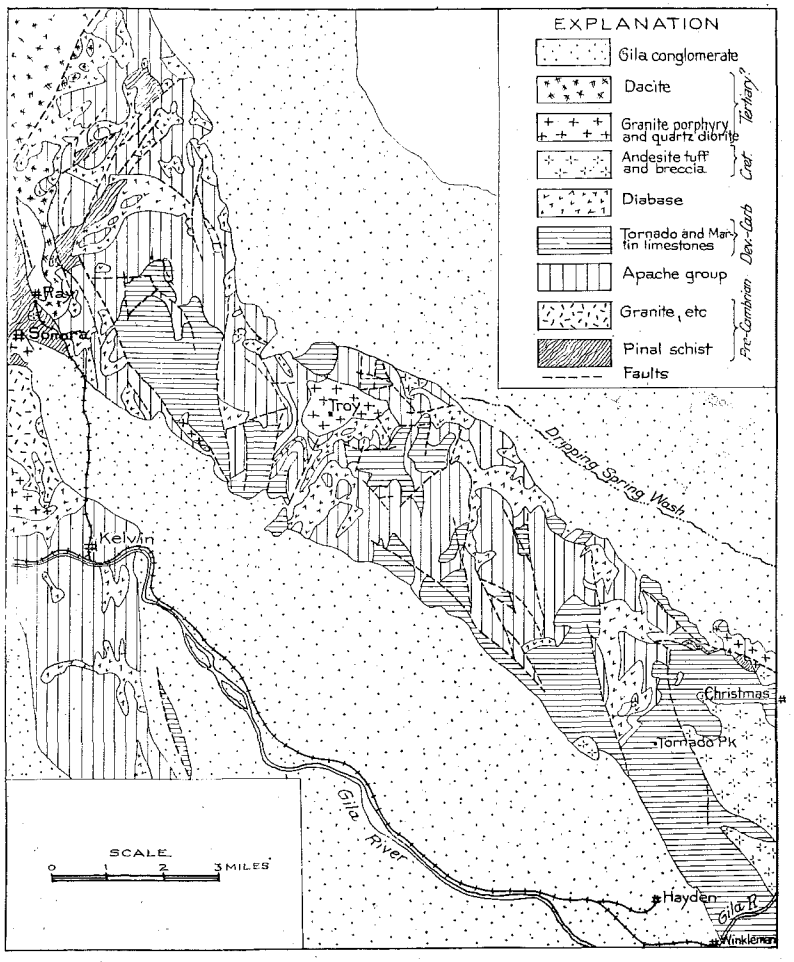


Fig. 78.—Geologic map of the Dripping Spring Mountains, after Ransome.

region into irregular blocks of various sizes. One interesting overthrust of the Pinal schist onto the Dripping Spring quartzite is shown in Plate 69b. Ransome also describes a remarkable overthrust of Troy quartzite onto diabase and Dripping Spring quartzite 2 miles north of Tam O'Shanter Peak.

The faulting in this general region occurred at two or more periods, for some of the faults do not break the Gila conglomerate.

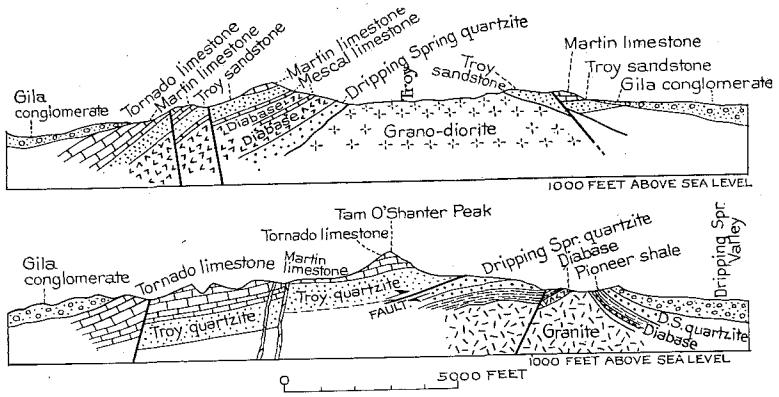


Fig. 79.—Cross sections of the Dripping Spring Mountains, by Ransome. Looking west.

GREENLEE COUNTY

Clifton-Morenci District.—The Clifton-Morenci district is an area in which the older rocks are considerably uplifted, and locally bared by erosion. The pre-Cambrian granite is exposed for about 40 square miles, overlain by sedimentary rocks from Cambrian to Cretaceous in age, somewhat faulted and invaded by igneous rocks comprising porphyries of various kinds. There are also andesites, basalts, and rhyolites of Tertiary age. Extensive mineralization, mainly of copper, exists in lodes and rock impregnations. The geology and mineral deposits of this district have been described in detail by Lindgren.[1] The granite is mostly a massive, coarse-grained rock similar to other pre-Cambrian granites of eastern Arizona. In places it is cut by dikes of granite aplite. The Coronado quartzite attains a thickness of 250 feet near Morenci but is from 100 to 150 feet thick at other places. A basal conglomerate generally occurs, but is absent at the mouth of Apache Gulch south of Morenci. The next formation, the Longfellow limestone, 200 to 400 feet thick, closely resembles the El Paso limestone of New Mexico and contains similar Ordovician fossils in its upper part. Possible Upper Cambrian fossils occur in its lower beds, but no evidence of separation of the strata has been found. The Morenci shale (Devonian) consists of 100 feet of shale, in places underlain by 75 feet of fine, clayey limestone.

The Modoc limestone, 170 feet thick, of Mississippian age, outcrops in Morenci and at scattered areas in other places in the district. The Tule Spring limestone, of Pennsylvanian age and Mississippian age, appears in a belt extending across part of the northern section of the Clifton quadrangle. The Pinkard formation, of Colorado age, consisting of

[1] Lindgren, W., The Copper Deposits of the Clifton-Morenci District, Arizona: U. S. Geol. Surv., Prof. Paper 43, 375 pp., 1905; and Clifton Folio: U. S. Geol. Surv. Geologic Atlas of the U. S., No. 129.

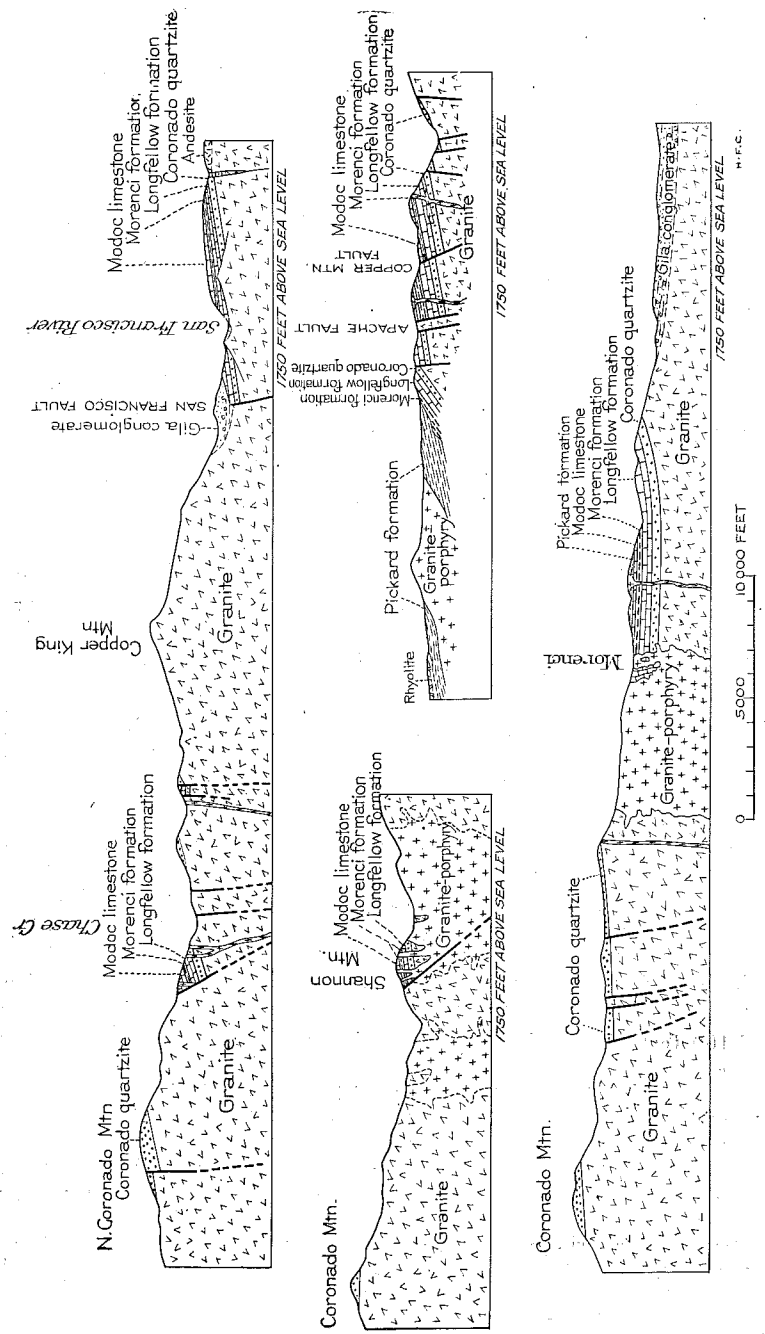


Fig. 80.—Sections across the Clifton-Morenci district, after Lindgren.

sandstone and shale several hundred feet thick, is well exposed in Silver Basin Creek 2 miles southwest of Morenci. This formation lies unconformably on Paleozoic limestones and is intruded by porphyry. The Tertiary igneous rocks in the Clifton-Morenci district are on the southern margin of the great volcanic succession which extends from the White Mountain district. The earliest flows were massive and tufaceous rhyolite succeeded by fine basalts, brown pyroxene andesite, thick flows of scoriaceous basalt, and a second rhyolite, mostly of light yellowish or brownish tuff breccia. Next above are basalt flows having an aggregate thickness of 1,500 feet, and on their eroded surface lies a thick body of the third rhyolite, including much tuff breccia. The Gila conglomerate is conspicuous in the Clifton district, notably in bluffs along San Francisco River, where it attains an altitude of 4,500 feet; the thickness exposed near Clifton is 600 feet, and 5 miles up the river from that place nearly 900 feet are exposed.

Blue Mountain and Prieto Plateau.—A reconnaissance from Springerville past Escudilla Mountain down the Blue River and across the plateau to the headwaters of Eagle Creek, yielded interesting data. The entire region is mantled by volcanic rocks, more than 2,500 feet thick in places, which extend from the White Mountains continuously to the vicinity of Morenci on the south, far into New Mexico on the east, and over the Natanes Plateau on the west.

South of Springerville were found 800 feet of soft sandstone, loams, and fine sands of light color, doubtless of Tertiary age, capped by basalt. These sediments appear in the face of Escudilla Mountain under a heavy cap of basalt. Here they include, somewhat below the middle, a massive, light-colored sandstone memer, below which are pale brownish-red sandstones, in part slabby, and of considerable hardness. All these beds are well exposed in the canyon of Stone Creek 5 miles northeast of Alpine, where there is a local bed of tuff in the upper part. This tuff is fine-grained, massive, compact, and of columnar structure and is 50 to 70 feet thick. The reddish sandstones are conspicuous in the slopes south of Alpine. In the steep slopes north of Cameron Blue River there is a thick succession of coarse sandstone, most of it conglomeratic and carrying considerable volcanic material, mostly in the form of a coarse agglomerate. This latter member is conspicuous near the junction of the Blue and the Cameron Blue rivers near the State line. Sheets of volcanic rock appear at intervals in the lower part of the series, especially to the southward along the Blue River. At Blue Post Office 3 or 4 sheets of basalt, in part separated by gravel beds, cap 300 feet of brown conglomerate, which is underlain by a sheet of light colored rhyolite lying on red conglomerate. The latter is exposed at intervals on the stream bed and farther south grades into purplish agglomerate, of which nearly 1,000 feet are exposed near latitude 33° 30′, including lava sheets and mud flows. The aspect of the valley at this place is shown in Plate 73-B. Some of the igneous rock appears to be latite, but rhyolite was also noted. Much of the material in the agglomerate is in very

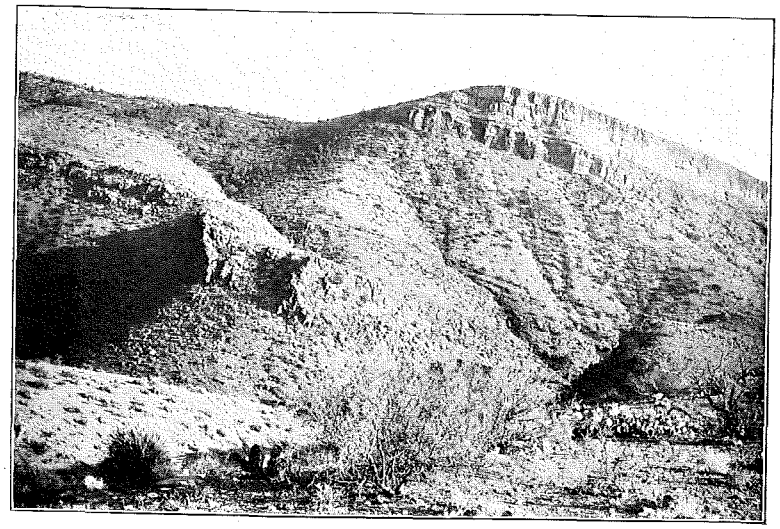


Plate 71a.—East side of Capitan Canyon, Mescal Mountains. The mountain is capped by Tornado limestone; below are slopes of Martin limestone and to left are cliffs of Troy quartzite. Photo by Ransome.

Plate 71b.—El Capitan Mountain, Mescal Range. Shows long dip slopes of quartzites of Apache group. Photo by Ransome.

large, angular fragments, some of them being 6 feet in diameter. This material constitutes the divide to the west as far as Raspberry Canyon and past Rose Peak to and down the headwaters of Eagle Creek. Some of the agglomerate has the aspect of Gila conglomerate. West of Double Circle Ranch on Eagle Creek there is an exposure of 100 feet of fine-grained, loamy, soft sandstone 100 feet thick, which appears to be of Tertiary age.

Peloncillo Mountains.—The long range of hills and ridges known as Peloncillo Mountains extends from the Gila River below Clifton to the State line at Steins Pass east of San Simon. The range was crossed at several places and found to consist of a thick succession of igneous rocks of Tertiary age lying mostly horizontal or dipping gently to the eastward or northeastward. There are alternations of tuffs and flows closely similar to those constituting the Gila Mountains which are a northerly continuation of the same range.

GRAHAM COUNTY

Very few data have been published regarding the geology of this county. Gilbert[1] crossed the region in 1873 and recorded a few facts as to the rocks noted. He stated that Mount Graham is made up of gneiss and syenite; that Gila and Peloncillo mountains and Natanes Plateau consist of eruptive rocks mainly "trachytes," which in the latter plateau are 460 feet thick and capped by 1000 feet of "sanadine" dolerite. I found that the area of granite and schist in the Pinaleno Range was of large extent, but flanked in places, especially to the south, by igneous rocks of Tertiary age. These igneous rocks in a thick, slightly tilted succession also constitute the greater part of the Peloncillo and Gila mountains and Natanes Plateau as stated above.

Jones[2] has briefly described the rocks exposed on the south slope of Gila Mountain north of Fort Thomas where he found rhyolite, andesite, and obsidian with interbedded yellow tuffs, lying mostly horizontal or gently inclined. Schwennesen[3] gives data as to the relations of the valley fill, Gila conglomerate, and lake deposits in the Gila Valley in the western part of the county.

In 1921 I visited part of the Turnbull Range and the region about Stanley and Arivaipa where Bolsa quartzite, Abrigo limestone, Martin and Tornado limestones, and various crystalline rocks were observed. They are broken by faults and penetrated by dikes and sills of igneous rocks. Later a more detailed examination was made by Ross especially in relation to mineral deposits.[4]

[1]Geog. and Geol. Surveys West of 100th Meridian: Wheeler, Vol. 3, pp. 509-513-514, 527-528, 1875.

[2]Jones, E. L., Jr., and Ransome, F. L., Deposits of Manganese in Arizona, U. S. Geol. Surv. Bull. 710d, p. 129, 1920.

[3]Schwennesen, A. T., Geology and Water Resources of the Gila and San Carlos Valleys: U. S. Geol. Surv., Water Supply Paper 450 (a), pp. 7-9, 1919.

[4]Ross, C. P., Arivaipa and Stanley Mining Districts, Arizona; U. S. Geol. Surv. Bull. 763. 120 pp. 13 pl., 1925.

PINAL COUNTY

Vekol Mountains.—The nearly circular group of ridges constituting the Vekol Mountains and the Vekol Mining District lies about 25 miles south of Casa Grande. These ridges exhibit many features of great significance in the geology of the southern part of Arizona. At the base are pre-Cambrian schists, overlain in the eastern part of the uplift by quartzite, red shale, and conglomerate with a great sill of intruded diabase. Next above are Abrigo, Martin, Escabrosa, and Naco limestones. In the center and on the outer margins is an overlap of Tertiary volcanic rocks and probable Gila conglomerate. The following sketch map shows some of the relations observed in a very brief visit to the area:

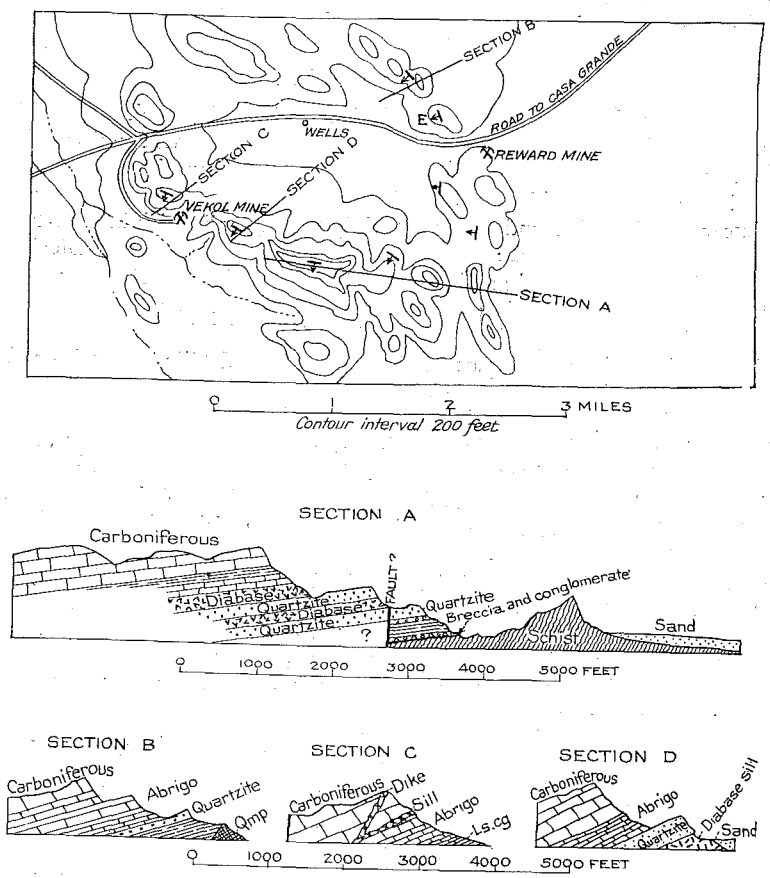


Fig. 81.—Sketch contour map and cross sections of Vekol Mountains.

The hard, red shale in section A closely resembles Pioneer shale and is capped by conglomerate remarkably like Barnes. The overlying quartzite here and in section D is penetrated by thick sills of diabase and so closely resembles the Dripping Spring quartzite of central Arizona that it seems probable that these rocks are an outlying area of the Apache group. Next above are rusty, sandy shales, grading up into thin-bedded limestone with interbedded chert layers suggesting Mescal limestone, but containing fossils determined by C. E. Resser as *Dicellomus* sp. and

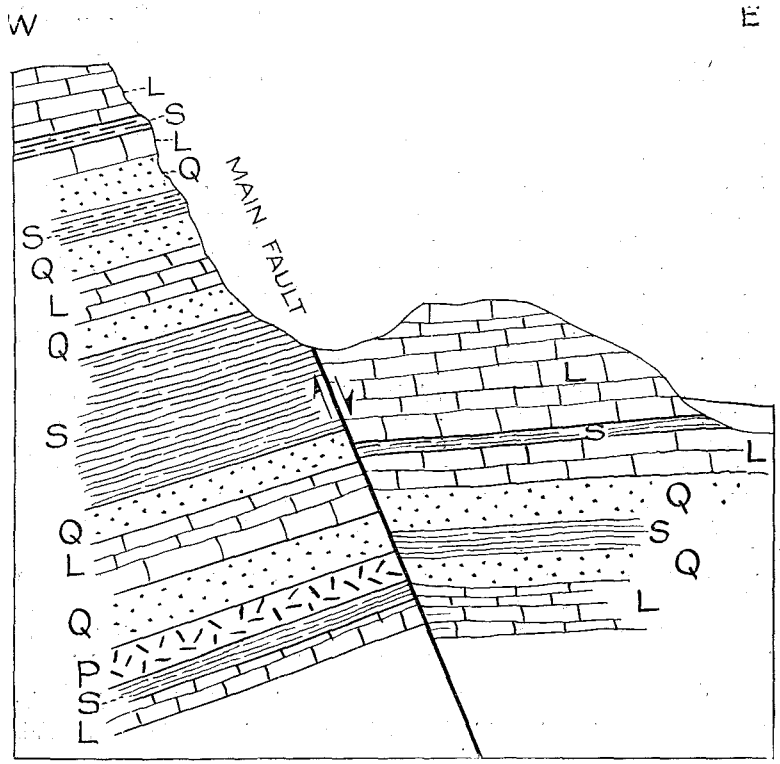


Fig. 82.—Section at the Reward Mine at east end of the Vekol Mountains, after Higgins: L, limestone; S, shale; Q, "quartzite", (probably mostly silicified limestone); P, porphyry sill.

Lingulella sp., probably of Upper Cambrian age and representing the Abrigo limestone. In similar limestones one mile northwest of the Reward Mine, section B, were found sections of crinoid columns and a sponge which were examined by Edwin Kirk, who regards them as comparable to fossils found in El Paso limestone (Ordovician) of the New Mexico region. From the overlying limestone at this place

(section B) were collected fossils identified by G. H. Girty as characteristic of the upper beds of the Escabrosa limestone (Mississippian). (See p. 75.) At E on the slope of a nearby detached limestone knob were collected a few fragments of limestone in which G. H. Girty found an abundance of minute fossils, pelecypods, scaphopods, and gasteropods, about 25 species in all, suggesting Manzano (Permian) age. Bryan[1] collected the Pennsylvanian fossils listed on page 74 from the limestone on the south slope of the mountain at the Vekol Mine (section C), and he noted similar limestone at a point about 3 miles east of Stout's Well, northwest of Vekol, where about 100 feet of beds are exposed dipping southeast.

A brief report by Higgins[2] on the Reward Mine throws light on the local relations at the east end of the Vekol range. A short distance south of the mine an east-west fault separates the Carboniferous limestone from the schist. Extending along the eastern end of the mountain for a mile or more is a narrow exposure of volcanic tuff overlapping the older rocks, and just south of the main shaft this tuff is cut by a narrow dike of monzonite porphyry. A fault also extends along the east side of the ridge cutting through the limestones just west of the shafts. At this place the section is as shown in Fig. 82.

San Tan Mountains.—This group of small ridges and hills lies on the north side of the Gila Valley north of Casa Grande. According to Schrader[3] they consist of pre-Cambrian granite and schist cut by younger granitic rocks and flanked locally by lavas. The latter cover an irregular area of about 9 square miles on the southern part of the range. They consist of superimposed flows dipping gently south-southwest and have a thickness of several hundred feet. At one locality Schrader found 100 feet of olivine basalt on 200 feet of latite, the latter in part tufaceous, lying on granite. The basalt was holocrystalline and composed principally of andesine-labradorite, augite, much altered olivine, and magnetite. This rock is also present in Walker Butte and caps Jackson Butte. The latite consists mostly of volcanic glass crowded with microliths and contains some orthoclase, albite, biotite, and probable olivine.

Table Top Mountain.—Table Top, a prominent landmark from the Casa Grande region, is a high, outlying mesa of volcanic rock. This rock also constitutes the southern end of the range. The northern ridges show granite with areas of old lavas, and according to Bryan a small mass of sandstone of Tertiary age.

Sacaton Mountains.—This group of low mountains and ridges lies between the Gila River and the Southern Pacific Railroad, north of

[1]Bryan, K., *op. cit.*, p. 23.

[2]Higgins, Edwin, The Vekol Copper Deposits: Eng. & Min. Jour., vol. 91, pp. 473-474, 1911.

[3]Schrader, F. C., Manuscript Report on the Gila Indian Reservation in U. S. Geol. Surv.

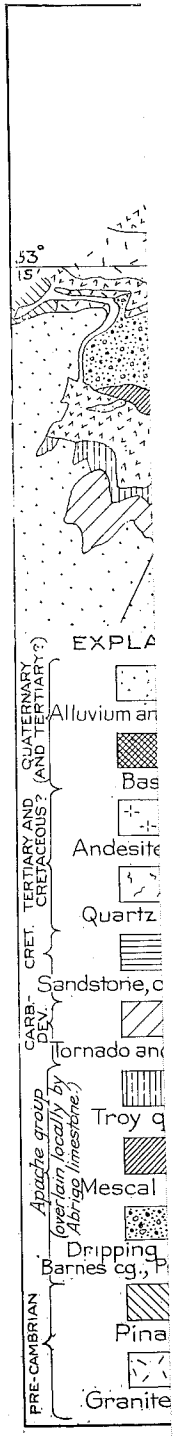


PLATE 72

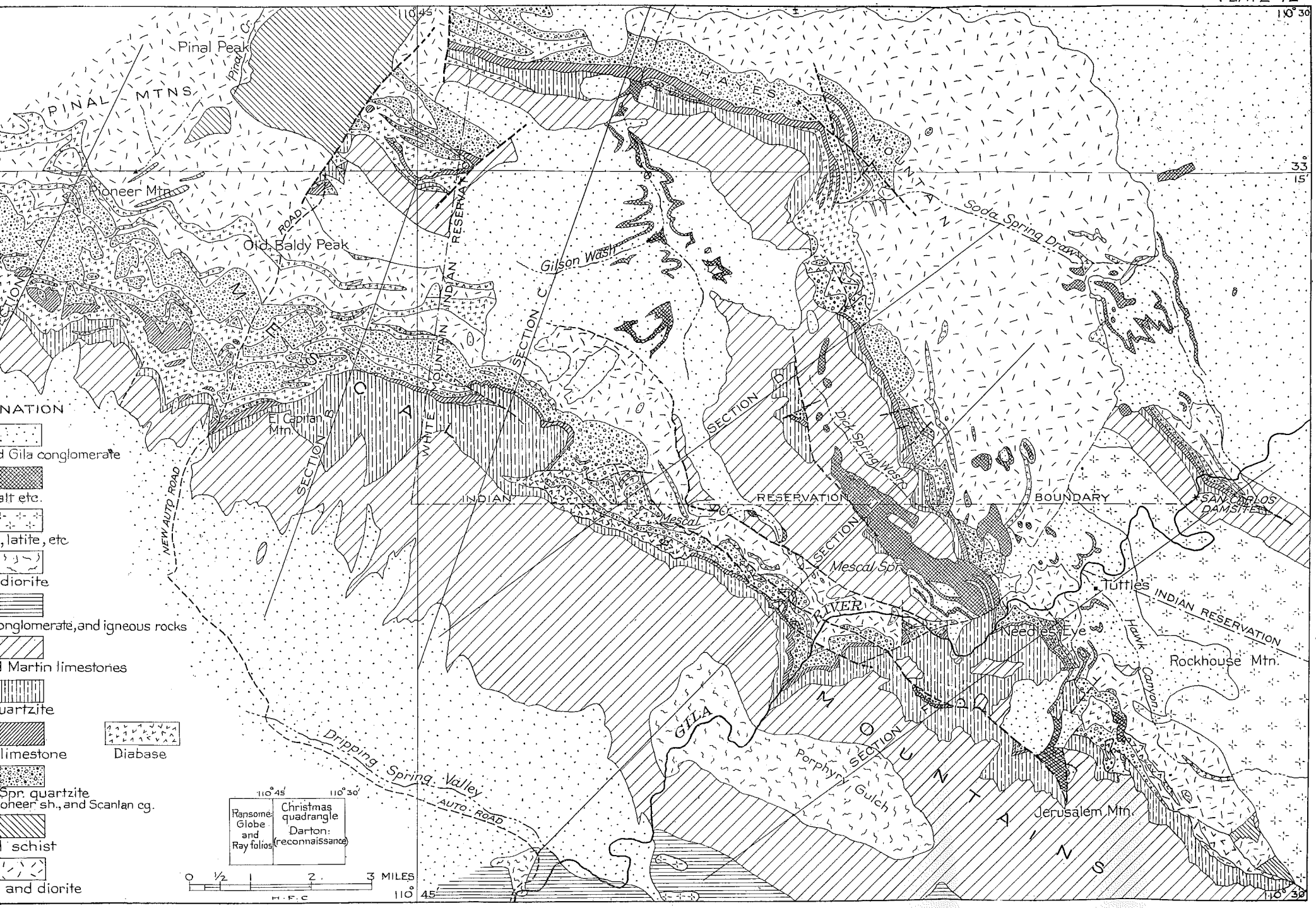


Plate 72.—Geologic map of the Mescal Mountains

Casa Grande. Schrader[1] has found that they consist mainly of granitic rocks cutting the pre-Cambrian complex, the latter appearing in places in the center of the group. The principal intrusive rock noted is mica diorite.

Slate Mountains.—The Slate Mountains, which lie about 15 miles southwest of Casa Grande, were found to consist largely of schist, presumably of pre-Cambrian age, overlain on the west slope and in outlying knobs by an interesting succession of Paleozoic rocks including Bolsa quartzite, Abrigo limestone, and Martin and Tornado limestones. The following sketch section shows the general relations:

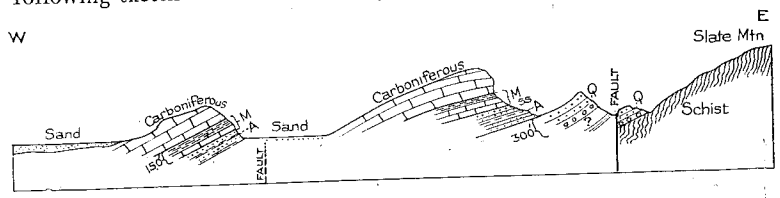


Fig. 83.—Section on west slope of Slate Mountain 15 miles southwest of Casa Grande: Q, quartzite; A, Abrigo limestone; M, Martin limestone (shale and limestone).

The quartzite closely resembles the Bolsa quartzite of southeastern Arizona. The overlying beds consist of slabby, brown sandstones, in part glauconitic, with brown and gray shale resembling the non-calcareous portions of the Abrigo limestone. It contains similar worm markings and lingulae. The overlying buff, impure limestone and shale (Martin), about 150 feet thick, yielded abundant Upper Devonian fossils. The limestone next above is Carboniferous, possibly with Mississippian at base. There is a sharp break at the base of the Martin beds, but the strata above and below have essentially the same dip.

Superior region.—According to Ransome[2] there outcrop in the hills about the copper mines of Superior and Silver King, pre-Cambrian schists, Troy quartzite, Martin and Tornado limestones, and a thick flow of dacite, the latter forming the "Apache Leap." Some thick sills of diabase are intruded in the quartzite and there are intrusive dikes or stocks of quartz diorite porphyry. At Superior there is a fault striking a little west of north, which is plainly visible just north of the village. Its plane dips west at an angle of about 60° and by the movement, which amounts to 500 or 600 feet, the Carboniferous on the west is brought against diabase and quartzite on the east. The fault is believed to be younger than the dacite (Tertiary) and probably causes the steep west front of the mesa known as "Apache Leap." An east-west dike of porphyry about 40 feet wide cuts the strata on the upthrust side of the

[1]Schrader, F. C., *op. cit.*, mss.

[2]Ransome, F. L., Copper Deposits near Superior, Ariz.: U. S. Geol. Surv. Bull. 540-d, pp. 2-22, 1913.

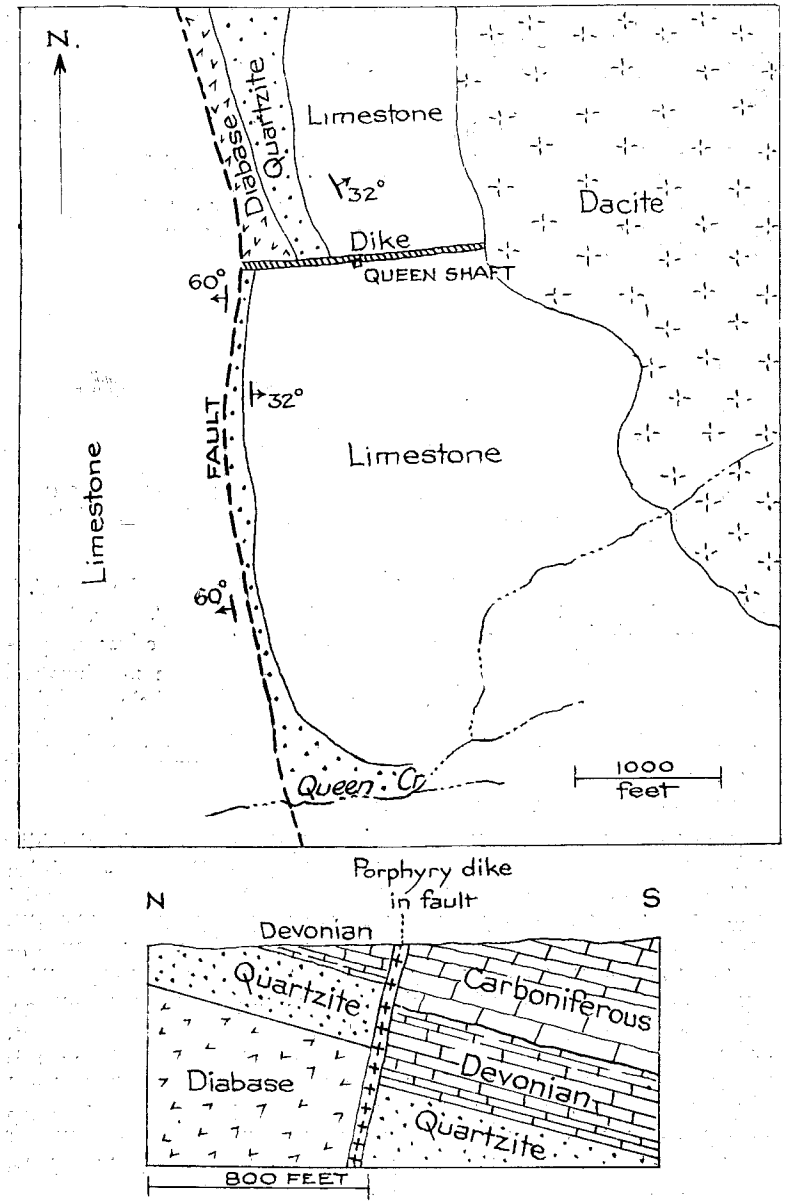


Fig. 84.—Geologic map of the Superior region, and north to south section across porphyry dike at the Queen Mine, Superior, showing relations of cross fault, after Ransome.

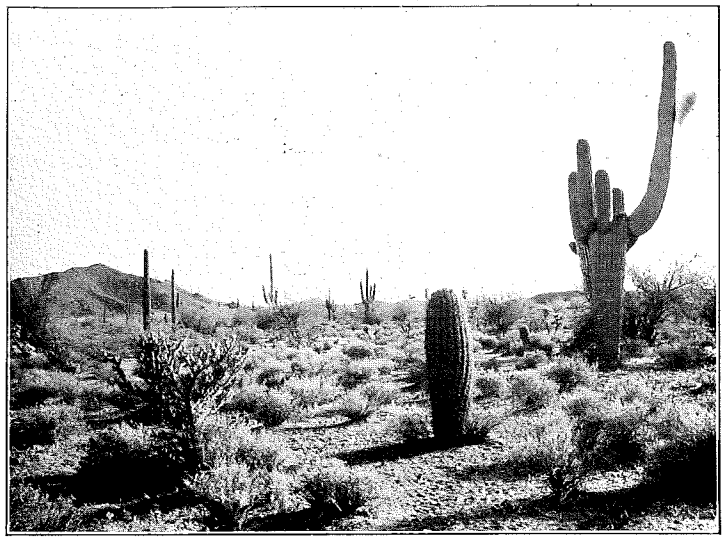


Plate 73a.—Desert Valley with typical vegetation, Pinal County.

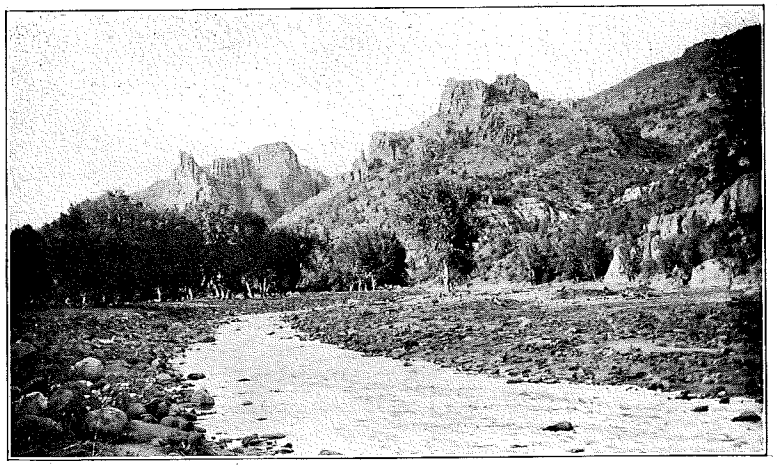


Plate 73b.—Agglomerate, rhyolite, and the volcanic rocks of Tertiary age on Blue River 30 miles above Clifton, Arizona. Looking south.

fault at the Queen Mine. It occupies a cross fault bearing relations shown in Fig. 84, and carries considerable ore. The ore at the Silver King Mine was also in a mass of porphyry, probably a quartz diorite porphyry, which is intruded in Pinal schist and also cuts the diabase.

The section at the mouth of the canyon of Queen Creek, just east of Superior presents the following features:

SECTION AT SUPERIOR, ARIZONA

	Feet
Limestones, mostly massive, light colored	1500+
Limestone, dark, massive, age	60±
Shale and thin limestone	30
Limestone, very fossiliferous (Devonian)	1
Limestone, blue (Devonian)	20
Quartzite (Devonian)	10
Limestone, buff (Devonian)	25
Limestone, blue and gray, lower part carries much iron	50
Limestone, soft, buff, earthy (probably Devonian)	20±
Quartzite (Troy) to edge of slope	100

In limestone about 600 feet above the base of this section were collected the Pennsylvanian fossils *Rhombopora lepidodendroides* and *Chonetes granulifera*.

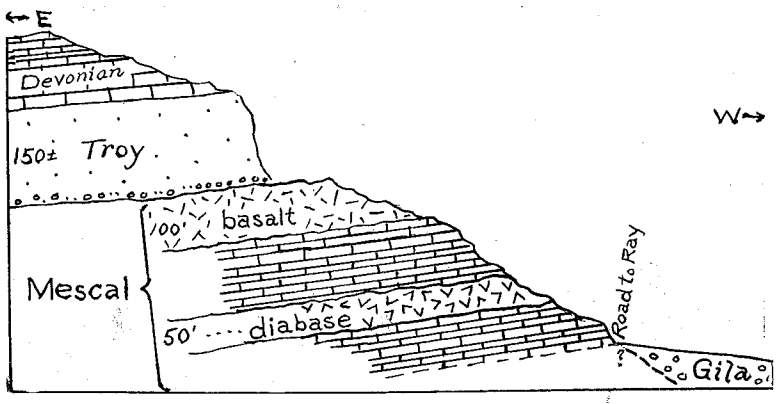


Fig. 85.—Section south of Superior, Arizona.

In the ridge about one-half to one mile south of Superior, near the road to Ray, there are exposed in the lower slopes fully 220 feet of Mescal limestone split by a 50-foot sill of diabase and overlain by Mescal basalt about 100 feet thick. The relations at the place are shown in Fig. 85.

Galiuro Mountains.—The high mesas and ridges constituting Galiuro Mountains extend south from Arivaipa Creek across the southwestern corner of Graham County into the northwestern part of Cochise County,

a distance of about 60 miles. Two outlying ridges that may be regarded as a northern extension of the range lie between Arivaipa Creek and Deer Creek. These highlands consist mainly of a great thickness of Tertiary volcanic rocks with some included beds of tuff, ash, and conglomerate, for the most part dipping gently eastward. They present to the west a bold escarpment in which, from townships 4 to 9 south, the underlying older formations appear. The deep canyon of Arivaipa Creek exposes a fine cross section of all the rocks, including the overlapping Gila conglomerate, which is especially well exhibited just east of the Graham-Pinal county line.

The volcanic rocks so well displayed in these ranges were not studied in detail. The older formations were examined on Copper, Arivaipa, and Ash creeks where the cross sections in Fig. 86 were prepared.

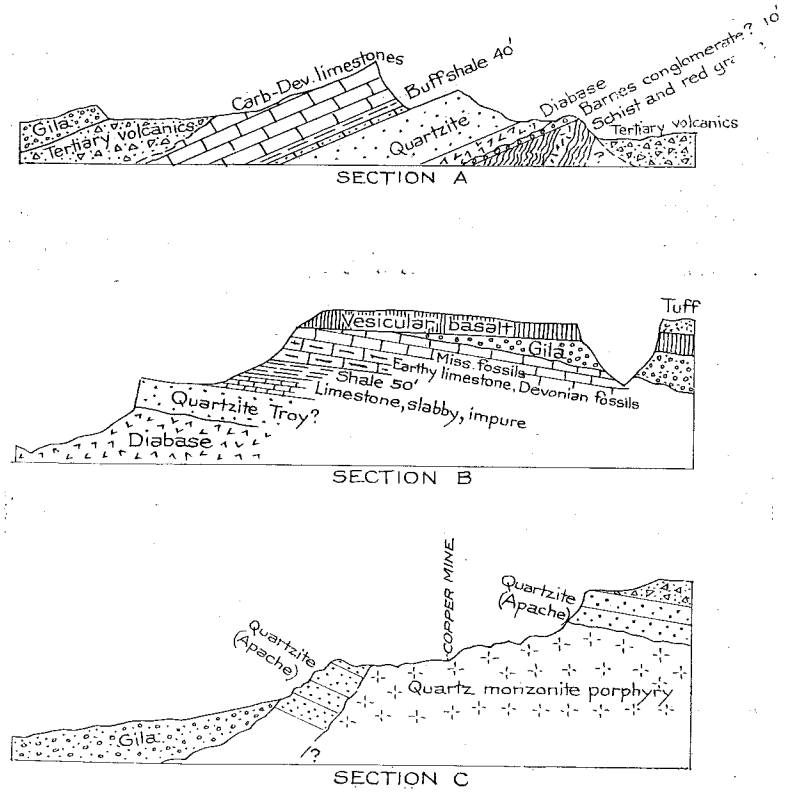


Fig. 86.—Sketch sections in the western slope of the northern part of the Galiuro Mountains in Pinal County, by N. H. Darton: A, Near Ash Creek; B, Near Arivaipa Creek north of Buzaine Ranch; C, Copper Creek, looking north.

The rocks of the Apache group were found well exposed on Camp Grant Wash west of Arivaipa School, about 12 miles south of Winkleman. The section is shown in Fig. 87.

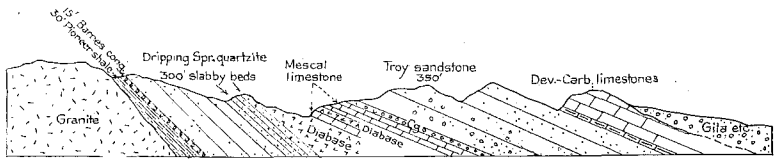


Fig. 87.—Section of the Apache group on Camp Grant Wash, 12 miles south of Winkleman.

The Mescal limestone here is invaded by two sills of diabase and some of the contact relations are exhibited for a considerable distance. Jones[1] has described some of the relations at the limestone-diabase contact at this place in connection with the occurrence of manganese ore. At the base of the Troy quartzite there is a thin member of conglomerate, including much fragmentary material from old Mescal ledges. The Pioneer shale, Barnes conglomerate, and Dripping Spring quartzite, constitute the high cliff shown in Plate 4a.

Blake[2] has described some features of part of the Galiuro Range, stating that on Rattlesnake Gulch where the rhyolite presents steep dips a succession of various lavas and tuffs were observed.

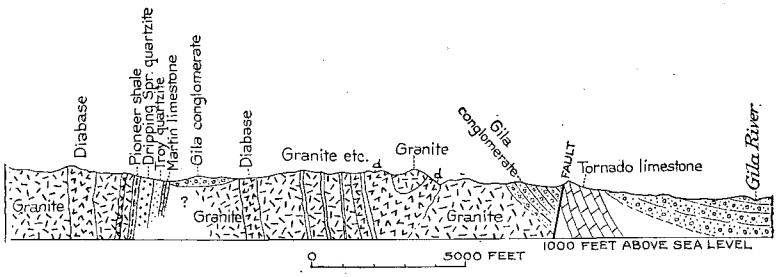


Fig. 88.—Section across the Tortilla Range south of Kelvin (Ransome).

Reed Basin-Christmas Region.—The geology of the mining district about Christmas and in Reed Basin, Ash Creek, and adjoining regions south of Winkelman has recently been studied in detail by Ross.[3] The rocks are mainly a thick mass of volcanic eruptives of Cretaceous age, with interbedded sandstones, some of them coal-bearing, and overlain by

[1] Jones, E. L., *op. cit.*, Bull. 710b, pp. 171-172.

[2] Blake, W. P., Geology of the Galiuro Mountains: Eng. and Min. Jour., vol. 73, pp. 546-547, 1902.

[3] Ross, C. P., Geology and Mineral Resources of the Saddle-Mountain-Banner District, Arizona, U. S. Geol. Surv., Bull. 771 to be published in 1925.

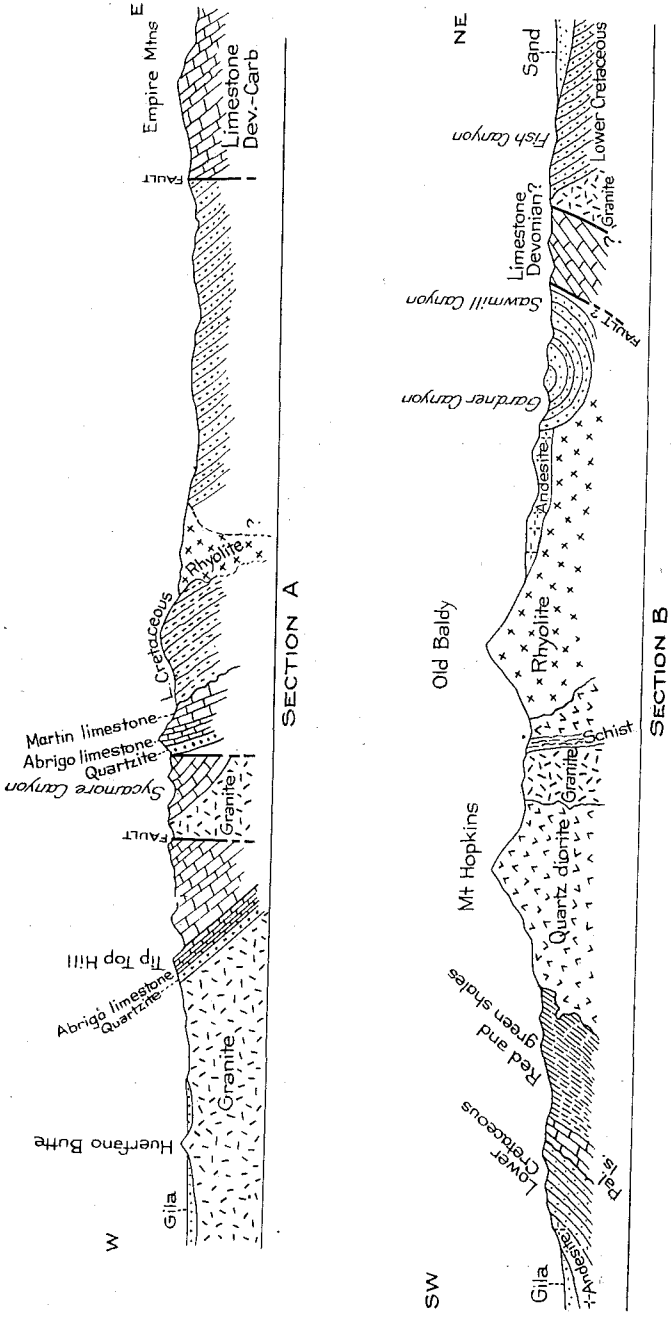


Fig. 89.—Section across the central and southern portions of the Santa Rita Mountains, modified after Schrader: A-A, Through Helvetia region; B-B, Southwest and northeast through Old Baldy Peak.

tuffs and later flows. Small areas of Carboniferous, Devonian, Cambrian, and pre-Cambrian rocks are exposed.

Tortilla Mountains.—Part of this short range lying west of Kelvin has been mapped by Ransome,[1] who has determined the structure as shown in the section in Fig. 88. The strata of the Apache group are well exposed in the southern part of the range, dipping steeply and cut by diabase. Tornado limestone, faulted up against Gila conglomerate, outcrops along the east slope for some distance.

PIMA AND SANTA CRUZ COUNTIES

Santa Rita Mountains.—This range, which extends from Pima County into Santa Cruz County, consists very largely of Tertiary igneous rocks, pre-Cambrian granite, and Paleozoic sandstone and limestone. Lower Cretaceous rocks appear at various places on the flanks and constitute the northern end of the range. The structural relations have been set forth by Schrader,[2] who has also described the various mines and prospects of the region. The sections in Fig. 89 show the principal features.

Schrader also gives some large scale sections through the Helvetia district (Plate 9) showing great overthrusts on planes of low angle. The quartzite of Cambrian age is exposed at many places about Helvetia and southward. The rocks are principally heavy-bedded quartzites "about 700 feet thick and of dark reddish color." Three miles south of Helvetia the bedding ranges from thin to heavy, and conglomerate beds at the base lie on coarse porphyritic granite. Schrader classes some quartz mica

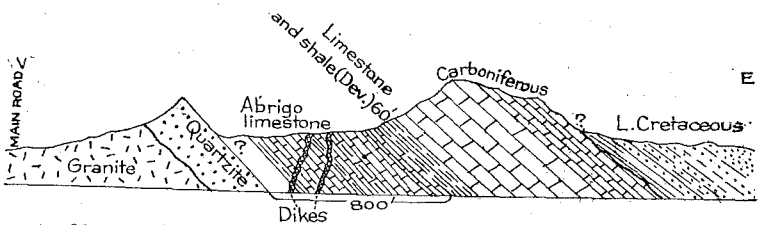


Fig. 90.—Sketch section passing about one and one-half miles north of Helvetia, Arizona, by N. H. Darton.

schists on the west slope of Old Baldy Ridge as possible Cambrian. They are flanked and cut by igneous rocks. Greenish and reddish shales in Montosa Basin, 5 miles west southwest of Old Baldy, are classed as Cambrian and apparently there are 5,000 feet of them.

In the Helvetia district I found the Bolsa quartzite overlain by highly distinctive Abrigo limestone 800 feet thick, and this in turn by 60 feet of shaly beds at the base of the Martin limestone. A section sketched at this place is given in Fig. 90.

[1]Ransome, F. L., *op. cit.*, Prof. Paper 115, pl. 2.

[1]Schrader, F. C., *op. cit.*, Bull. 430.

The Abrigo rocks consist of slabby limestones in part with considerable interbedded silica in layers 1-50 to ½ inch thick. Some of the limestone layers showed the reticulating brown stains of probable seaweeds a feature distinctive of the Abrigo as well as of the El Paso limestone. Some of the lower beds are sandy and contain interbedded, greenish-gray, sandy shale.

The Lower Cretaceous rocks in this district lie on an irregularly eroded surface of the Paleozoic limestones. A prominent feature mentioned by Schrader is a 300-foot member of basal conglomerate, in places reddish, that grades into sandstone both upward and horizontally. There are extensive exposures of these beds north, south, and west of Greaterville, where the dips are eastward at steep angles. The strata comprise slabby, arkose sandstone, dolomite, and mudstone, in places altered by metamorphism. To the southward in this area the strata are mostly massive, red shale with deep red to pale pink sandstone, conglomerate, and grit. In Adobe Canyon, where 620 feet of beds are exposed, a 40-foot member of white quartzite is included. Here the formation is overlain by about 650 feet of Tertiary rocks, including at base a 200-foot member of conglomerate containing a considerable amount of pebbles of volcanic rocks, and overlain by sandstones and shales. Some calcareous layers in the latter yielded fresh-water fossils, probably of Eocene age.

Of the great variety of igneous rocks in the Santa Rita Mountains the granite is believed to be the oldest. It is classed as Mesozoic because it apparently cuts Paleozoic limestones and does not extend into the Cretaceous strata. There is, however, considerable granite of pre-Cambrian age which has not been separated on the map. Quartz diorite constitutes much of the west central portion of the range, cutting the granite. A large mass of granite porphyry occurs in the south end of the range and two small stocks of this rock appear a short distance east of Helvetia and southwest of Greaterville. Many dikes of various intrusive rocks cut the others above mentioned, some of them being stocks of the later Tertiary eruptives. The latter, in the Santa Rita Range, consist mainly of rhyolite, of which there are large masses in the ridge culminating in Old Baldy, in the San Cayetano Mountains, and in Squaw Gulch. Large masses of andesite occur on the western and eastern slopes of the central and southern parts of the range.

Patagonia Mountains.—This prominent range is a continuation of the Santa Rita Mountains lying south of Sonoita Creek and extending to the International Boundary. The principal structural features as determined by Schrader[1] are shown in Fig. 91, which consists of two sections from his report.

The greater part of this range consists of a quartz monzonite cut in places by granite porphyry, rhyolite, and andesite. A large body of rhyolite occurs in its northwestern part constituting the prominent peak of Red Mountain. In the vicinity of Mowry there is an area of Lower

[1]Schrader, F. C., *op. cit.*

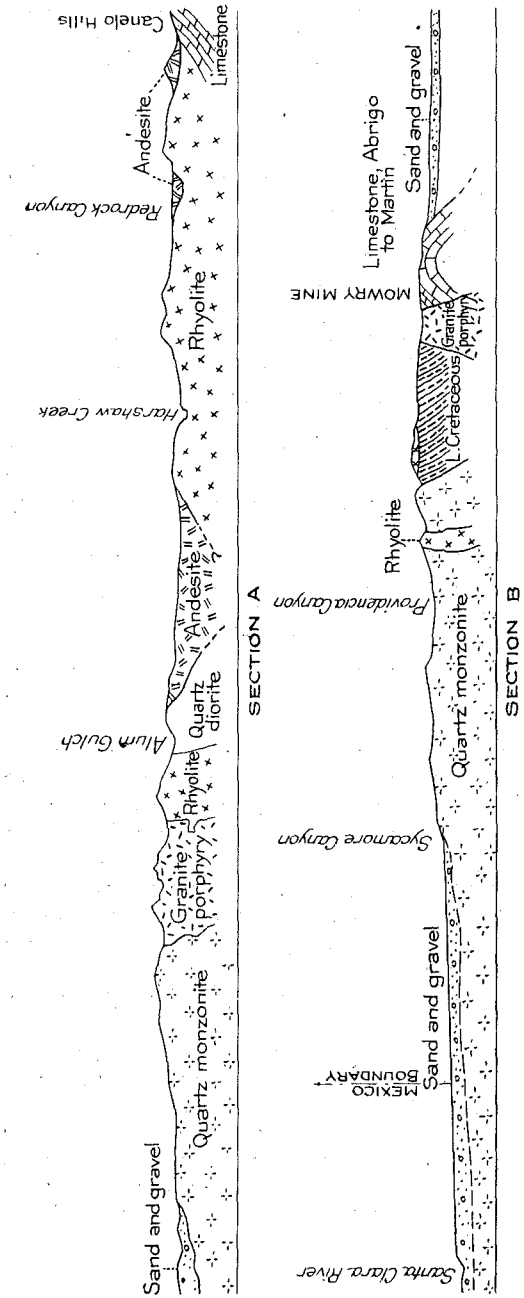


Fig. 91.—Sections across the Patagonia Mountains, after Schrader: Section A, from southwest to northeast 4 miles south of Patagonia; Section B, from Santa Cruz River to the mouth of Corral Canyon.

Cretaceous strata with fossils. On the main road, not far south of Mowry, I observed typical Abrigo limestone, with trilobite fragments, underlain by Bolsa quartzite. At Washington Camp there is a large body of Devonian and Carboniferous limestone cut off on the west by quartz monzonite and on the east by granite porphyry. A prominent quartzite appears to be a local member of the Carboniferous succession and not Bolsa. The relations are as shown in Fig. 92. No evidence of Abrigo was found at this place. Crosby[1] has given some data regarding this part of the range, erroneously assigning the quartzite to the Bolsa and the limestone to the Abrigo of the Bisbee region.

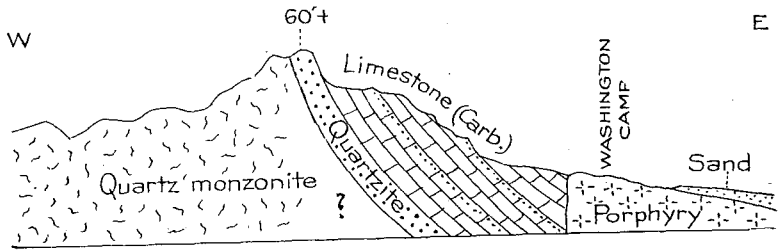


Fig. 92.—Section across eastern ridge of the Patagonia Mountains at Washington Camp, Arizona, by N. H. Darton.

Empire Mountains.—This small group of mountains lies a few miles south of Pantano Station and is crossed by the State automobile road which extends from Tucson to Bisbee. The principal features as described by Schrader[2] are an overthrust of a block of Carboniferous and Devonian limestones on pre-Cambrian granite, the latter constituting part of the summit and the northwestern slope. In Davidson Canyon some quartzites, probably Bolsa, are exposed. They are of dark greenish color. The outer slopes of the mountains consist of sandstone, shale, and conglomerate of Lower Cretaceous age, which to the eastward lie unconformably on, and to the southwest are overthrust by the older limestones. Schrader mentions a basal conglomerate in the Cretaceous, consisting of medium to coarse pebbles and cobbles of green, reddish, and white limestone, quartz, and other materials. The basal contact trends across the bedding of the Paleozoic limestones.

Santa Catalina Mountains and ridges to the southeast.—The principal facts on record regarding the geology of the Santa Catalina Mountains are given by Blake.[3] C. F. Tolman has made a detailed geologic survey

[1]Crosby, W. O., The Limestone-granite Contact Deposits of Washington Camp, Ariz.: Am. Inst. Min. Eng., Trans., vol. 36, pp. 626-646, 1906.

[2]Schrader, F. C., *op. cit.*

[3]Blake, Wm. P., Geological Sketch of the Region of Tucson, Arizona, in Botanical Features of North American Deserts, by D. T. MacDougal: Carnegie Institution, pp. 45-49, 1909.

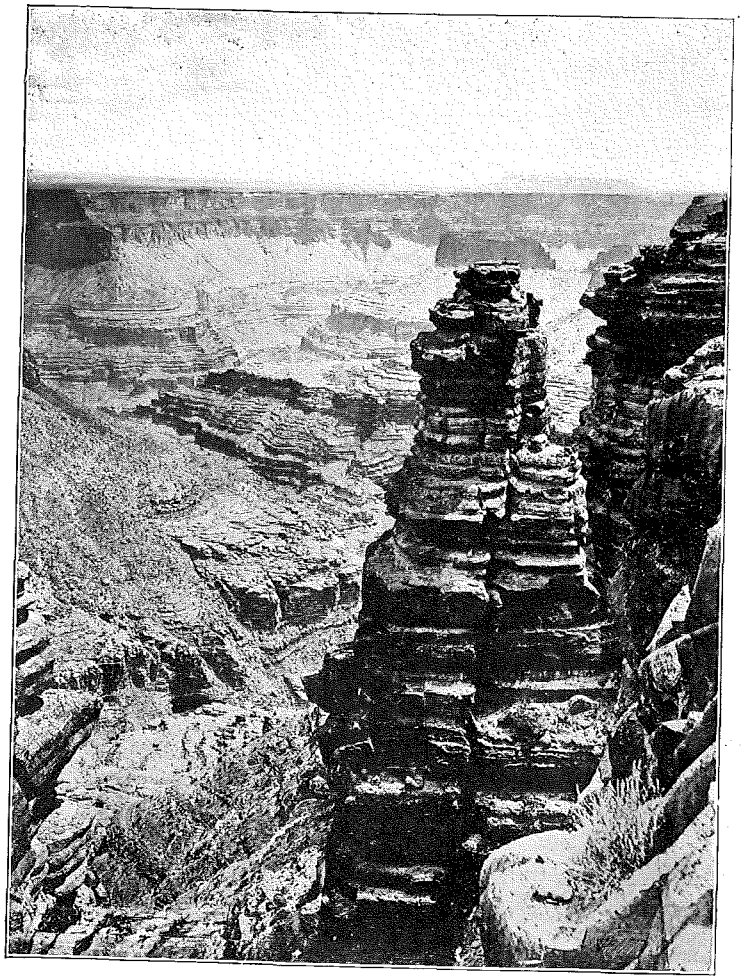


Plate 74. Marble Canyon of the Colorado River. The rocks in view are Supai formation, Hermit shale, Coconino sandstone, and Kaibab limestone, the latter forming the plateau. Shinumo Altar in the distance is an outlier of Moenkopi capped by Shinarump conglomerate. Looking northeast.

of the Tucson folio for the U. S. Geological Survey, but it is not yet published. Blake found the slopes of the main ranges to consist of pre-Cambrian schists and gneiss of various kinds with a nucleus of granite rocks which also extend into the Oracle region. Overlying Paleozoic rocks occur extensively, especially in the north slope, including shaly limestone with many Devonian fossils. Great masses of diorite penetrate the granite and overlying strata, and some of the limestones in the

latter are changed to marble. Bryan[1] has observed Tertiary conglomerate overlapping the southern margin of the range, which at the mouth of Sabino Canyon are tilted steeply and overlain by more recent sand and gravel.

Ransome[2] has given a brief resumé of the Santa Catalina geologic section as observed on a joint trip with Tolman. The following statement is made:

"The central feature of the range, as worked out by Mr. Tolman, is a great post-Carboniferous intrusive mass of siliceous muscovite granite modified to a gneissic rock near its margins, surrounded by a zone of intense contact metamorphism in which rocks of widely different kinds have been conspicuously affected. The oldest rock cut by this granite is a coarse, porphyritic biotite granite which, apparently as a result of the later granitic intrusion, grades into augen gneiss, and locally this rock in turn has been transformed into a thinly fissile schist.

"Resting upon a worn and weathered surface of the pre-Cambrian granite, as may be well seen on the east side of Oracle Ridge, north of Apache, is the Scanlan conglomerate, 10 to 12 feet thick, composed of imperfectly rounded pebbles of white quartz in a much silicified matrix. The conglomerate grades upward through several feet of very hard, white quartzite into fine-grained sericite schists—the locally metamorphosed Pioneer shale. In some localities in the Santa Catalina Range the crystalline texture is so well developed that these altered shales might easily be mistaken for the pre-Cambrian Pinal schist. It may be noted in this connection that the Pioneer shale has been metamorphosed to crystalline schist by the intrusion of granodiorite at Troy, in the Ray quadrangle, also. The metamorphism there, however, is on a much smaller scale than in the Santa Catalina Range. Overlying the schist in the vicinity of Apache is the Barnes conglomerate, showing its well-rounded ellipsoidal pebbles. Its thickness here is about 12 feet. Although it is more silicified than the typical conglomerate of the Ray quadrangle, there can be little doubt of its stratigraphic identity. Southeast of Apache, on the east slope of the range, the Barnes conglomerate is overlain by a quartzite which is correlated with the Dripping Spring quartzite, although its character has been modified by the prevalent metamorphism. Stratigraphically above the quartzite is a formation that is probably the Mescal limestone. In a few places the limestone shows some of the cherty bands so characteristic of this formation near Ray, but as a rule the beds are much metamorphosed. Some have been squeezed and kneaded so that the chert layers have been drawn out into thin, curly laminae; others have been changed to crystalline schist or to fine-grained garnet-epidote rock. The vesicular basalt that overlies the Mescal limestone in the Ray quadrangle was not recognized in the brief examination made of the Catalina Range.

[1]Bryan, K., *op. cit.*, Bull. 730b.

[2]Ransome, F. L., *op. cit.*, Prof. Paper 98-K, pp. 144-145.

"Above the Mescal limestone is a pebbly quartzite with bands of conglomerate and with thin, shaly, worm-marked beds near the top; in all probability this is the Troy quartzite.

"The quartzite is overlain by generally rather thin-bedded Devonian limestones, from which Mr. Tolman has collected fossils, followed in ascending stratigraphic succession by the thicker-bedded gray Carboniferous limestone. Finally, these formations are unconformably overlain by a thick series of red shales, containing some impure, sandy limestone, with a heavy limestone conglomerate at the base. These beds may possibly belong to the Manzano group, but Mr. Tolman has not yet found any fossils in them."

In a brief visit to the ridge south of Stratton Creek, on the northeastern slope of the range, I found the relations shown in Fig. 93. The precise locality is 1½ miles south of Tule Springs, or about 1 mile west by south of B. M. 4630.

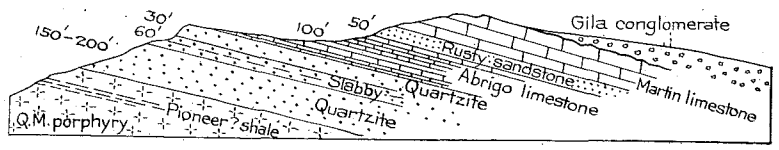


Fig. 93.—Cross section on northeast slope of the Santa Catalina Mountains.

The basal member in this section strongly suggests Pioneer shale, the quartzite not far above it is like the Dripping Spring, and the 60 feet of slabby beds next above resemble a siliceous representative of Mescal limestone such as I have seen in some parts of Gila County. It is overlain by 30 feet of sandstone somewhat like Troy. The 100 feet of slabby limestones, mostly sandy and dark, yielded trilobites and lingulae which enable us to correlate them with the Abrigo. The overlying Martin limestone contained characteristic Devonian fossils.

I made a somewhat detailed examination of the area about Shaw's Ranch 3 miles east of Vail on a spur of the southern part of the Santa Catalina Range. The results are set forth in the map and cross sections in Fig. 94. The Abrigo limestone, mostly very impure and sandy, yielded characteristic fossils. The underlying quartzite with its intruded diabase sills strongly suggests the Dripping Spring quartzite. It is not certainly ascertained, however, that it is separated from the overlying Abrigo beds by an unconformity. At the base to the westward is a conglomerate very like Scanlan conglomerate and some red shale of Pioneer type lying on pre-Cambrian granite. Faults complicate the relations somewhat and at several places portions of the younger limestone (Devonian and Carboniferous) are replaced by silica in large bodies which might easily be mistaken for quartzite. In the northern part of the area this limestone is thrust northward up the granite slope. The fault

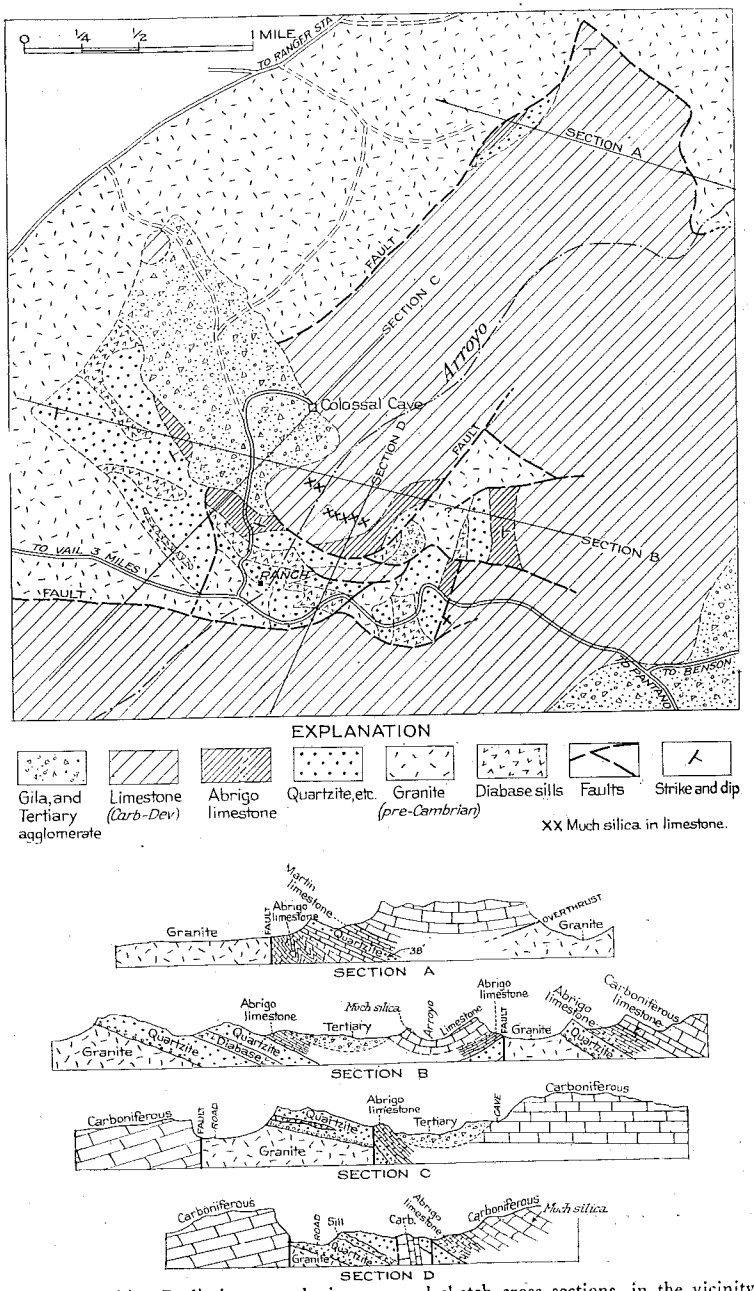


Fig. 94.—Preliminary geologic map, and sketch cross sections, in the vicinity of Shaw's Ranch, 3 miles east of Vail, Ariz., by N. H. Darton.

plane dipping south at an angle of about 20° is plainly exposed in the mountain slope, but to the southwest it develops into or is cut off by a nearly vertical fault plane. In section D is shown a block of it that is wedged in between areas of the quartzite.

Sierrita Mountains—Mineral Hill.—The Sierrita Mountains are a group of peaks and ridges of moderate elevation in the divide between Altar and Santa Cruz valleys, about 30 miles southwest of Tucson. Some data regarding their geology have been given by Ransome.[1] He found that the area consists mainly of intrusive granite with sedimentary rocks and later eruptives on the flanks. On the east are gray limestones with quartzite, shale, and altered andesite rocks. The strata are faulted and considerably metamorphosed. On the west the rocks are prevailingly schistose, closely compressed, and regionally metamorphosed. They include rocks which were conglomerate, sandstone, "graywacke," shale, limestone, and contemporaneous rhyolite and tuff; they appear to be older than the beds on the east side, but their age is undetermined. The crest and higher slopes of the range, judging by their aspect from a distance and material in streams, consist of fine-grained biotite granite somewhat resembling quartz monzonite. The schist on the west side of the range rises in ridges and knobs and in it occur the mines of the Papago district, mainly in limestone, which constitute many bodies from a few feet to 100 feet thick and from 100 feet to more than a mile in length, apparently lenticular deposits. These limestones are considerably silicified. Next west are schists with a few thin beds of dark quartzite, with probable basal conglomerate, which make the ridge known as Hiram Mountain, on the west side of which is coarse granite of probable pre-Cambrian age. Ransome gives the following section:

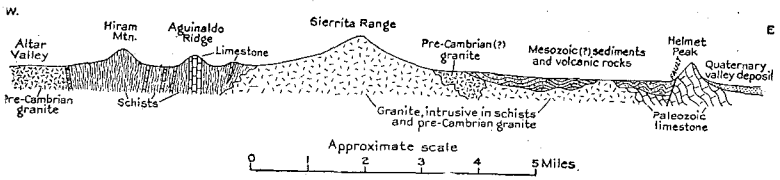


Fig. 95.—Sketch section across the Sierrita Mountains, Arizona.

On the east side of the mountain is a slope of fine-grained intrusive granitic rock, with limestone and interbedded quartzite appearing in Mineral Hill, Helmet Peak, and the hills near Twin Buttes. A few fossils from this limestone were determined by G. H. Girty as probable Pennsylvanian. A poorly preserved form which I found in limestone on the west slope was submitted to E. Kirk and determined as a probable *Camerotoechia* of Devonian age. About Mineral Hill and Twin Buttes is porphyritic intrusive granite, and west of Mineral Hill is a coarse,

[1]Ransome, F. L., Ore Deposits of the Sierrita Mountains: U. S. Geol. Surv., Bull. 725 (j), pp. 407-428, 1922.

crumbling granite with diorite, thought to be pre-Cambrian. In Mineral Hill quartzite appears, and on the south side is limestone downfaulted and penetrated by granite. Between San Xavier Mine and Helmet Peak are red and green shales and hard, thin-bedded sandstone, probably Mesozoic (Lower Cretaceous) in age, in one place faulted against the limestone. West of this area is a rock locally regarded as rhyolite, but which may be an altered arkosic sandstone. Andesite occurs about the Prosperity and Paymaster mines, west of which is granite which may be pre-Cambrian.

Tucson and Amole mountains.—The short range of mountains lying just west and northwest of Tucson have been described by Jenkins and Wilson.[1] The principal rocks of the higher ridges are flows and stocks of rhyolite and andesite, in part porphyritic. Amole Peak and some other knobs consist of intrusive rhyolite. Granite and granodiorite, apparently all intrusive, occur on the west side of the north end of the range. In the Picacho de la Calera is Pinal schist, overlain by 200 feet of quartzite, probably Bolsa, and slabby limestone of typical Abrigo character, 300 feet thick, in which I found *Lingulella* sp., and trilobites of Upper Cambrian age. This formation is overlain by massive limestone and limy shales carrying abundant *Atrypa reticularis* (Devonian), and the overlying massive limestones are of Carboniferous age. The following section shows the relations at this place:

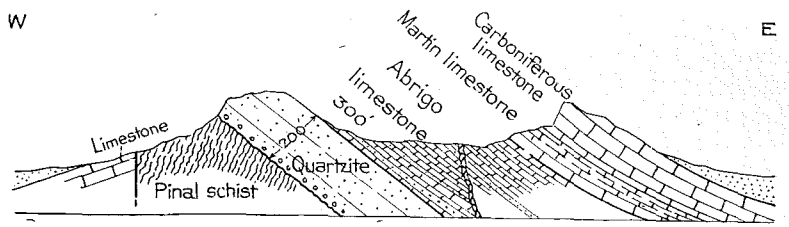


Fig. 96.—Section at Picacho de la Calera, 16 miles northwest of Tucson, by N. H. Darton.

Along the foot of the southwest side of the Tucson Mountains are gray sandstones and shales believed to be of Lower Cretaceous age. They lie nearly level and are overlain by the Tertiary volcanic succession to the east and a sheet of rhyolite on the west. Farther north they are faulted against a thick body of red, sandy shale and arkosic sandstone with an included bed of typical agglomerate or conglomerate with much andesitic material, all of Tertiary age. The fault is well exposed. The relations at this place are shown in the following section:

[1]Jenkins, O. P., and Wilson, E. D., A Geological Reconnaissance of the Tucson and Amole Mountains: Univ. of Ariz. Bull. 106, Geol. Series No. 2, pp. 1-8, 1920.

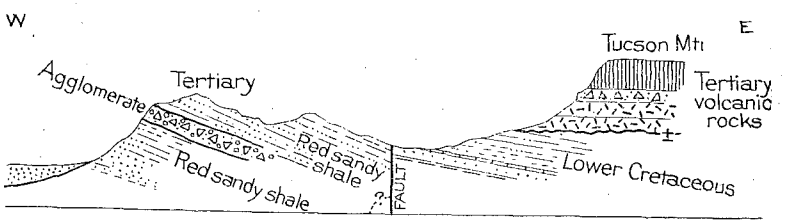


Fig. 97.—Section of the west side of the Tucson Mountains about 3 miles south of the Ajo Road or 2 miles south of Amole Peak. By N. H. Darton.

The rocks in the Tucson Mountains, according to Guild,[1] comprise rhyolite, rhyolite tuff, biotite hornblende andesite, pyroxene andesite, and several basalts. In the Tumamoc Hills Tolman[2] found a succession of andesite, basalt in two flows, rhyolite tuff and basalt flows, and intrusives. It is probable that the latter are Pleistocene.

Silver Bell Mountains.—Excepting in the vicinity of the mines of Silver Bell very few facts have been recorded regarding the geology of this range. According to Tolman[3] there occur in Silver Hill at Silver Bell 3,700 feet of alternating quartzite, shaly quartzite, and limestone, the latter yielding Carboniferous fossils. An extensive intrusion of alaskite porphyry contains blocks of the limestone and there are also later dikes of andesite and trachyte porphyry. Near by is an overlap of rhyolite, andesite tuff, and conglomerate of the Tertiary volcanic series, and recent lava flows.

Many details of relations of the rocks and ores have been given by Stewart.[4] He mentions one block of altered limestone nearly 2 miles long and more than 2,000 feet wide enclosed by the alaskite. The marbles present many interesting metamorphic features. He also describes relations of biotite granite and quartz porphyry intrusives and of other porphyry and andesite dikes. Some of the so-called quartzites are believed to be silicified igneous rocks.

Waterman Mountains.—This small range, 25 miles northwest of Tucson, presents extensive outcrops of Carboniferous limestone, apparently in large part Naco. On the east side of the range this rock is faulted against reddish shale which may be Tertiary, and it is cut by an intrusive rock, apparently quartz monzonite porphyry. A prominent lens of quartzite is included in the middle of the limestone succession. Not far above this quartzite member (east) I found fossils determined

[1]Guild, F. N., Petrography of the Tucson Mountains, Pima County, Arizona: Am. Jour. Sci., 4th ser., vol. 20, pp. 313-318, 1905.
[2]Tolman, C. F., Geology of the Vicinity of the Tumamoc Hills: Carnegie Inst., Pub. 113, pp. 67-82, map, 1909.
[3]Tolman, C. F., Jr., Copper Deposits of Silver Bell, Arizona: Min. & Sci. Press, vol. 99, pp. 710-711, 1909.
[4]Stewart, Charles A., The Geology and Ore Deposits of the Silver Bell Mining trict, Arizona: Am. Inst. Min. Eng., Trans., vol. 43, pp. 240-290, 1913.

by G. H. Girty as follows: sponge?, *Triplophyllum?* sp., *Batostomella?* sp., *Phyllopora?* sp., *Productus occidentalis*, *Squamularia* aff. *perplexa*, *Composita* aff. *mexicana*, and *Phymatifer* sp. This fauna is that of the Kaibab limestone, of Permian age. A spirifer found in another bed suggests the presence of Mississippian strata lower in the section.

Comobabi Mountains.—The two groups of ridges in this range consist mainly of granite and schist. Bryan[1] discovered in the center of the area about the Indian village of Comobabi, a mass of sandstone and arkose of supposed Tertiary age.

Baboquivari and Coyote Mountains.—Very little is on record regarding the geology of this prominent range which extends for 50 miles north and south through the south-central part of Pima County. Granite and schists appear to be the principal rocks. Bryan[2] refers to gneiss of supposed pre-Cambrian age sheeted on a large scale, a feature which is strongly expressed in the configuration of the ridge. Red shale and arkose (Cretaceous?) were noted by Bryan faulted against the gneiss of Coyote Mountain, but are not shown on the map in his report.

Quijotoa and Brownell Mountains and Sierra Blanca.—These ridges consist of granites of various kinds and the portions to the north and south present a thick succession of Tertiary volcanic rocks. Very few data are available as to their relations. At the Black Prince Mine north of Pozo Blanco on the east foot of the Sierra Blanca, Bryan[3] noted blue limestone, possibly Paleozoic in age, associated with red shale and arkose sandstone of probable Cretaceous age. On the west slope of this range I found a succession of west-dipping strata lying on the schist. At the base is quartzite suggesting Bolsa, which is overlain by 400 feet of limestones having many of the features of the Devonian to Pennsylvanian succession, but yielding no fossils.

Little Ajo Mountains.—According to Bryan,[4] the copper ores of Ajo are in part disseminated in monzonite and in part occur in veins in rhyolite and tuff into which the monzonite is intruded. These rocks, which I believe are of Tertiary age, constitute much of the eastern part of the Little Ajo Mountains. Ajo Peaks consist of younger conglomerate, and Black Mountain consists of lava flows. The western part of the range is mainly gneiss and schist of supposed pre-Cambrian age. Details regarding the relations at the Cornelia copper mine are given by Joralemon.[5] Here the rhyolite succession comprises lava, breccia, and tuff beds which are cut and domed by a great intrusion of monzonite that varies somewhat in character from place to place. Later dikes of diorite or diabase porphyry also occur. The most recent rock in the vicinity is a coarse conglomerate containing fragments of rhyolite and monzonite.

[1]Bryan, K., *op. cit.*, map.
[2]Bryan, K., *op. cit.*, p. 22.
[3]Bryan, K., *op. cit.*, pp. 24-25.
[4]Bryan, K., *op. cit.*, p. 25.
[5]Joralemon, I. B., The Ajo Copper District: Am. Inst. Min. Eng., Trans., vol. 49, pp. 593-609, 1914.

Growler Mountain.—According to Bryan very nearly all of this prominent range consists of a succession of 1,200 to 1,500 feet of Tertiary lava, tuff, and conglomerate. Its northern part presents a high face to the west and in places along the flanks, notably in Growler Pass, the underlying granites and gneiss are exposed.

In Growler Pass are at least five faults trending north. In the easternmost block the beds are horizontal, but in the others the strata are tilted at low angles. South of the pass there are large lava plateaus separated by narrow canyons and probably separated by faults as the beds dip in various directions. Bryan[1] also mentions an outcrop on the east side of Growler Pass of limestone and quartzite much altered and broken. Fractured and altered porphyritic felsite also occurs at this place.

I found that the limestone was extensively exposed at the Dixie Mine, and again in a large butte some distance north, where part of the beds are cut off by a coarse granite. Most of the limestone is considerably altered. No fossils were observed, but the beds present many characteristics of the Carboniferous succession to the east and north, and I believe that they represent this age.

Puerto Blanco Mountains.—This range consists mainly of the Tertiary volcanic rocks with the old schists showing in places. In outlying knobs, west and southwest of Dripping Spring, I found exposures of limestone which probably are of Carboniferous age, for they yielded a few crinoid stems and strongly resemble the strata of that age in other parts of the Southwest. At one point a 20-foot bed of basal quartzite is exposed lying on the schist. The greatest thickness of strata observed was about 600 feet, and many of the beds are altered to marble, probably by an intrusive granite which cuts them off to the north.

Tumacacori Mountains.—This range consists of several high ridges and scattered groups of hills lying mostly in the western part of Santa Cruz County and extending south to the International Boundary. Very few data are on record as to the geology. It was noted that a large part of the central range consists of the Tertiary volcanic succession similar to that which occurs in the Santa Rita Mountains.

Bryan[2] mentions supposed Cretaceous rocks in this range. Just east of the Montana Mine is a great mass of red sandstone, conglomerate, and shale dipping steeply west and overlain unconformably by tuff. Both east and west of Arivaca are red and green shales with incipient, slaty cleavage, all probably Cretaceous.

COCHISE COUNTY

Mule Mountains and Bisbee Region.—The greater part of the Mule Mountains, together with the Naco Hills and portions of the adjacent plains, are included in the Bisbee quadrangle. The geology of this

[1]Bryan, K., *op. cit.*, p. 23.
[2]Bryan, K., *op. cit.*, p. 24.

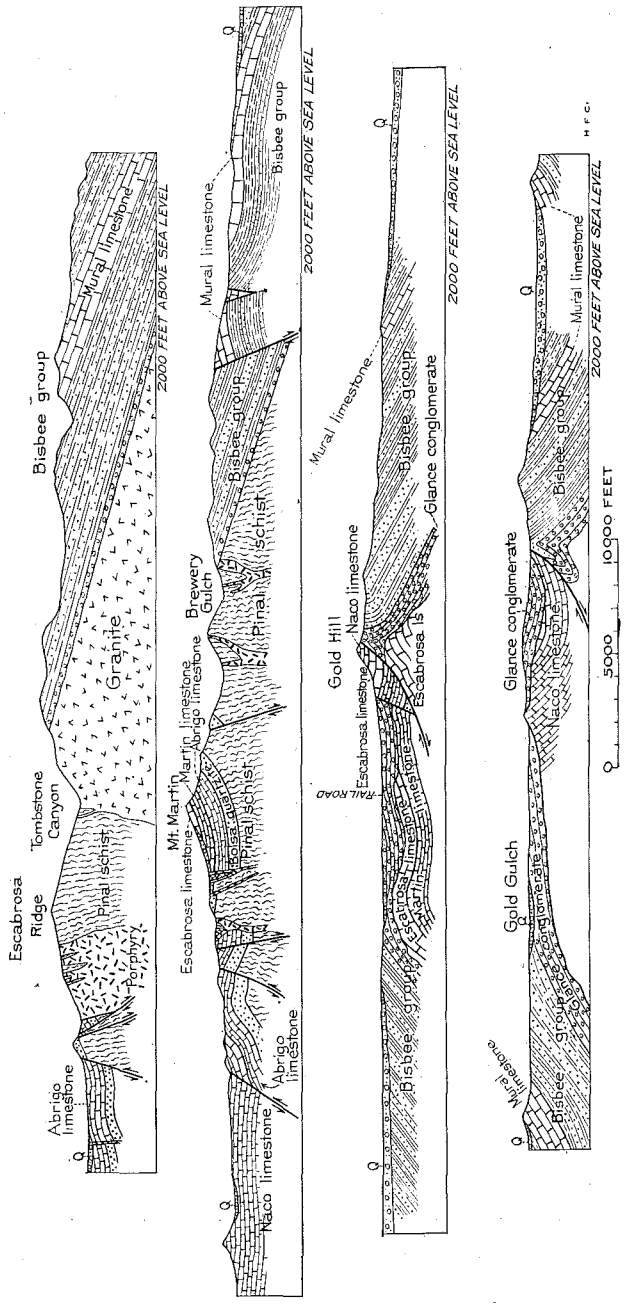


Fig. 98.—Sections across the Mule Mountains in the Bisbee Region, by Ransome.

quadrangle has been described in detail by Ransome,[1] Bonillas[2] and others. The principal features of rock succession and general structure are shown in Fig. 98, copied in slightly simplified form from the professional paper by Ransome. The formations comprise Pinal schist, Bolsa quartzite, Abrigo, Martin, Escabrosa, and Naco limestones, Comanche series and igneous granites. The Pinal schists, which are believed to have been shales and arkosic sandstones, were folded and metamorphosed to their present crystalline condition in pre-Cambrian time. The basal, Paleozoic formation lying unconformably on the schist is the Bolsa quartzite. It is from 400 to 500 feet thick and is overlain by about 750 feet of slabby, Abrigo limestone which has many intercalated, cherty layers; both formations are regarded as Upper Cambrian. (See Pls. 6 and 7.) The Martin limestone, 300 to 350 feet thick, is of later Devonian age. Ordovician, Silurian and early Devonian, and later Mississippian time are not represented.[3] The early Mississippian is represented by the Escabrosa limestone, 700 feet thick, and the Pennsylvanian and probable Permian by the Naco limestone, probably 3,000 feet thick. These rocks are overlain unconformably by a thick succession of Lower Cretaceous (Comanche) rocks comprising at base the Glance conglomerate, 25 to 500 feet, Morita formation of sandstones and shales, 1,800 feet, Mural limestone, massive-bedded above and thin-bedded and in part sandy below, 650 feet, and at the top the Cintura formation, shales and sandstones, 1,800 feet or more. There has been general uplift of the strata with considerable faulting at two or more periods and erosion has bared the various rocks, in places down to the basement of Pinal schist. The Lower Cretaceous beds were deposited on an unevenly eroded surface of the uplifted rocks and they in turn have been uplifted, faulted, and eroded. Prior to this epoch considerable granite and porphyry were intruded which had much to do with the beginning of mineralization, which progressed at later times.

Tombstone Hills.—The geology of the Tombstone district has been studied in detail by Ransome, but only a brief resume of the results has been published.[4] The geologic features resemble those at Bisbee in many respects. There is a local uplift of Paleozoic rocks lying on a basement of pre-Cambrian schist and granite and overlain by sandstone, shale, and limestone of probable Lower Cretaceous age. There are large, intruded bodies of quartz monzonite and porphyry which cut both older and

[1]Ransome, F. L., Geology and Ore Deposits of the Bisbee Quadrangle, Arizona: U. S. Geol. Surv., Prof. Paper 21, 165 pp., maps, 1904. Bisbee Folio, U. S. Geol. Surv., No. 112; republished with slight additions. Also Geology and Copper Deposits of Bisbee, Arizona: Am. Inst. Mng. Engrs., Trans., vol. 34, 1903, pp. 618-642, 1904.

[2]Bonillas, Y. S., Tenney, J. B., and Feuchére, M., Geology of the Warren Mining District: Am. Inst. Min. Eng., Trans., vol. 55, pp. 284-355, 1917.

[3]Possibly some of the Abrigo strata are Ordivician.

[4]Ransome, F. L., Bisbee and Tombstone Districts, Cochise County, Arizona: U. S. Geol. Surv., Bull. 710 (d), 1920; and Ransome, F. L., Some Paleozoic Sections in Arizona and Their Correlations: U. S. Geol. Surv., Prof. Paper 98 (k), pp. 148-149, and plate XXV, 1916.

younger strata. There is also considerable faulting. The map in Fig. 99 shows the distribution of the formation and indicates the principal structural relations.

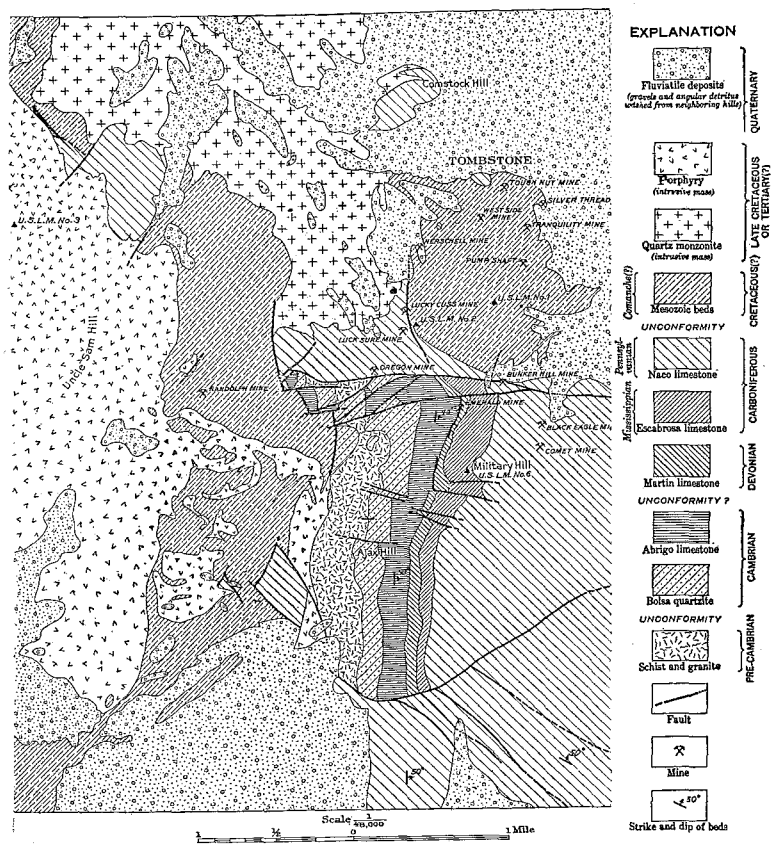


Fig. 99.—Preliminary geologic map of the Tombstone District, Arizona, by F. L. Ransome.

The basement rocks are fine-grained Pinal schist with intruded gneissic granite, which outcrop in a small area near Ajax Hill. They are overlain by 440 feet of Bolsa quartzite and 700 feet of Abrigo limestone, the latter presenting its characteristic alternations of thin limestone and cherty layers, with a 5-foot bed of white quartzite at top. (See Pl. 7b.) Next above is Martin limestone (Devonian) 340 feet, Escabrosa limestone (Mississippian) about 500 feet, and Naco limestone from 2,000 to 3,000 feet.

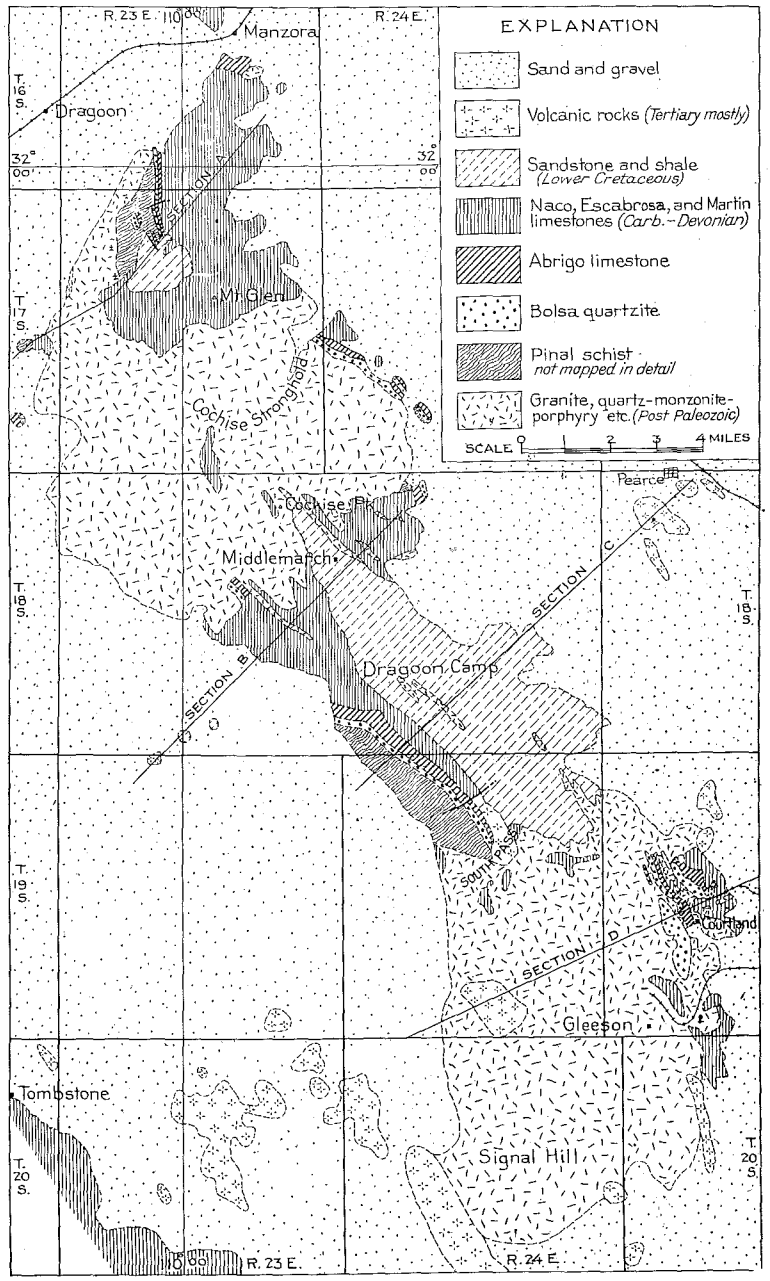


Fig. 100.—Reconnaissance geologic map of the Dragoon Mountains, by N. H. Darton.

Dragoon Mountains.—The prominent ridge known as the Dragoon Mountains extends along the west side of Sulphur Spring Valley from the middle of Township 20 to the Southern Pacific Railroad which passes through Dragoon Gap at its northern end. The geology has not

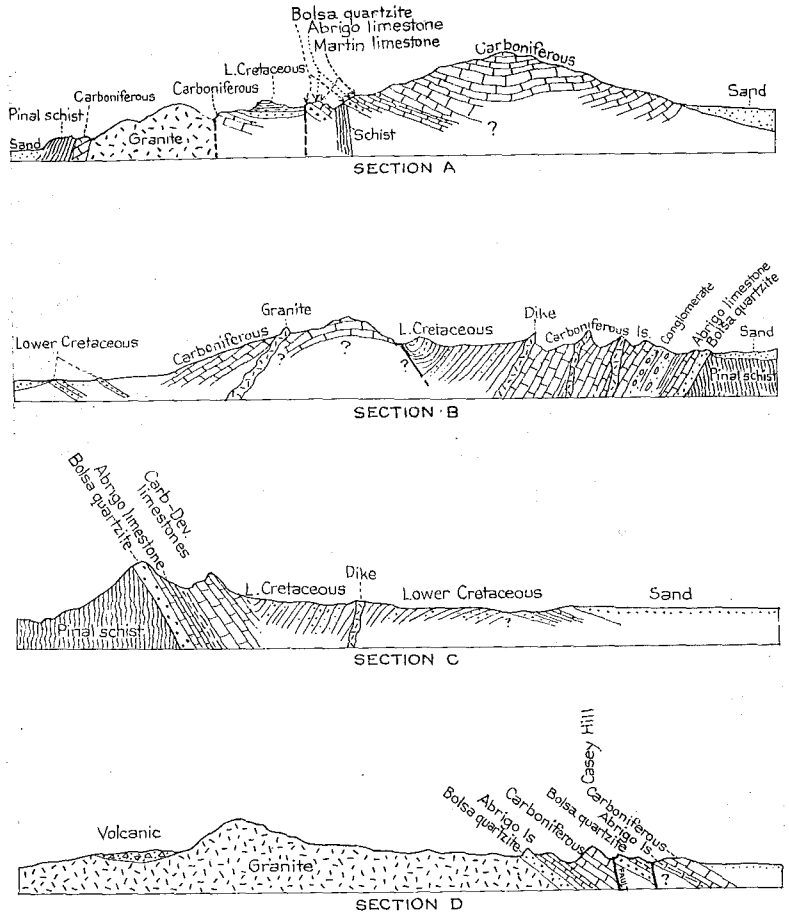


Fig. 101.—Sketch sections across the Dragoon Mountains along lines shown on the map, Fig. 100.

all been mapped in detail, but the facts available as to distribution of the rocks and their structure are given in the reconnaissance map in Fig. 100, and the cross sections in Fig. 101. The important mining districts about Courtland and Gleeson are in the southeastern part of the mountains. The range consists largely of post-Cretaceous granite with some

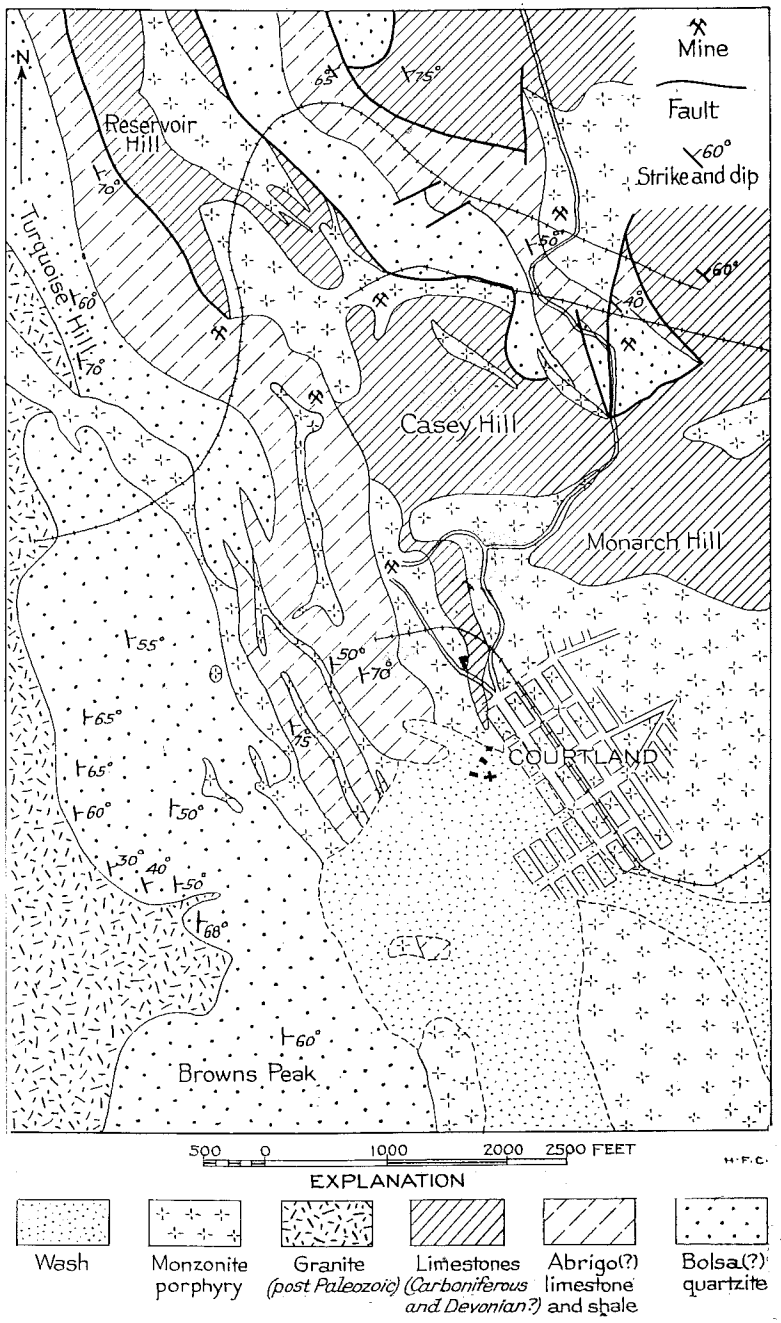


Fig. 102.—Geologic map of the region about Courtland, Arizona, after W. G. McBride, with slight changes by F. L. Ransome.

monzonite and other intrusive rocks. Most of these cut Pinal schist, Bolsa quartzite, Abrigo limestone, Martin limestone, limestones of Carboniferous age, and strata of Lower Cretaceous age. Small areas of Tertiary volcanic rocks occur among the ridges and on the flanks of the range. The strata are considerably altered by the igneous intrusions and many large detached masses of the limestone are included in the granite.

The limestone succession exposed in the northern end of the Dragoon Mountains, with a thickness in excess of 2,000 feet, is mainly Naco limestone. Some of the underlying (Martin or Escabrosa?) beds on the west side are altered to marble, which has been quarried to a small extent. In the higher part of the succession is a member of red sandstone and much coarse, limestone conglomerate. The latter appears to grade into the fine-grained limestone and also into gray shale, otherwise it might be regarded as post-Carboniferous. The boulders are limestone of various colors, some marble, and considerable sandstone. Another large mass of the conglomerate was noted west of Dragoon Camp. A few narrow dikes of diabase occur in the limestone near the south end of the mountain. Near the old Golden Rule Mine, a few rods south of Manzoro Station, the Abrigo limestone outcrops for a short distance, cut off to the south by a mass of igneous rock resembling monzonite. This limestone also occurs in the west slope of the range 3 miles southeast of Dragoon Station, where it is underlain by Bolsa quartzite lying on Pinal schist. (See section A.) An outlier of Cretaceous rocks occupies a basin in the center of the range in this area. In the vicinity of Cochise Stronghold, where the mountain is about 7 miles wide, there is a large mass of intrusive granite which cuts across the limestone and also includes large detached masses of the latter rock. North of South Pass for some distance the crest of the range consists of typical Bolsa quartzite dipping steeply eastward and lying on Pinal schist. On the east slope this quartzite is overlain by a regular succession of Abrigo, Martin, Escabrosa, and possibly higher limestones, overlapped to the east by a thick body of gray and brown sandstones of Lower Cretaceous age, dipping steeply west as shown in section C. A mass of Tertiary volcanic deposit consisting mainly of agglomerate lies against the south slope of the mountain on the South Pass road.

In the mining districts of Gleeson and Courtland the Bolsa quartzite and overlying limestones are exposed, cut by granite and monzonite porphyry. Ransome[1] has briefly described the features and reproduced with slight alteration a geologic map of the Courtland district by W. G. McBride of the Great Western Copper Company, which is given in somewhat simplified form in Fig. 102. (See also section D, Fig. 101.)

I found the Abrigo limestone well characterized at this place, although locally considerably altered, lying on Bolsa quartzite. The latter lies on granite, but, as Ransome stated, the contact appears to be a plane of

[1]Ransome, F. L., Turquoise Copper Mining District, Arizona: U. S. Geol. Surv., Bull. 530-c, pp. 3-12, 1912.

intrusion. The Martin and Escabrosa, and probably the Naco limestones are represented, but there is so much faulting that the relations of these beds could not be ascertained without detailed study. Quartz monzonite intrusions are extensive and may include two varieties of porphyry.

Dos Cabezas Mountains.—Very few facts are on record regarding the structure of this range. It includes an important mining district about Mascot, the geology of which will be described in a forthcoming report to be published by the Bureau of Mines.[1]

In 1919 I found that the section of lower Paleozoic rocks near the railroad about 2 miles west of the village of Dos Cabezas has relations shown in the following section:

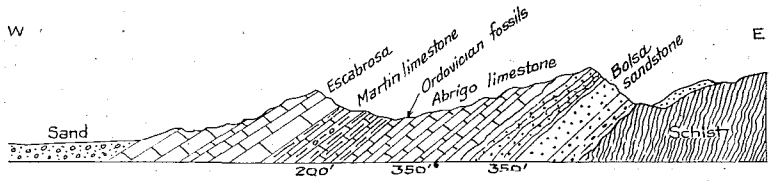


Fig. 103.—Sketch section of the foothills of the Dos Cabezas Mountains, 2 miles west of Dos Cabezas village.

The limestone under the Martin had all the characteristics of the Abrigo beds at Bisbee, but Ordovician fossils were found in the upper beds. (See p. 54.) Most of the limestone of the formation has slabby bedding, weathers to a light blue-gray color, and has brown reticulating stems of a supposed seaweed on many of the bedding planes. In

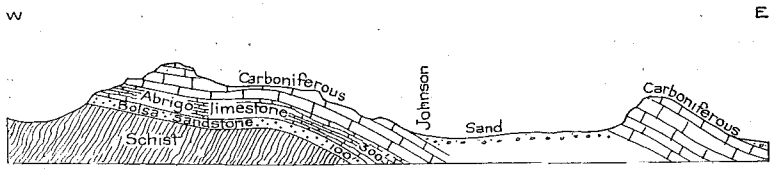


Fig. 104.—Sketch section through the Johnson mining district.

these peculiarities it resembles the El Paso limestone of southwestern New Mexico, as well as the Abrigo, Longfellow, and Muav limestones. The underlying beds for 200 feet are mostly slabby sandstones and limestones lying on 150 feet of quartzite, doubtless Bolsa, but here somewhat limy and shaly at the base. The basal member lies on pre-Cambrian schist.

[1]Abstract: Sarle, C. J., Sketch of the Geology of the Dos Cabezas Mountains, Science, new ser., vol. 55, p. 544, 1922 (in which Beekmanton fossils are mentioned).

Little Dragoon Mountains.—The ridges lying north of Dragoon Station in the southeastern part of Cochise County are known as the Little Dragoon Mountains. They include the important mining district about Johnson. The rocks exposed are pre-Cambrian schist, granite of post-Paleozoic age, Bolsa quartzite, and Abrigo, Martin, and overlying Carboniferous limestones. The latter constitute the high ridge just west of Johnson mining camp and also a ridge on the east side of the valley east of the camp. The section in Fig. 104 shows the general features. The Abrigo limestone, about 300 feet thick, consists mostly of slabby beds and includes considerable sandy shale. At the top is a sandy member somewhat similar to the top sandstone near Bisbee.

Whetstone Mountains.—Very few facts are on record regarding the geology of this range. Its high ridges consist of a regular succession of the Paleozoic rocks lying on a basement of pre-Cambrian granite and flanked on the north and on the southwest by Lower Cretaceous strata. Granite constitutes the ridges and peaks on the northeastern end of the mountain, and a small area of Pinal schist was found along its eastern margin faulted against Carboniferous limestone. The section in Fig. 105 shows the principal features in the western part of the range.

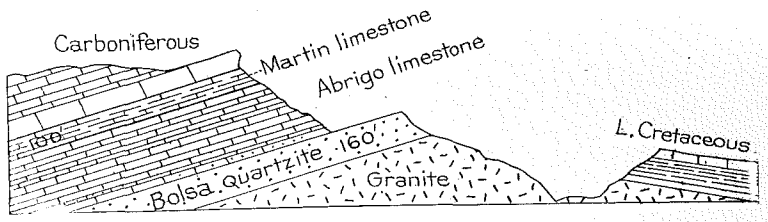


Fig. 105.—Sketch section across the northern end of the Whetstone Mountains, by N. H. Darton.

The basal quartzite is similar to the Bolsa quartzite in the Bisbee region and doubtless represents that formation. Above it are 300 feet or more of typical Abrigo limestone, in the lower part of which a few lingulae and trilobite fragments were found. It is nearly all slabby limestone, much of it weathering to a light blue color, and on many of the bedding planes are the characteristic brown reticulating stains supposed to be caused by a seaweed. The lower beds are less pure than the upper ones and they include many layers of brown sandstone and greenish gray shale. In overlying shaly limestone abundant fossils were found of the Martin fauna (Devonian) at the foot of a prominent cliff of white limestone. There is a great thickness of overlying limestones in the higher central part of the mountain, doubtless representing the Escabrosa and Naco. In a downfaulted block of this limestone, on the east side of the mountain, I collected the following fossils: *Campophyllum torquim*, *Syringopora* sp., *Productus coloradoensis*, *Dielasma bovidens?*, *Spirifer rockymontanus*, *Composita subtilita*, *Deltopecten?* sp., and *Belle-*

rophon? sp. They were determined by G. H. Girty, who regarded them as Pennsylvanian (Magdalena) forms. The high southern summit known as Granite Peak appears to be a porphyritic intrusive rock cutting the Cretaceous strata.

Sulphur Spring Valley.—The geology of this long, wide valley, which occupies a large part of the central area of Cochise County, has been described by Meinzer.[1] Special attention is given to the valley fill and its water content available for economic use. Stream deposits and lake deposits are treated and records given of various deep borings which throw light on the underground conditions. It is shown that the great playa extending south from Willcox has had an extended lacustrine history. A lake extended into the north basin in comparatively recent geologic time and probably a larger lake existed at an earlier period. Beach deposits and shore sand dunes indicate the location of the shores for the longer periods of inundation.

[1]Meinzer, O. E., and Kelton, F. C., Geology and Water Resources of Sulphur Spring Valley: U. S. Geol. Surv., Water-Supply Paper 320, 231 pp., pls. 1913.