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BULLETIN 435

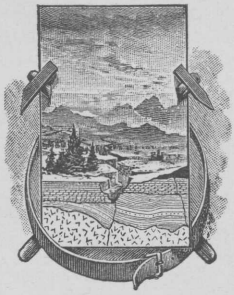
A RECONNAISSANCE

OF PARTS OF

NORTHWESTERN NEW MEXICO AND NORTHERN ARIZONA

BY

N. H. DARTON



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A RECONNAISSANCE OF PARTS OF WESTERN NEW MEXICO AND NORTHERN ARIZONA.

By N. H. DARTON.

INTRODUCTION.

This report sets forth the results of an investigation of the geology in the vicinity of the Atchison, Topeka and Santa Fe Railway from Albuquerque, N. Mex., to Kingman, Ariz. The principal purpose was to determine the prospects for obtaining deep-seated underground water supplies, and to do this it was necessary to ascertain the succession and structure of the rocks throughout a broad area, especially

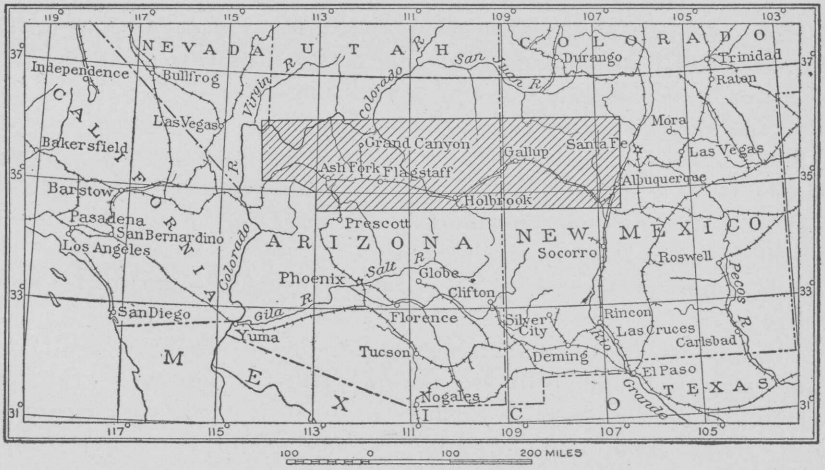


FIGURE 1.—Map showing location of area treated in this report.

in the high plateau of Arizona. Descents were made into the Grand Canyon of the Colorado at various places; other trips led to the southern margin of the plateau. The area examined is shown in figure 1.

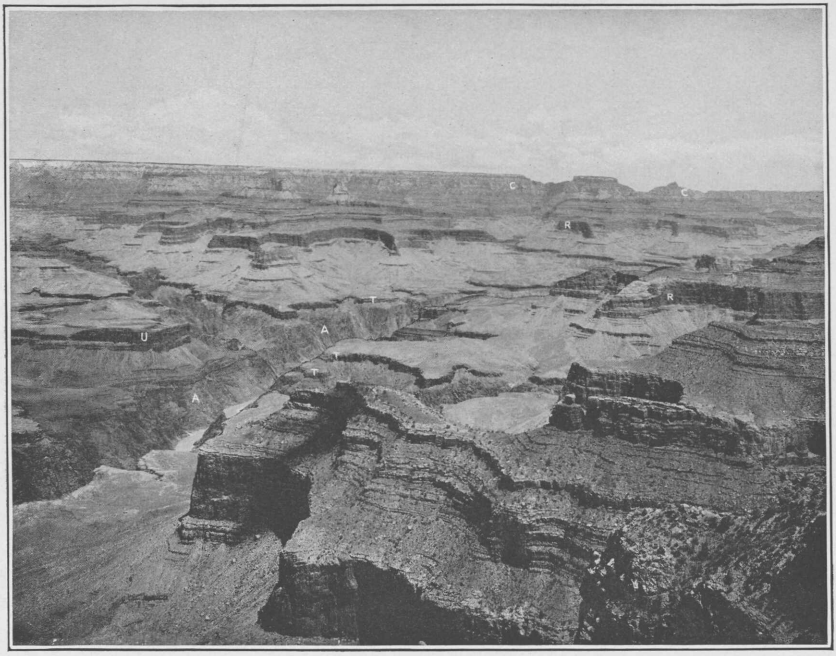
In past years several geologists have visited portions of the region and have recorded a large number of facts; and I have utilized these

as far as possible in this report, partly interpreting them in the light of later observations. In the course of the field work many new facts were obtained, especially as to the character, thickness, and boundaries of the formations. The principal publications of previous observers are listed at the end of this report.

GEOGRAPHY.

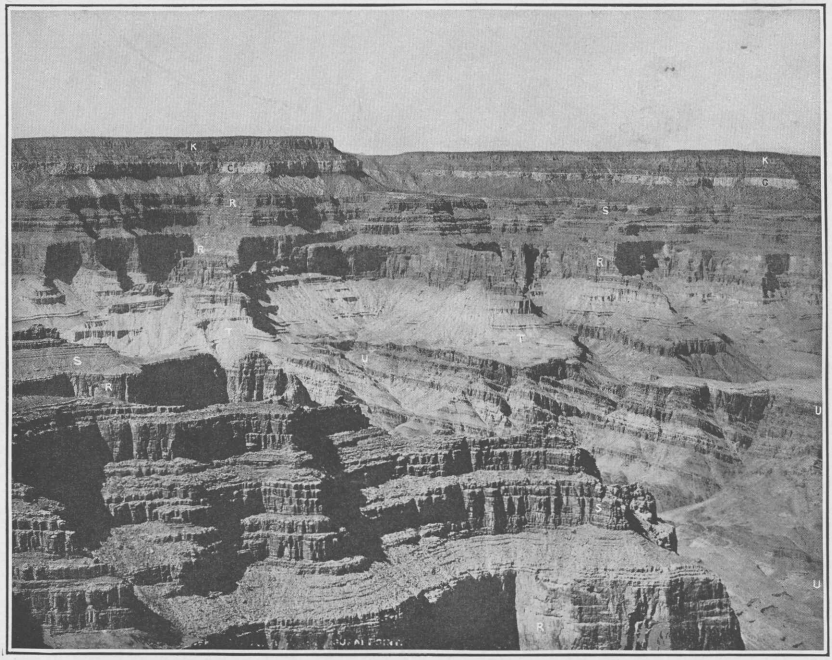
The region here treated lies mostly in the plateau province, but its east end is in the Rio Grande Valley and its western portion extends into the deserts. The plateau in north-central Arizona reaches an altitude of over 8,500 feet, and through it Colorado River has cut the deep gorge known as the Grand Canyon (Pl. II). The bottom of this canyon is 2,436 feet above sea level at the mouth of Bright Angel Creek. On a portion of the plateau are thick masses of lavas of various kinds, constituting several notable mountains, one of which, San Francisco Peak, has an altitude of 12,611 feet, standing about 5,500 feet higher than the adjoining region. South of Williams and Flagstaff the high plateau ends in an escarpment known as the Verde Breaks, which descends abruptly into the Verde Valley. The descent here is about 2,500 feet and is effected by high steps similar to those in the Grand Canyon. Northwestward from Ash Fork there is a drop of 1,000 feet or more to a lower plateau or shelf of Redwall limestone which occupies a wide area from the Juniper Hills northward. The Santa Fe Railway descends this escarpment in Johnson Canyon, a few miles east of Ash Fork, but here the slope is partly masked by lava flows, and farther west it is hidden for some distance by the great flows in the Mount Floyd area. This escarpment forms the prominent Aubrey Cliffs north of Seligman and extends continuously to the Grand Canyon, beyond which it marks the southwest margin of the Shiwits Plateau. It finally approaches close to the Grand Wash Cliffs north of Pierce Ferry.

The plateau of Redwall limestone alluded to above is nearly 20 miles wide, reaching from the Juniper Hills to longitude 114°. It terminates on the west in a great escarpment, which with long slopes of the Tonto group and of granite descends to the great desert valley on the west. This scarp attains its greatest prominence in Music Mountain, where its height is 3,500 feet. Farther north, where it marks the Grand Wash fault and is known as the Grand Wash Cliffs, its height is 3,000 feet above the desert plain at its foot. South of Music Mountain the escarpment separates into two broad steps, the lower one covered by extensive lava flows lying on an irregular floor of granite. The western margin of the lower step, termed the Cottonwood Cliffs, is about 2,000 feet high for some distance



A. VIEW ACROSS GRAND CANYON AT THE MOUTH OF BRIGHT ANGEL CREEK.

R, Redwall limestone; **T,** sandstone of Tonto group; **C,** Coconino sandstone; **U,** Unkar group; **A,** granite and gneiss.



B. VIEW ACROSS GRAND CANYON NEAR MOUTH OF SHINUMO CREEK.

R, Redwall limestone; **C,** Coconino sandstone; **S,** Supai (red sandstone and shale); **K,** Kaibab limestone; **U,** Unkar group, overlain by Tonto group. **T.**

south of Truxton. A few miles east is the Redwall limestone escarpment of somewhat less height, which extends by Cross Mountain to the south end of the Juniper Hills. West of the Grand Wash and Cottonwood cliffs are desert valleys of which Hualpai Wash is a part. Out of these valleys a number of long, narrow granite ridges trending north and south rise from 2,500 to 4,000 feet; Hualpai Peak, one of the summits, reaches an altitude of 8,266 feet.

The high limestone plateau ends on the northeast in slopes descending gradually to the valley of the Little Colorado. East of that valley is a wide district of rolling highlands, which to the north rise by massive steps and long slopes to the high mesas on which the Hopi pueblos are situated. These steps and slopes are known as the Painted Desert, from the high walls of bright-colored sandstones extending through the country. The land gradually rises to the east, finally culminating in the continental divide in western New Mexico. This divide is crossed by the railway near Thoreau, at an altitude of about 7,225 feet, in a transverse valley with the bare high cliffs of bright-red Triassic sandstones on the north and the wooded slopes of the Zuni Mountains on the south. These mountains form a narrow isolated range extending about 70 miles from northwest to southeast and reaching, in Mount Sedgwick, an altitude of 9,200 feet, or about 2,200 feet above the surrounding region. To the east is an area of very irregular configuration, sloping to the Rio Grande valley and presenting a succession of wide valleys and high plateaus. Two of the most notable of the plateaus are the Acoma Mesa, capped by lava, and a similar mesa north of the San Jose Valley, surmounted by the great volcanic mass of Mount Taylor, which rises to an altitude of 11,389 feet. Sixty miles northeast are the Nacimiento Mountains, a long, narrow ridge extending north and south with a steep western face and broad rough eastern slopes. In San Pedro Peak, this ridge reaches an altitude of 10,162 feet, or over 3,000 feet above the plains to the west.

GEOLOGY.

STRATIGRAPHY.

PRELIMINARY OUTLINE.

In the region treated in this report there is an extensive succession of strata ranging in age from Algonkian to Quaternary. The general order and average thickness of the rocks of the region are shown in the accompanying table (pp. 12–13) and in figure 2.

In northwestern New Mexico the sedimentary succession begins with the Pennsylvanian. The Jurassic and Lower Cretaceous are not known to be present, but the Upper Cretaceous appears to be com-

plete from Dakota to "Laramie," with a total thickness of 4,000 feet. It is overlain unconformably by the Puerco, Torrejon, Wasatch (?), and later Tertiary rocks.

In northern Arizona the Grand Canyon series of the Algonkian, nearly 12,000 feet thick, is overlain unconformably by the Middle Cambrian Tonto group. The upper Cambrian and Ordovician are absent probably throughout the area; part of the Silurian is known to be represented only by a small outlier at one locality; the Devonian occurs in thin remnants at the widespread unconformity between the Cambrian and the Carboniferous. The Mississippian and Pennsylvanian divisions of the Carboniferous are presented in a thick succession of limestones and sandstones, surmounted by 500 feet or more of sandstones which are believed to belong to the Permian. The Triassic is thick, but its limits and classification are in doubt. Part of the Jurassic is probably present to the north, but apparently the Lower Cretaceous is absent. The Upper Cretaceous succession is extensive, reaching the coal measures in the great basin northeast of the Hopi region. Tertiary deposits occur, but their classification has not been effected. Much of the Quaternary material consists of valley filling and lava flows. Many features of the succession of rocks in the Grand Canyon are shown in Plates II and III, *B*, and figure 3.

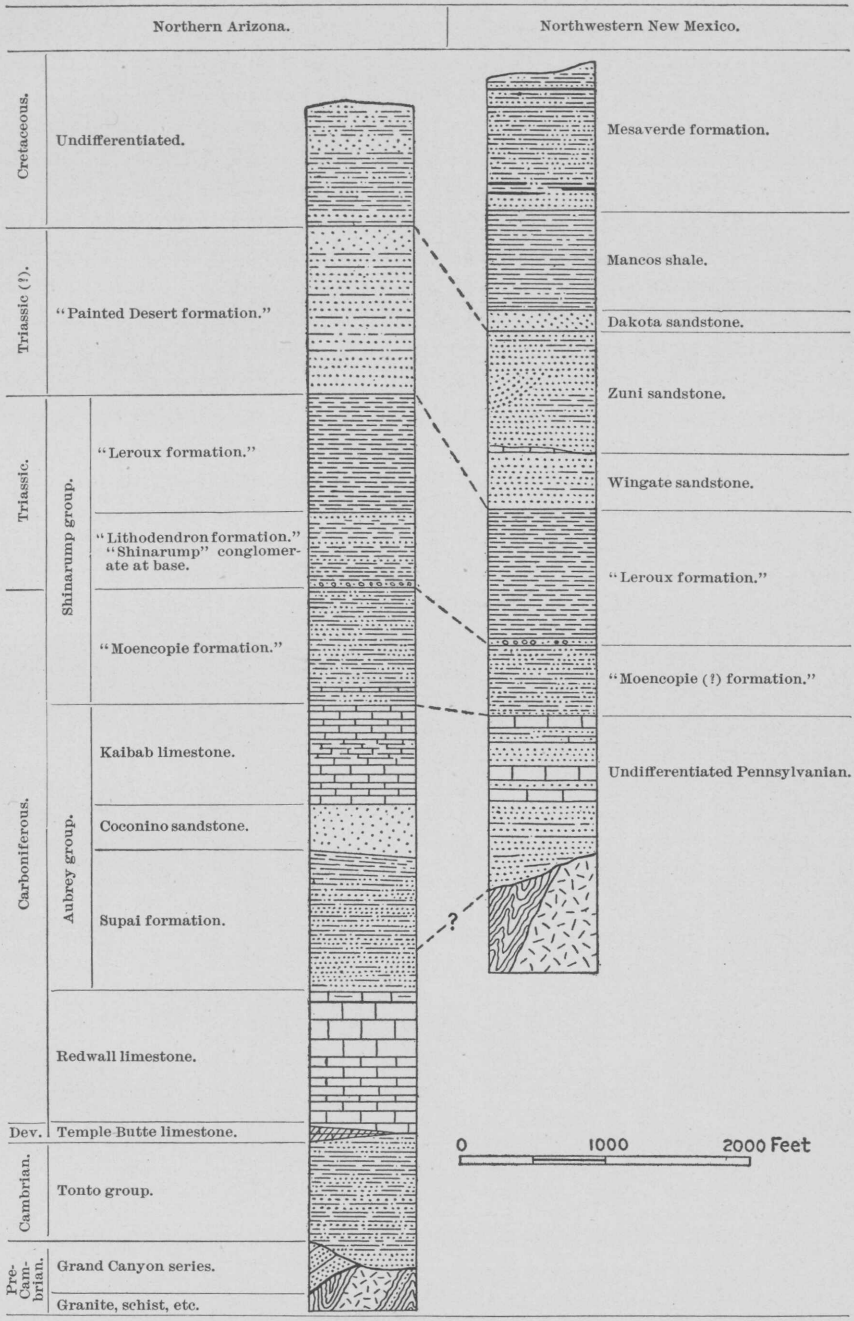


FIGURE 2.—Partial columnar sections in northern Arizona and northwestern New Mexico.

Generalized section of the rocks of northern Arizona and northwestern New Mexico.

System and series.	Northern Arizona.				Northwestern New Mexico.		
	Group and formation.		Lithologic description.	Thickness.	Formation.	Lithologic description.	Thickness.
				Feet.			*Feet.*
Quaternary			Valley filling and lava flows				
Tertiary	Unclassified		Sands, gravels, and lava flows	100–800	Volcanic rocks Santa Fe marl Wasatch (?) formation Torrejon formation Puerco formation		
Cretaceous (Upper)	Unclassified		Sandstones and shales, local coal beds. Shales with sandstone layers Sandstone	300 300–700 25–100	Laramie formation Lewis shale Mesaverde formation Mancos shale Dakota sandstone	Sandstones, with coal beds Dark shales, with thin sandstone. Sandstones with interbedded dark shale; coal beds. Dark shale, in part sandy; local coal beds. Hard sandstone, in part conglomeratic.	900 200–2,000 200–1,000 500–1,000 60– 300
Unconformity							
Triassic (?)	"Painted Desert formation."		Bright-colored, regularly stratified sandstone.	1,200	Zuni sandstone Wingate sandstone	Sandstones and sandy shales, with local gypsum beds. Massive bright-red sandstone	770–1,300 400
Triassic	Shinarump group.	"Leroux formation"	Calcareous clays, some sandstone	600–900	Shinarump group. "Leroux formation"	Sandy shale, clay, and sandstone, mostly of reddish tints.	1,000
		"Lithodendron formation." ("Shinarump" conglomerate at base.)	Sandstone and conglomerate, separated by light-colored shales and "marls."	300–800	("Shinarump" conglomerate at base.)		
Unconformity							
Permian.		"Moencopie formation."	Reddish-brown saliferous and gypsiferous laminated shales, with sandstones, limestones, and "marls."	500–700	"Moencopie (?) formation."	Sandy shales and sandstones, reddish to gray gypsum, and limestone.	200–600
		Unconformity					

Carboniferous	Pennsylvanian	Aubrey group	Kaibab limestone	Gray limestones, upper part cherty	700–820	Undifferentiated	Sandstone	0–150
			Coconino sandstone	Cross-bedded gray sandstone	300–600		Limestone and sandstone	200–400
			Supai formation	Red sandstones and shales	670–1,400		Sandstone (?)	200–600
	Mississippian	Redwall limestone		Massive gray limestone, with some sandstone and shale.	200–2,100	(?)		
Devonian		Temple Butte limestone		Purple and cream-colored limestone and sandstone.	0–100			
Silurian				Small outlier near Fort Apache		Lacking.		
Unconformity								
Cambrian		Tonto group		Marbled limestone	0–300			
				Shales and sandstones	225–650			
				Sandstone	50–290			
Unconformity								
Algonkian	Grand Canyon series	Chuar group		Sandy and clay shales, with interbedded sandstones and limestones.	5,120			
		Unconformity						
		Unkar group		Sandstones and limestones, with interbedded igneous rocks.	6,830			
Archean		Vishnu		Granite, schist, and gneiss			Gneiss, mica schist, and granite	

PRE-CAMBRIAN ROCKS.

Pre-Cambrian rocks outcrop in a wide area west and southwest of the plateau region in western Arizona and appear in the Zuni and other uplifts in New Mexico. They are also exposed in portions of the Grand Canyon. My observations have thrown very little light on the character and relations of these rocks, but a few facts have been gathered as to their distribution.

WESTERN ARIZONA.

W. T. Lee[a] has recorded many features of the pre-Cambrian rocks in northwestern Arizona, where they constitute much of the lower bench of the plateau escarpment and numerous outlying desert ranges separated by wide detritus-filled valleys. Coarse, massive granites[b] predominate, but gneiss was noted at the south end of the Cerbat Mountains and in Hualpai Wash. In the Cottonwood Cliffs south of Truxton the slopes are made up of granite for 2,500 feet, with a thin cap of andesite that covers most of the plateau surface. Granite reaches far up the slopes of Music Mountain, to the base of the sandstone of the Tonto group. Marvine noted schists and slates in the lower slopes of the Juniper Hills. A characteristic view of the pre-Cambrian granite is shown in Plate III, *A*.

GRAND CANYON.

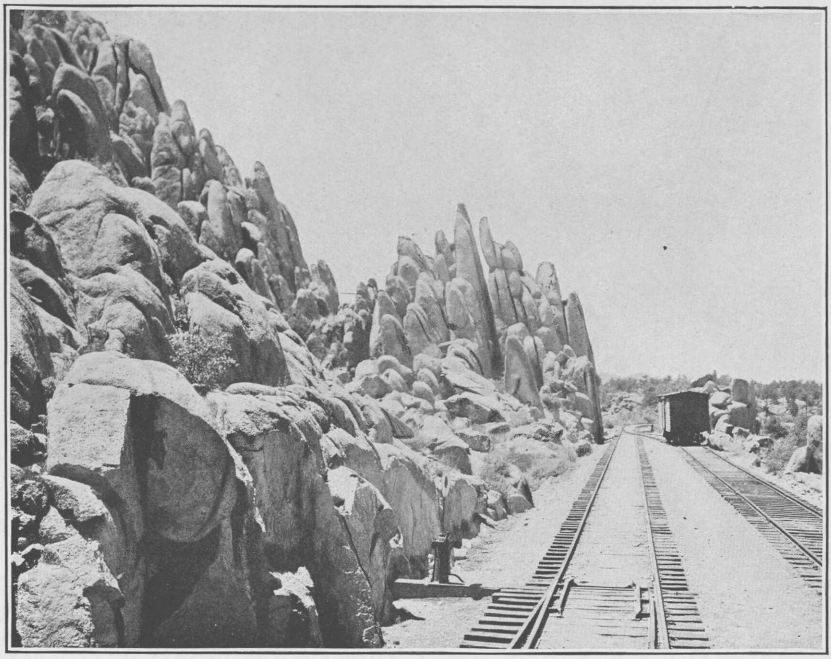
At the mouth of the Grand Canyon, east of Pierce Ferry, the Tonto group is underlain by coarse granite cut by dark intrusive dikes. This rock rises about 80 feet above the river and extends up the canyon to an undetermined point southeast of Mount Dellenbaugh, near latitude 36°. At the mouth of Diamond Creek, 20 miles north of Peach Springs, I found dark schists associated with granite. Granite and gneiss appear also in the canyon at longitude 112° 33′ (Walcott), and continue, with a short interruption in the big bend at latitude 36° 15′, to a point 4 miles east of longitude 112°, where they disappear unconformably under the Grand Canyon series. Opposite the mouth of Bright Angel Creek their surface rises to its maximum elevation of 3,800 feet above sea level, or about 1,300 feet above the river. They have been called the Vishnu series in this region.

The largest area of the Grand Canyon series[c] begins near longitude 112° and extends around the big bend opposite the mouth of the Little Colorado as far north as the Kwagunt basin. This series has been

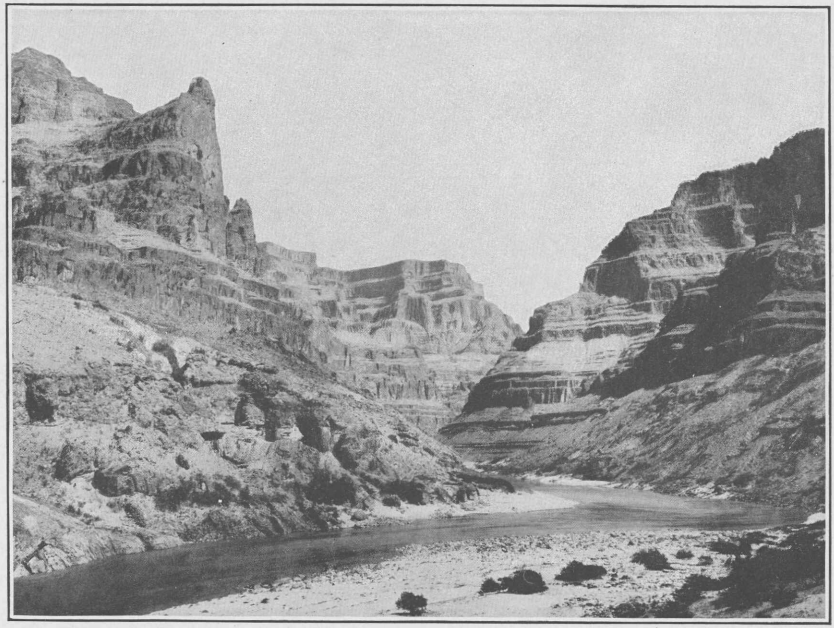
[a] Bull. U. S. Geol. Survey No. 352, 1908.

[b] Throughout this report the word granite is used in its old broad sense to cover a great variety of rocks.

[c] Powell, J. W., Geology of eastern portion of the Uinta Mountains, [etc.]: U. S. Geol. and Geog. Survey Terr., 1876.



A. PRE-CAMBRIAN GRANITE WITH NEARLY VERTICAL JOINTING AT GRANITE SIDING, NORTH OF PRESCOTT, ARIZ.



B. MOUTH OF GRAND CANYON EAST OF PIERCE FERRY, ARIZ., LOOKING EAST.

Granite, Tonto, and Redwall. Photograph by W. T. Lee.

described by C. D. Walcott,[a] who has divided it into two groups separated by unconformity. The upper group, the Chuar, consists of sandy and clay shales and interbedded sandstones and limestones, with a heavy bed of brown sandstone at the top. Of this group, 5,120 feet remains. The lower group, the Unkar, consists of 6,830 feet of sandstones with interbedded lava flows in the upper part and some included limestones. The total thickness of the Grand Canyon series is 11,950 feet. It contains a few fossils, which do not afford a basis for classification, and as it was extensively upturned and its surface planed before the deposition of the sandstone of the Tonto group, Walcott regards it as Algonkian in age. It presents no evidence of metamorphism, except in the immediate vicinity of igneous rocks.

F. L. Ransome [b] has described some relations of a small outlier of red sandstone and shale of the Unkar group on the north side of the Grand Canyon, lying on a depressed faulted block and extending from Bright Angel Creek to a point 2 miles farther west. There is still larger area on the lower part of Shinumo Creek, which has recently been described in detail by L. F. Noble,[c] together with the associated Vishnu rocks. I am informed by Mr. R. T. Evans that small masses appear in the Hindu Amphitheater and in the main canyon near latitude 36° 20′, 4 miles northwest of Powells Plateau. A small exposure is exhibited in the Ottoman Amphitheater, 3 miles northeast of the mouth of Bright Angel Creek. These areas are all in line along a northwest-southeast course. According to Powell[d] the series is again exposed in the Grand Canyon at the south end of Shiwits Plateau; and some of the Algonkian rocks described by A. B. Reagan[e] as occurring in the Fort Apache region appear to represent the Grand Canyon series.

CAMBRIAN SYSTEM.

TONTO GROUP.

CHARACTER AND OCCURRENCE.

The Tonto group underlies at least 30,000 square miles of the high plateau of northern Arizona, but probably does not extend to the western boundary of New Mexico. It is exposed along Colorado River from the foot of Marble Canyon to the Grand Wash Cliffs and thence southward and eastward for many miles along the western and southern faces of the plateau. The easternmost exposures in

[a] Am. Jour. Sci., 3d ser., vol. 26, 1883, pp. 402–442; Bull. Geol. Soc. America, vol. 1, 1890, pp. 49–64; Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1894, pp. 503–519; Jour. Geology, vol. 3, 1895, pp. 312–330; Bull. Geol. Soc. America, vol. 10, 1899, pp. 215–218.

[b] Science, vol. 27, 1908, pp. 667–669.

[c] Am. Jour. Sci., 4th ser., vol. 29, 1910, pp. 369–386, 497–528.

[d] Geology of the eastern portion of the Uinta Mountains: U. S. Geol. and Geog. Survey Terr., 1876, p. 62.

[e] Am. Geologist, vol. 32, 1903, pp. 270, 277–278.

this district, as shown on the maps of the Wheeler Survey, are on the south slopes of the Mogollon Mesa in the vicinity of longitude 110°. There are very extensive exposures of the Tonto group all along the lower slopes of the Grand Canyon, where the thickness varies from 750 to 1,000 feet. Two formations are included—a basal sandstone 50 to 200 feet thick causing a shelf and cliff (see Pl. IV, *A*) and overlying shales containing varying amounts of sandstone and limestone. The latter becomes a conspicuous feature to the west.

The name Tonto group was proposed by G. K. Gilbert for the sandstones and shales underlying the great series of Carboniferous rocks in the Grand Canyon district. Undoubtedly, the type locality is Tonto Basin or Tonto Creek, which heads in the southern margin of the Mogollon Mesa. A brief notice of the rocks was given in 1874,[a] and the name Tonto group, comprising "Tonto" sandstone, "Tonto" shale, and "marbled limestone," was applied in the geologic report of the Wheeler Survey the following year.[b] The age was regarded as "Primordial." The rocks were first described by J. S. Newberry, who accompanied the Ives expedition to Colorado River[c] in 1857–58. Newberry found the sandstone lying unconformably on the granites, and although he obtained no determinable fossils he recognized the antiquity of this member and the overlying shales. He measured the section exposed at the mouth of the canyon of Diamond Creek as follows:

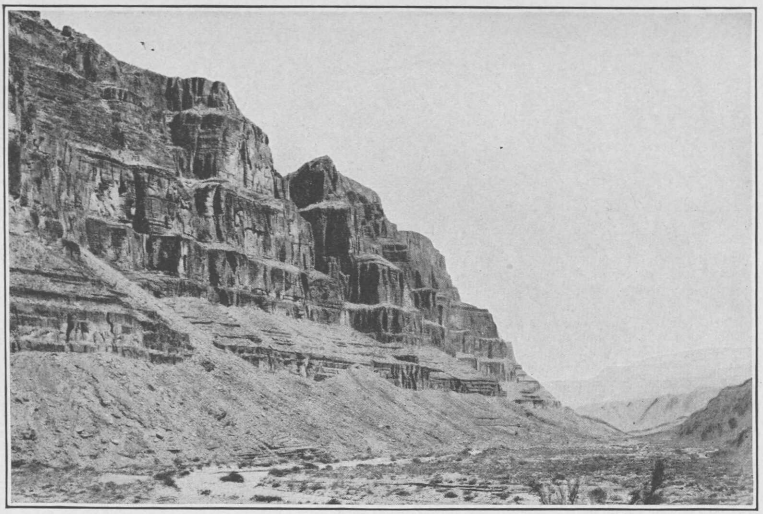
Section of Tonto group at mouth of Diamond Creek.

	Feet.
Bluish-gray limestone (Redwall), 1,000+feet.	
Mottled red and gray siliceous limestone interstratified with red, white, and brown shales; much silica	300
Red, green, and yellow shales, with bands of argillaceous iron and black oxide of manganese	100
Red and brown limestone in thin layers, with grits and shales containing imperfect corals	60
Green shales.	
Ferruginous limestones, shales, and mud rocks; the limestones contain corals (*Chætetes*?) and greenish shales with mud furrows and carbonaceous particles. Closely resembling rocks of Chemung group in New York	75
Blue, thick-bedded limestone everywhere penetrated by lines of deep red having the form of branching corals	25
Soft and cherty sandstone	25
Shales with bands of limestones and grits	180
Speckled, white or brown, and dark-red hard foliated fine-grained sandstones with shales	260
Red, gray, and green shales with mud furrows, resembling casts of worm holes	250

a Gilbert, G. K., On the age of the Tonto sandstones (Abstract): Bull. Washington Philos. Soc., vol. 1, 1874, p. 109.

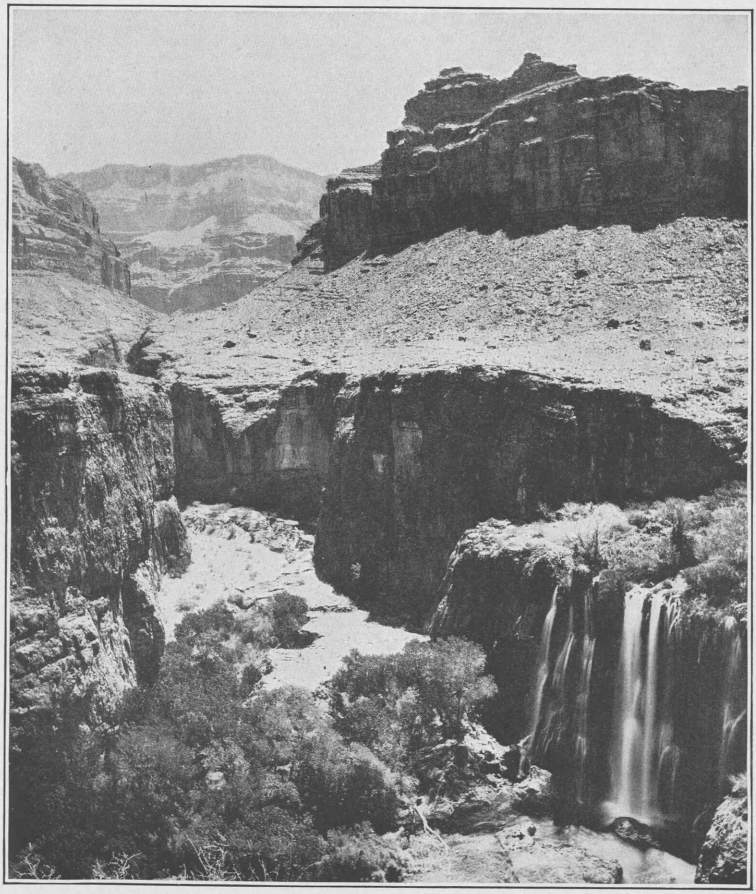
b Gilbert, G. K., Rept. U. S. Geog. Surveys W. 100th Mer., vol. 3, Geology, 1875, pp. 163, 184–186, 521, 522.

c Report upon the Colorado River of the West, explored in 1857–58 by Lieut. J. C. Ives, pt. 3, Geological report, 1861, p. 42.



A. SANDSTONE OF TONTO GROUP NORTH OF PEACH SPRINGS, ARIZ., LOOKING NORTH.

Granite to right, on east side of fault.



B. UPPER FALLS OF CATARACT CREEK BELOW SUPAI, ARIZ.

Top of Redwall limestone overlain by Supai red beds. Coconino sandstone and Kaibab limestone in the distance.

	Feet.
Gray coarse siliceous sandstones	160
Red quartzose sandstone, often purple and beautifully striped	150
Conglomerate	3
Granite.	
Total thickness of Tonto beds	1,588

Newberry regarded the lower beds as equivalent to the Potsdam sandstone of New York. The surface on which they lie is stated to be very irregular, with many hills rising several hundred feet into the Tonto strata. Most of this apparent relation, however, is, as shown by G. K. Gilbert, due to a fault extending down the valley at this locality.

According to Gilbert [a] the Tonto section at the mouth of the Grand Canyon consists of the following beds:

Section of Tonto group in Grand Canyon at Grand Wash Cliffs, Arizona.

	Feet.
Limestone with coralloid markings	75
Soft green shale, with intercalated pale-red sandstones	100
Sandy limestone with obscure coralloid markings	25
Greenish shaly sandstone	40
Sandy limestone	25
Green and purple shales, sandy toward the base and in part shaly sandstone (*Cruziana*)	415
Glassy sandstone, white to yellow and red, heavy bedded	80
Granite and gneiss.	
	760

The Tonto group was traced southward from this section along the continuation of the Grand Wash Cliffs by A. R. Marvine.[b] He found the lower sandstone to increase gradually in thickness and in a section 20 miles farther south to consist of a lower member of red color and an upper member of yellowish white mottled with salmon-colored spots. The shale decreases in thickness and the included limestones become thicker and more numerous toward the south. In later observations in this region W. T. Lee [c] noted considerable variation in thickness. In a section of the Grand Wash Cliffs 12 miles south of the Grand Canyon the shale is only 200 feet thick and the sandstone 80 feet, but in the pass followed by the road a few miles north of Music Mountain the sandstone is 50 feet thick and the overlying shale 300 to 400 feet. At the south end of the Juniper Hills the basal sandstone is about 100 feet and the shale 225 feet thick. My estimate of the thickness of the group on Diamond Creek was about 800 feet. At the base is 100 feet or more of banded

[a] Rept. U. S. Geog. Surveys W. 100th Mer., vol. 3, Geology, 1875, p. 163 and fig. 82, opp. p. 196.
[b] Idem, pp. 198-201 and fig. 82.
[c] Geologic reconnaissance of a part of western Arizona: Bull. U. S. Geol. Survey No. 352, 1908, pp. 19, 21.

quartzite, weathered dark, followed by slaty sandstones of purplish gray and greenish tints. Next above is limestone and sandy shale, about 150 feet thick in all, overlain by 100 feet or more of massive gray sandstone. The middle and upper members consist largely of thin-bedded sandstones with some shale and local massive sandstones. There is considerable limestone at the top.

The following section of the Tonto group on the Hance trail in Congress Canyon, given by Frech,[a] is the only one on record for that general region:

Section of Tonto group in Congress Canyon, Arizona.

	Feet.
Greenish shales with small cliff in the midst formed by a greenish sandstone	85
Snuff-colored sandstone with a bed of limestone in the upper part forming a small cliff	44
Greenish or snuff-colored shales with small ripple marks, forming a gentle slope	85
Snuff-colored sandstone forming a well-defined cliff 8 feet high; in the upper part some calcareous shale	85
Brown sandstone and greenish or snuff-colored shaly limestone; large ripple marks in the lower part and a glauconitic layer 5 to 15 cm. thick in the upper part; contains *Obollela* sp.?	32
Greenish or snuff-colored shaly sandstone with worm tracks (*Cruziana*), ripple marks, and glauconite (?); contains *Obollela polita* Hall?, *Lingula monticula* Walcott?	65
Well-defined bed of brown sandstone with glauconite (?) containing *Obollela*	4
Yellow and chocolate-colored sandy shales alternating with cross-bedded sandstones and conglomerates	45
Thin-bedded brown quartzitic sandstones and shales	14
White sandstone, spotted black	30
Coarse red cross-bedded sandstones, with pebbles of quartz at base and *Scolithus* at the top	260
Granite.	
	749

According to C. D. Walcott[b] the thickness of the group is 1,050 feet in the eastern part of the Kaibab region northeast of Congress Canyon.

In November, 1901, Walcott measured the following section of the Tonto group 9 miles south of Seligman, as follows:

Section of Tonto group 9 miles south of Seligman, Ariz.

Redwall limestone.	Feet.
Shale, sandy, gray, and brown, with thin sandstone partings	210
Sandstone, thin bedded, brown and gray, with 25-foot bed of coarse cross-bedded sandstone near top	115
Sandstone, coarse, cross-bedded, red and gray	260
Granite.	
	585

[a] Compt.-Rend. 5e Cong. géol. internat., p. 479.
[b] Bull. Geol. Soc. America, vol. 1, 1890, p. 50.

A section of the Tonto group on the south side of the Coconino Plateau, 60 miles south of Winslow, is given by G. K. Gilbert:[a]

Section of Tonto group on Canyon Creek, Arizona.

	Feet.
Brown to red coarse vitreous sandstone, massive to shaly	100
Gray fine-grained sandstone; weathers red; angular blocks	75
Shaly calcareous sandstone	75
Vitreous red, purple, and white sandstone	150
Coarse siliceous conglomerate on crystalline rocks	25
	425

FOSSILS AND CORRELATION.

In 1879[b] and 1880 C. D. Walcott made an extended study of the Tonto group of the Grand Canyon in and above Kanab Canyon. At the mouth of Kanab Canyon he found 450 feet of a mottled limestone on 100 feet of arenaceous and micaceous shales, the latter extending to the river, and obtained Cambrian fossils comprising *Lingulepis, Conocephalites,* and *Bathyurus* in the upper portion and *Hyolithes primordialis, Lingulepis,* and *Crepicephalus* in the lower beds. In 1883 he gave an account[c] of the discovery of additional fossils, *Cruziana, Lingulepis, Iphidæ, Conocephalites, Crepicephalus,* and *Dikelocephalus,* in the upper 700 feet of sandstone, shales, and limestones in the Kaibab portion of the canyon. At the summit of the lower sandstone member, here about 300 feet thick, he obtained *Olenoides, Ptychoparia, Lingulepis,* and *Leperditia,* which he classed as Middle Cambrian.[d] He believed the Lower Cambrian to be absent and earlier Cambrian time to be represented by the great hiatus between the basal sandstone of the Tonto group and the underlying Chuar (Algonkian).

F. L. Ransome[e] has stated his opinion that the lower sandstone of the Tonto "is probably equivalent to the Apache group in the Globe district, to the Coronado quartzite in the Clifton district, and without much question to the Bolsa quartzite of the Bisbee district." The shale "apparently becomes more calcareous to the south and is correlated with the Abrigo limestone of Bisbee."

DEVONIAN SYSTEM.

TEMPLE BUTTE LIMESTONE.

Rocks of Devonian age were discovered by C. D. Walcott[f] near Kanab Creek in the Grand Canyon in 1879. The beds were stated to be purple and cream-colored limestone and sandstone, passing upward

[a] Rept. U. S. Geog. Surveys W. 100th Mer., vol. 3, Geology, 1875, p. 164.
[b] Am. Jour. Sci., 3d ser., vol. 20, 1880, pp. 221–225.
[c] Idem, vol. 26, 1883, pp. 437–442.
[d] Pre-Cambrian fossiliferous formations: Bull. Geol. Soc. America, vol. 10, 1899, p. 217.
[e] Comparison of some Paleozoic and pre-Cambrian sections in Arizona: Science, vol. 27, 1908, p. 69.
[f] Am. Jour. Sci., 3d ser., vol. 20, 1880, pp. 224–225.

into gray calciferous sandstone. The strata vary in character and range in thickness from 100 feet down to the vanishing point. They lie in depressions on the very irregularly eroded surface of the top limestone of the Tonto group. In places where there are ridges or knolls of the limestone the Devonian lies above them with a thickness of 10 to 30 feet. Some of the hollows in the Tonto, however, are 80 feet deep.

In 1880 Walcott extended his observations up the Grand Canyon and traced the unconformity at the top of the Tonto eastward to the Marble Canyon. He writes:[a]

> In places the Devonian is entirely absent, either through erosion or nondeposition, so that the Redwall limestone rests directly on the massive calciferous strata of the upper Tonto. It rarely has a thickness 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 which cyathophylloid corals, casts of brachiopods and gasteropods, and plates of placoganoid fishes usually occur.

Early in 1883 Walcott discovered Devonian rocks in Chuar Valley in the Grand Canyon,[b] and in his description of the faults in that region[c] he gave to these rocks the name Temple Butte limestone, and stated that their thickness was 94 feet. Undoubtedly the type locality is Temple Butte, on the west side of Colorado River 3 miles below the mouth of the Little Colorado. No search was made for Devonian rocks in other portions of the Grand Canyon region and the country to the south. A. B. Reagan[d] has discovered that the Devonian is well represented in the Fort Apache region; and F. L. Ransome found Devonian fossils in the lower portion of the Globe limestone in the Globe region.[e]

CARBONIFEROUS SYSTEM.

GENERAL RELATIONS.

A large area in northeastern Arizona and northwestern New Mexico is underlain by limestones and sandstones of Carboniferous age. The limestones constitute the greater part of the high plateau, but east of Little Colorado River they pass beneath red beds largely of post-Carboniferous age. They reappear in the Zuni and other uplifts in western New Mexico. The most extensive exposures are in the Grand Canyon of the Colorado, which presents almost 4,000 feet of nearly horizontal rocks, mostly in cliffs and steep slopes. The succession in that region is limestone at the top, gray sandstone, red shales, and sandstone in the middle, and massive gray limestone at the base. (See fig. 3.) To the three upper formations the name

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[a] Am. Jour. Sci., 3d ser., vol. 26, 1883, p. 438.
[b] Fourth Ann. Rept. U. S. Geol. Survey, 1884, p. 47.
[c] Bull. Geol. Soc. America, vol. 1, 1889, p. 50.
[d] Am. Geologist, vol. 32, 1903, pp. 274, 278–279.
[e] Globe folio (No. 111), Geol. Atlas U. S., U. S. Geol. Survey, 1904.

Aubrey group has been applied; the basal limestone, over 1,000 feet thick, is known as the Redwall. These members are well characterized over a wide area in Arizona, but in the Zuni and Nacimiento uplifts the lower formations are absent and the upper limestone and sandstone lie directly on pre-Cambrian rocks. This relation indicates an eastern upslope of the floor under the Paleozoic rocks on which the upper formations overlap beyond the edges of lower ones down to and including the Cambrian.

The three formations included in the Aubrey group in Arizona require individual names according to present methods of nomenclature, so that in the following descriptions I shall introduce the terms Kaibab limestone, Coconino sandstone, and Supai formation. These formations, together with the Redwall limestone below and the Permian above, constitute the Carboniferous system in this region.

REDWALL LIMESTONE.

GENERAL DISTRIBUTION.

The great lower limestone of the Carboniferous is a prominent feature in northern Arizona, for it constitutes the highest and most

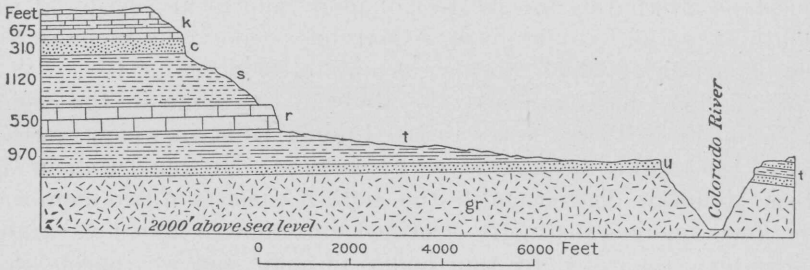

FIGURE 3.—Section in south wall of Grand Canyon at Grand Canyon station, Arizona. k, Kaibab limestone; c, Coconino sandstone; s, Supai formation; r, Redwall limestone; t, Tonto group; u, Unkar group; gr, granite.

extensive cliffs in the Grand Canyon. Along the western and southern margins of the plateau it forms a wide, elevated bench about a thousand feet lower than the main plateau. This shelf is 15 to 20 miles wide in the Juniper Hills and the region north of Music Mountain. The name Redwall was given by Gilbert on account of the red color of the cliffs, but the rock itself is mostly of light-gray color. A type locality recently selected is Redwall Canyon, in the Shinumo drainage basin, on the north side of the Grand Canyon, where it consists mostly of the usual heavily bedded massive limestone. Some characteristic features of the formation are shown in Plates II, III, and V.

THICKNESS AND LOCAL FEATURES.

In Redwall Canyon the limestone is about 800 feet thick. On the trail near Grand Canyon station a thickness of 550 feet was measured. Walcott found the amount to be 555 feet in exposures 9 miles south-

east of Seligman, 962 feet on the east side of the Kaibab Plateau 20 miles northeast of the mouth of Bright Angel Creek, and 970 feet in Kanab Valley, where the top 235 feet is arenaceous and cherty. In the deep boring at Picacho, midway between Nelson and Aubrey, the Redwall limestone extended from 140 to 1,132 feet, which indicates a thickness of 992 feet.[a] The boring at Seligman entered the Redwall at 832 feet, and was discontinued in the same formation at a depth of 1,479 feet. Frech[b] estimated the thickness in Congress Canyon (on the Hance trail, 20 miles east of Grand Canyon station) as 1,000 feet, the rocks consisting of a great cliff of very massive light-colored limestone underlain by thin-bedded limestone with *Spirifer striatus*, grading into a basal member of alternating limestones and sandstones.

Gilbert[c] gave the thickness as 2,165 feet at the mouth of Grand Canyon. The upper member is gray limestone, 800 feet thick, massive to heavily bedded, and in part cherty, rising in a sheer cliff. The lower member 1,365 feet thick, is limestone alternating with calcareous shale, the latter breaking the escarpment into huge steps. According to Gilbert there are also at the top in places sandstone and limestone alternating for 200 feet or more, and in his section at the mouth of Grand Canyon given in Marvine's report[d] he includes 510 feet of such beds, which I believe belong to the Supai.

W. T. Lee[e] has examined the Redwall limestone in the region extending from Pierce Ferry to the Juniper Hills, in which more or less of the top has been removed by erosion. He found that in the Music Mountain district and to the south it consists of two members. The lower one is a distinctly stratified limestone in layers of various thicknesses, separated by thin bodies of shale and weathering to a light-brown or pale-buff color. Its thickness was found to be 250 feet at Bud Grounds Springs, near Music Mountain, and 150 feet in Juniper Canyon, in the Juniper Hills. Its outcrop is marked by steep slopes and steps at the base of the high cliff formed by the overlying massive member, which consists of limestone with but little sign of bedding. Of this rock 600 feet remains as a capping on the Grand Wash Cliffs near Music Mountain. Its outcrop is of a distinct reddish tint, even where the overlying red shales of the Supai formation have long since been removed, indicating that the color is due in part at least to weathering. The red color appears only on weathered surfaces and is most marked in the more decomposed portions, where it appears in streaks and spots.

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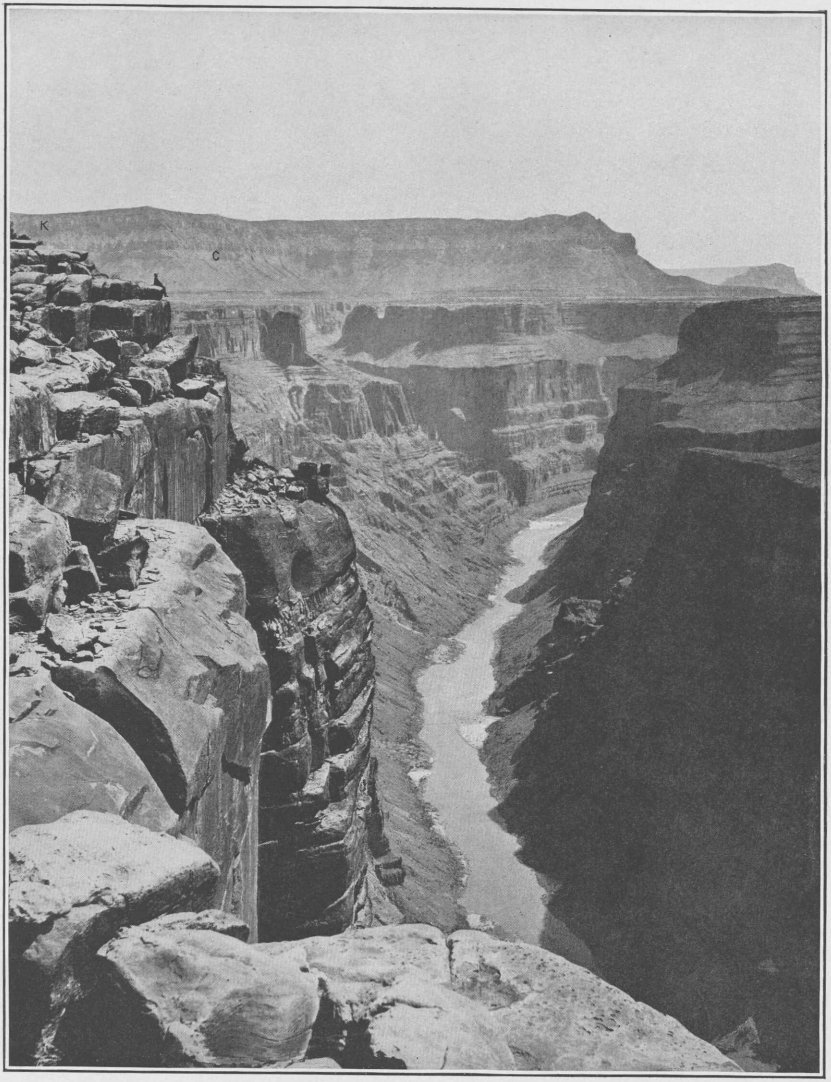
a From 110 to 1,170 or 140 to 1,289 feet according to other reports, which would indicate a thickness of either 1,060 or 1,149 feet.

b Compt. Rend. 5e Cong. géol. internat., p. 478.

c Rept. U. S. Geol. Surveys W. 100th Mer., vol. 3, Geology, 1875, p. 162.

d Idem, fig. 82, p. 196.

e Bull. U. S. Geol. Survey No. 352, 1908, pp. 15-16.



GRAND CANYON AT MOUTH OF TOROWEAP VALLEY.

C, Coconino sandstone; **K** Kaibab limestone.

Photograph by J. K. Hillers.

Lee found that the limestone in this region contains numerous caves. One of these, near Nelson, is said to have been penetrated for a thousand feet and to contain notable stalactites and columns.

H. H. Robinson [a] has found 300 feet of the upper part of the Redwall exposed in the uplifted beds in the east side of Elden Mountain and 180 feet in the center of Marble Hill, near San Francisco Mountain.

G. K. Gilbert has given several sections on the south side of the plateau. One 15 miles southeast of Bill Williams Mountain shows 400 feet of the Redwall limestone, but does not reveal its base. The next section, at Canyon Creek, shows that the formation has greatly decreased in thickness and changed its character. The following beds were measured by aneroid from the base of the red sandstones of the Supai formation to the top of the sandstones of the Tonto group:

Section of Redwall limestone at Canyon Creek, 60 miles south of Winslow.

	Feet.
Limestone	5
Unseen (shale ?)	100
Limestone (*Athyris subtilita*)	10
Red calcareous sandstone	4
Shale	40
Limestone	4
Unseen (shale ?)	25
Massive limestone	10
Unseen (shale ?)	75
Limestone	2
Unseen (shale ?)	50
	325

On Carrizo Creek, 20 miles farther east, Gilbert found at the top of the section 100 feet of dark-gray limestone with numerous Pennsylvanian fossils, then 500 feet of soft shale of alternating cream or gray and red colors, 200 feet of bedded red sandstone, shaly in the lower portion, and at the base 20 feet of gray limestone with chert, containing *Athyris subtilita* and *Spirifer cameratus*. The total thickness is 820 feet. Near Camp Apache, 20 miles to the east, there is a still further change, and it is very difficult to separate the Supai and the Redwall. The latter consists of 125 feet of fossiliferous limestone, lying on 835 feet of red gypsiferous shales with limestones and sandstones which are difficult to classify without further study. Gilbert says: [b]

> Eastward from Canyon Creek to Camp Apache the progress of a rapid transformation can be traced. The lower shaly portion of the Aubrey [Supai] sandstone becomes interrupted by numerous bands of limestone, and red shales appear in the Redwall limestones; and in this way the two series approximate in character until the division can no longer be recognized.

[a] Geology of the San Franciscan volcanic field, Arizona: Prof. Paper U. S. Geol. Survey (in preparation).
[b] Rept. U. S. Geog. Surveys W. 100th Mer., vol. 3, Geology, 1875.

FOSSILS AND AGE.

As described by Gilbert, the Redwall limestone contains both upper Carboniferous and lower Carboniferous fossils. Those of the latter age were found a short distance below the middle of the formation. W. T. Lee [a] believes that the line of separation is the division between the upper massive and the lower laminated division. He collected fossils from the lower division as follows:

Menophyllum excavatum.
Schuchertella inæqualis.
Spirifer centronatus.
Spirifer striatus var. madisonensis?
Zaphrentis sp.
Straparollus sp.

These were determined by G. H. Girty, who regards them as indicating the earlier portion of the Mississippian, or the Madison limestone, the Leadville limestone, the lower part of the "Wasatch" limestone, and the Escabrosa limestone of the Bisbee region.

At Yampai, near the top of the Redwall limestone, the following species were collected by Lee:

Derbya? sp.
Composita aff. C. subtilita.
Aviculipecten, 3 sp.
Myalina sp. aff. M. meliniformis and M. congeneris.
Edmondia? sp.

These were determined by G. H. Girty, who regards them as of probable Pennsylvanian age. Robinson found *Spirifer forbesi* and *Derbya keokus* in the upper beds of the formation on the east side of Elden Mountain.

The following fossils from the upper part of the Redwall in western Arizona were determined by Meek [b] and others:

Pinnatopora.
Septopora shumardi.
Archæocidaris sp.
Orthotetes crassus.
Productus semireticulatus.
Productus nebraskensis.
Spirifer cameratus.
Spirifer aff. S. kentuckyensis.
Seminula subtilita.
Aviculipecten occidentalis.
Aviculipecten interlineatus.
Uryalina sp.
Euomphalus aff. E. nodosus.
Murchisonia sp.
Macrocheilus sp.
Pleurotomaria sp.
Bellerophon crassus.
Tainoceras occidentalis.
Phillipsia sp.
Platysomus sp.

These are believed to represent an early portion of the Pennsylvanian, and accordingly are considerably older than the fauna in the Kaibab limestone.

G. H. Girty, in a letter to me, states that he regards the upper portion of the Redwall in general as equivalent to the upper part of the "Wasatch" and the lower part of the Naco of Bisbee, Ariz., and the lower portion as equivalent to the lower part of the "Wasatch." In other words, the Redwall as a whole is equivalent to the "Wasatch"

[a] Bull. U. S. Geol. Survey No. 352, 1908, p. 16.
[b] Rept. U. S. Geog. Surveys W. 100th Mer., vol. 3, Geology, 1875, p. 178.

and to the Naco (Pennsylvanian) and underlying Escabrosa (Mississippian) limestone of the Bisbee region. The two latter appear to be in conformable succession, while the upper part of the Naco has a fauna more like that of the Kaibab.

SUPAI FORMATION.

NAME.

The red sandstones and shales constituting the lower portion of the Aubrey group in northern Arizona form a definite stratigraphic unit over a wide area. Accordingly I propose that they be designated the Supai formation, from the Supai village on Cataract Creek, where they are very conspicuously exposed. (See Pl. IV, *B*.) In previous literature these rocks, together with the overlying gray sandstone, have usually been referred to as the "Aubrey sandstone series." They are, however, distinct from the gray sandstone throughout northern Arizona, but, as explained above, their separation from the underlying Redwall is not everywhere so clear as could be desired.

GRAND CANYON REGION.

In Cataract Canyon and the side canyons near the Supai settlement the formation appears to be about 1,400 feet thick. At the top are 400 feet of red shales, in part sandy, with thin red sandstone layers. The lower member, about 1,000 feet thick, consists of red sandstones varying from coarse to fine and from slabby to cross-bedded, lying on about 75 feet of red shales and soft red sandstones. Next below is the Redwall limestone, of which the upper part is soft and contains some shale partings.

At the trail at Grand Canyon station the formation is about 1,120 feet thick, comprising 210 feet of red shales, in part sandy, lying on 900 feet of red sandstones and shales, with some red shale at the base. The separation from the overlying gray sandstone is distinct, and the base of the formation is fairly well defined, although there are a few feet of passage beds. At the Bass trail, 16 miles northwest of Grand Canyon station, there are according to a recent measurement by G. K. Gilbert, 215 feet of red shales and 970 feet of red sandstones and shales, 1,185 feet in all. In the lower canyon of Kanab Creek, according to the same observer,[a] there are 980 feet of red beds, including a 2-foot bed of limestone 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." This 200-foot member doubtless is at the top of the Redwall. Walcott [b] gives the thickness of the reddish sandstones of the "Lower Aubrey" as

[a] Rept. U. S. Geog. Surveys W. 100th Mer., vol. 3, Geology, 1875, pp. 161–162.
[b] Am. Jour. Sci., 3d ser., vol. 20, 1880, p. 222.

1,455 feet in Kanab Valley. Gilbert gives the following section at the mouth of the Grand Canyon:

Section of Carboniferous rocks at mouth of Grand Canyon, near Pierce Ferry, Ariz.

	Feet.
1. Gray saccharoid cherty limestone	200
2. Massive cross-bedded yellow sandstone	300
3. Friable red sandstone	800
4. Alternating limestone and sandstone:	
(*a*) Cream fine-grained limestone (*Archæocidaris*)	75
(*b*) Dark-gray fine-grained limestone	25
(*c*) Cream fine-grained limestone	20
(*d*) White calcareous sandstone	35
(*e*) Gray fine-grained limestone	40
(*f*) Red and purple cross-bedded sandstone	315
5. Redwall limestone	2,165

No. 3 is undoubtedly Supai, and probably No. 4 is also, as indicated by the 315 feet of red beds at the base, giving a total thickness of 1,310 feet. No. 4 is part of the canyon wall; Nos. 1 to 3 are in an upper terrace some distance back.

Walcott [a] gives the thickness of the "Aubrey sandstones" as 1,485 feet in the eastern part of the Kaibab, which allows about 1,000 feet for the Supai. Frech [b] found the thickness to be about 1,000 feet in Congress Canyon, where the upper and lower portions are thin-bedded sandstone and shale and the middle portion is mostly massive sandstone.

Robinson has found the Supai beds on Marble Hill 670 feet thick, but greatly crushed, and this formation and the Coconino are 1,300 feet thick in the uplift on the east side of Elden Mountain.

AUBREY CLIFFS TO VERDE VALLEY.

The Supai formation outcrops along the face of the Aubrey Cliffs and underlies the Aubrey Valley northwest of Seligman. The rocks are the usual red shales and sandstones in a well-defined series about 1,000 feet thick. The boring at Seligman entered them at a depth between 145 and 254 feet, under lava, and passed into the Redwall limestone at 832 feet; but some of the upper beds are absent at this place. Small outliers of the Supai formation remain southwest of Aubrey and southeast of Seligman. The formation is covered by lava for many miles in the Mount Floyd area, but it reappears in the escarpment 15 miles southeast of Ash Fork and thence extends far to the south in the middle slopes along the east side of the Verde Valley. Gilbert describes a section 15 miles southwest of Bill Williams Mountain, in which the yellow Coconino sandstone is underlain by 200 feet of friable red sandstone lying on 400 feet of "alter-

[a] Bull. Geol. Soc. America, vol. 1, 1890, p. 50.
[b] Compt. Rend. 5e Cong. géol. internat., p. 478.

nating fine-grained limestones and calcareous red and yellow sandstones," which lie on the Redwall limestone. In Canyon Creek, according to Gilbert, the massive cross-bedded yellow sandstone (Coconino) is underlain by 65 feet of compact gray limestone containing *Spirifer cameratus*, which may be regarded as the top of the Supai formation. This is succeeded by 500 feet of typical "red and purple sandstone, soft at top, massive below." The lower limits are not well defined, but the underlying 325 feet of alternating gray limestone and shale and sandstone must be regarded as Redwall. On Carrizo Creek the formation is represented by 400 feet of "red and gray shales interrupted by calcareous beds," overlain by typical Coconino sandstone and underlain by typical Redwall. Near Camp Apache there are several hundred feet of red sandstone and soft red and gray shales, apparently grading down into the Redwall.

AGE.

As the Supai formation lies between rocks containing Pennsylvanian fossils there can be no question as to its age, but no evidence is at hand as to its correlation with formations of corresponding stratigraphic position in other regions.

COCONINO SANDSTONE.

NAME.

The name Coconino sandstone is proposed for the cross-bedded gray to white sandstone of the Aubrey group, which is so conspicuous in the walls of the Grand Canyon. (See Pls. II and V.) It underlies the entire Coconino Plateau, as well as the extensive plateau country north of the Grand Canyon. In Plate VI, *B*, is shown a prominent exposure.

CHARACTER AND THICKNESS.

Cross-bedding is a characteristic feature of this formation. The thickness of the sandstone is 305 feet on the trail at Bright Angel, 400 feet near the Hance trail, and apparently somewhat more toward the north. G. K. Gilbert found 270 feet at the Bass trail, 16 miles northwest of Grand Canyon station, and 300 feet at the mouth of the canyon, near Pierce Ferry, where it is a massive, cross-bedded, yellowish sandstone. In the lower canyon of Kanab Creek, north of the Grand Canyon, Gilbert found only 50 feet of "shaly and sandy limestone or calcareous sandstone" at this horizon, so soft that its outcrop zone is a slope between cliffs of limestone above and red beds of the Supai formation below. The sandstone is conspicuous in the Aubrey Cliffs, north of Seligman, where 400 feet was measured by C. A. Fisher. It reappears in the escarpment east of Ash Fork,

where the exposure shows about 400 feet of sandstone, massive gray and cross-bedded above and slabby gray to buff below. It is here partly covered by lava. Gilbert reported 700 feet of massive cross-bedded yellow sandstone in the escarpment 15 miles southwest of Bill Williams Mountain, according to rough aneroid determinations, and a few miles farther east I found the thickness to be about 500 feet. At the cliff dwellings in Walnut Canyon, 12 miles southeast of Flagstaff, the sandstone is cut into to a depth of 200 feet, as shown in Plate VI, *B*. There is a sharp contact with the overlying limestone at this place, a feature well exposed also at the dam some distance farther down the canyon. The boring at Winona, farther north, entered the sandstone at a depth of 185 feet (285 feet according to another record), and passed into red beds at 641 feet, indicating a thickness of 456 feet. According to Robinson, the sandstone appears in Marble Hill, Slate Hill, and Elden Mesa, north of Flagstaff. It is 570 feet thick at Marble Hill. He found 610 feet in Oak Creek Canyon. The sandstone is extensively exposed in the crater of Coon Butte, but the thickness could not be determined, owing to the mask of talus. Probably it is not over 500 feet. (See fig. 8, p. 73.)

On Canyon Creek, on the south face of the Mogollon Mesa, Gilbert found the sandstone to be 525 feet thick, massive and cross-bedded, lying on a 65-foot member of limestone carrying *Spirifer cameratus*. On Carrizo Creek he noted 150 feet of the "massive cross-stratified yellow sandstone," with gravel lying on its eroded surface. Near Camp Apache, where the top is eroded and gravel capped, there is 100 feet of yellow calcareous sandstone, lying on red sandstone which is probably Supai. There is some suggestion that the Coconino sandstone is represented in the Zuni uplift.

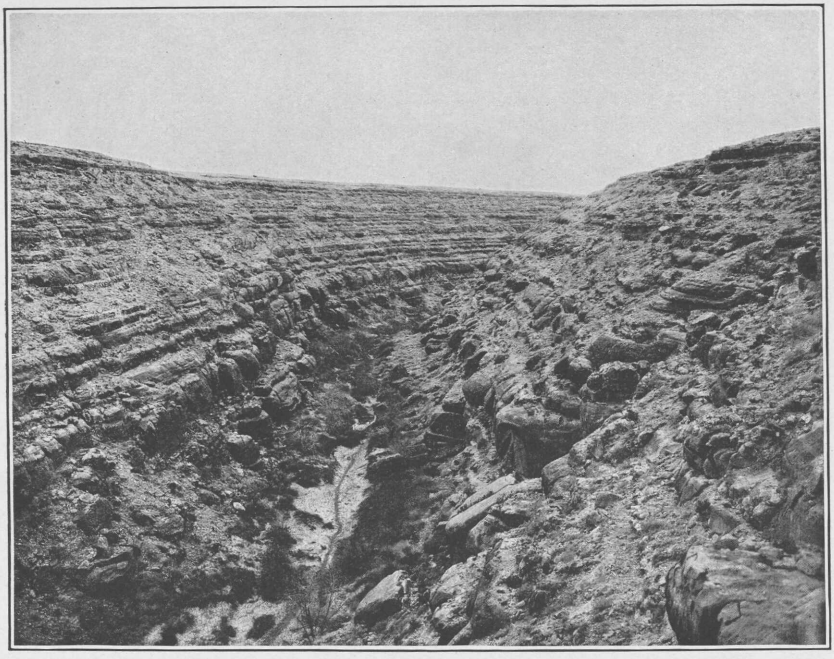
AGE.

No fossils have been reported from the Coconino sandstone, but it is included between formations containing a Pennsylvanian fauna, and is therefore undoubtedly of Pennsylvanian age.

KAIBAB LIMESTONE.

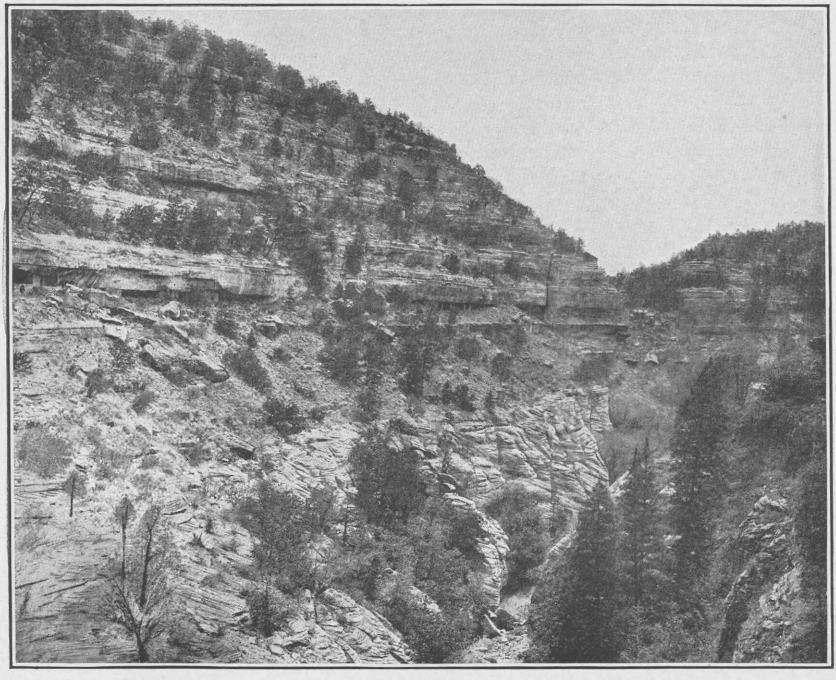
NAME.

The upper limestone of the Carboniferous in northern Arizona has heretofore been known as the "Aubrey" limestone, but as Aubrey has now been adopted by the United States Geological Survey for the group of which this limestone forms a part, a distinct name is required for it. Accordingly Kaibab has been selected, from the Kaibab Plateau, on the north side of the canyon, which is capped by the formation in typical development over a very large area.



A. CANYON DIABLO, ARIZONA, LOOKING NORTH FROM RAILROAD.

In Kaibab limestone; 300 feet deep.



B. COCONINO CROSS-BEDDED SANDSTONE OVERLAIN BY KAIBAB LIMESTONE AT WALNUT CREEK CLIFF DWELLINGS, SOUTHEAST OF FLAGSTAFF, ARIZ.

THICKNESS AND CHARACTER.

According to Walcott [a] the limestone is 805 feet thick on the east side of the Kaibab Plateau; and according to Gilbert [b] it reaches its maximum of 820 feet on the lower part of Kanab Creek. At the latter place it contains much chert, which locally in the upper beds amounts to half of the rock. Walcott states that the thickness of the "Upper Aubrey," here including some "calciferous sand rock" at the base, is 855 feet; the top limestone, 40 feet or less in thickness, included by Gilbert with the "Upper Aubrey," but containing "Permo-Carboniferous" fossils, is separated by Walcott as Permian. At Grand Canyon station the thickness is very nearly 675 feet, according to aneroid readings checked against bench marks. Gilbert measured 410 feet at the Bass trail, west of Bright Angel, and I found 700 feet on Cataract Creek, but at the three last-mentioned localities more or less of the top has been removed by erosion. This is also the case at the mouth of the Grand Canyon, where the thickness is about 200 feet; in Aubrey Cliffs, where it is from 100 to 400 feet; and in the escarpment east of Ash Fork, where it is 150 feet, the limestone being well exposed in railroad cuts under lava.

In Walnut Canyon 250 feet of the lower beds are exposed, lying on Coconino sandstone, and about the same amount is exhibited in Canyon Diablo. (See Pls. VI, VII.) In Coon Butte the thickness is only 200 to 300 feet. In the cliffs on the east side of the Verde Valley the amount remaining varies from place to place, owing to erosion and to the lava cover, which in places extends down to the underlying sandstone. Gilbert,[c] in a section 16 miles southwest of Bill Williams Mountain, measured under basalt 335 feet of gray, cherty, heavily bedded limestone, with a 15-foot member of gray shale 60 feet above the base. In all exposures showing the middle of the formation it is seen to include at that horizon more or less shale which usually weathers to a reddish color. On Cataract Creek I found the plateau capped by 300 feet of hard cherty limestone, underlain by 200 feet of softer limestones with some calcareous shales weathering reddish, and at the base 200 feet of massive hard gray limestone. Gilbert noted gypsum in the medial shale member on Kanab Creek. The red shale is conspicuous in the Aubrey Cliffs and along the southern escarpment of the plateau. The following is a section by Newberry:

Section of the Kaibab limestone at Cataract Creek.

	Feet.
Limestone, variegated crimson and lemon-yellow, with nodules of chert and iron, to top of hills	50
Sandstone, coarse, drab, sometimes pinkish, in places containing many quartz pebbles and imperfect vegetable impressions	20

[a] Bull. Geol. Soc. America, vol. 1, 1890, p. 50.
[b] Rept. U. S. Geog. Surveys W. 100th Mer., vol. 3, Geology, 1875, p. 177.
[c] Idem, p. 163.

	Feet.
Massive cream-colored limestones with geodes containing calcite	16
Chert	3
Cherty limestone	25
Blue limestone with *Productus semireticulatus*, etc., very abundant	4
Cherty limestone, light blue, containing *Productus semireticulatus*, *P. occidentalis*, *Spirigera subtilita*, *Orthisina umbraculum*, *Rhynchonella uta*, etc	175
Shales, green, red, and white, and snowy gypsum	180
Hard blue limestone containing crinoidal columns, spines of *Archæocidaris*, *Productus*, *Spirigera*, etc	100
Soft lemon-yellow limestone with few *Productus ivesi*, etc	90
Drab cross-bedded sandstones (Coconino).	

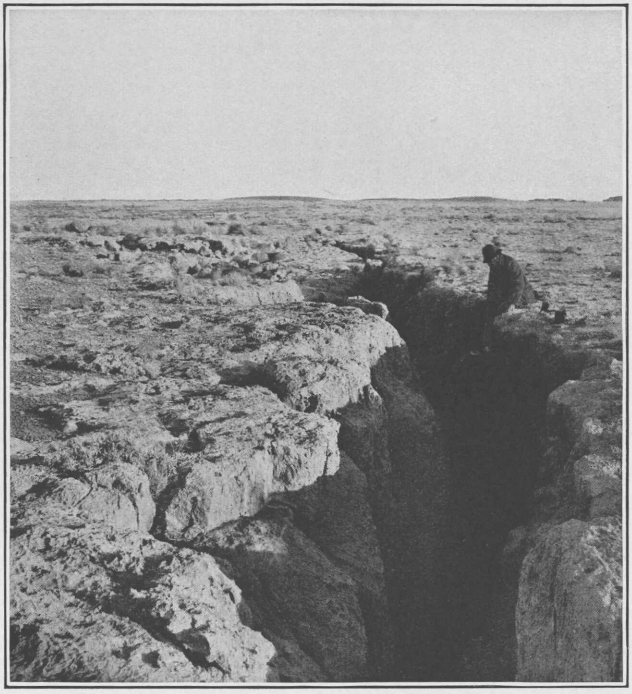
According to Frech's section[a] at Congress Canyon the Kaibab limestone is 500 feet thick, but the surface here has been somewhat eroded. The lower member is a pure limestone lying on the Coconino sandstone without transition. The upper part is cherty limestone, which yielded *Allorisma* and some poorly preserved gasteropods (*Euomphalus* and *Pleurotomaria*). In Walnut Canyon, south of Flagstaff, Frech obtained *Productus ivesi*, very common; *P.* aff. *scabriculus*, rare; and *Spirifer* (*Martinia*) *lineata*, rare.

FOSSILS AND AGE.

The Kaibab limestone contains an abundant fauna of Pennsylvanian age, including forms which indicate a considerably higher horizon than the upper member of the Redwall. Some of the characteristic species which have been identified by G. H. Girty and others are as follows:

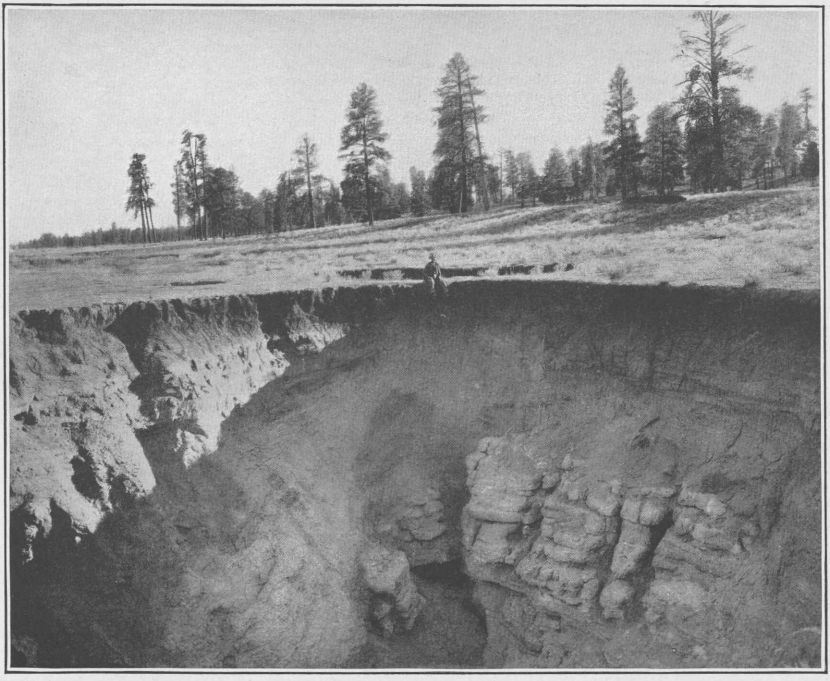
Michelinia sp.
Archæocidaris longispinus.
Archæocidaris ornatus.
Archæocidaris gracilis.
Conularia sp.
Meekella pyramidalis.
Meekella occidentalis.
Chonetes aff. C. geinitzianus.
Chonetes aff. C. variolatus.
Productus ivesi.
Productus occidentalis.
Productus costatoides?
Productus subhorridus?
Productus n. sp.
Squamularia aff. S. guadalupensis.
Spiriferina aff. S. campestris.
Seminula sp.
Pugnax aff. P. utah.
Dielasma? sp.
Aviculipecten coloradoensis.
Lima sp.
Pseudomonotis sp.
Myalina aff. M. permiana.
Bakewellia? sp.
Pinna? aff. P.? peracuta.
Allerisma capax.
Pleurophorus sp.
Schizodus aff. S. wheeleri.
Leda obesa.
Nucula perumbonata.
Pleurophorella gilberti.
Dentalium canna.
Phanerotrema grayvillensis?
Murchisonia terebra.
Patellostium aff. P. marcouiana.
Euphemus subpapillosus.
Bellerophon aff. B. crassus.

[a] Compt. Rend. 5e Cong. géol. internat., pp. 478–479.



A. CREVICE IN KAIBAB LIMESTONE NEAR MOUTH OF CANYON DIABLO, ARIZONA.

Photograph by G. K. Gilbert.



B. SINK IN KAIBAB LIMESTONE NEAR FLAGSTAFF, ARIZ.

UNDIFFERENTIATED CARBONIFEROUS ROCKS.

ZUNI UPLIFT.

The pre-Permian Carboniferous rocks which outcrop extensively in the Zuni uplift have not been studied in detail and very few data concerning them are available. There is a basal member of sandstone and an overlying series of limestones and sandstones, 1,000 feet in all in a part of the area but locally considerably less. At the top is a thin deposit of sandstone of doubtful age. The rocks are believed to be Pennsylvanian and probably represent the Kaibab limestone and perhaps more or less of the underlying Coconino sandstone and Supai formation, but no correlation is feasible at present. They were first described by E. E. Howell,[a] who gave the following general section:

Section of Carboniferous rocks in Zuni uplift.

	Feet.
Gray sandstone and limestone	150
Pale-red sandstone	150–200
Blue to gray limestone	100–150
Red sandstone	50–100
Pink to gray limestone	75–100
Pink and red sandstone on granite and schist	500–600

The limestones contain *Productus costatus* in large numbers, *P. semireticularis*, *Athyris subtilita* (?), and *Bellerophon crassus*, all Pennsylvanian. The basal sandstone shows considerable metamorphism at its contact with granite in the center of the uplift. It grades from red siliceous sandstone through bedded quartzite of reddish color into a crystalline quartzose rock containing mica and feldspar and closely resembling granite. C. E. Dutton[b] described this rock and some of its contact features. He found it in large amount in scattered blocks on slopes near Mount Sedgwick, where it varies from a reddish quartzite to a rock nearly identical, mineralogically, with quartz porphyry. The strata are distorted and shattered by the granite, and in places crossed by it for 200 feet or more. Notable exposures of these features appear on the slopes 12 miles south of Fort Wingate. Dutton refers to a section west of Grant, in which the Carboniferous strata occur in walls 800 feet high, consisting largely of limestone, with a heavy cap of extra hard quartzite forming extensive dip slopes. These slopes culminate in an escarpment that extends for many miles. West of Bluewater it is traversed by Bluewater Canyon, which exhibits part of the upper members. In the east end of this canyon the top limestone is 60 feet thick and is highly fossiliferous. It lies on white to gray cross-bedded sandstone resembling the Coconino. A fault that brings up the base of this sandstone shows a thickness of 80 to 100 feet of it lying on red sandstone, of which 100 feet is exposed to

[a] Rept. U. S. Geog. Surveys W. 100th Mer., vol. 3, Geology, 1875, p. 287.
[b] Mount Taylor and the Zuni Plateau: Sixth Ann. Rept. U. S. Geol. Survey, 1885, pp. 156–158.

the bed of the creek. South of Guam there is a long dip slope of the thick lower brown sandstone series overlain by limestones, which are capped by 60 feet or more of brown sandstone, merging upward into gray sandstone that may be Permian.

OJO CALIENTE.

According to M. K. Shaler the fault which passes near Ojo Caliente brings to view a small area of Carboniferous shale and limestone about a mile southeast of the spring. The rock contains fragmentary fossils recognized as probably *Productus.*[a]

NACIMIENTO MOUNTAINS.

According to A. B. Reagan[b] the Carboniferous rocks in the Nacimiento uplift are limestone, with some shale, 700 feet thick. They appear to be overlapped by red beds at the south end and along the west side of the mountains. The following fossils were reported: *Spirifer striatus, Seminula argentia, Productus mesialis, P. punctatus, P. nebrascensis,* and *Myalina subquadrata.*

PERMIAN SERIES ("MOENCOPIE FORMATION").

ARIZONA.

There appears to be general concurrence of opinion that the shales and sandstones overlying the Pennsylvanian limestones represent a part of Permian time. They are so sharply defined at the base as to suggest the presence of an unconformity, but in parts of the region at least their upper limit is not yet established. Apparently, however, they terminate at the base of a conglomerate which has been termed "Shinarump," but the continuity of this conglomerate at one definite horizon has not been demonstrated. A formation thus delimited has been termed "Moencopie" by L. F. Ward,[c] its type locality being on Moencopie Wash, near Little Colorado River. The formation crosses Colorado River just above Lees Ferry and occupies a wide area in northern Arizona. Walcott[d] studied the section in Kanab Valley in 1889, and found paleontologic evidence which indicated that 850 feet of strata should be classed in the Permian. The lower member, lying on the Kaibab limestone, is chocolate and cream colored limestone containing fossils, as noted by Gilbert.[e] Next above is 37 feet of reddish-brown sandstone grading upward into reddish-brown gypsiferous marl and sandy clay. These rocks constitute the lower division, 145 feet thick in all, terminated by a slight unconformity, above

[a] Bull. U. S. Geol. Survey No. 316, 1907, p. 383, and Pl. XXIII.
[b] Am. Geologist, vol. 31, 1902, p. 74.
[c] Am. Jour. Sci., 4th ser., vol. 12, 1901, p. 403.
[d] Idem, 3d ser., vol. 20, 1880, pp. 221-225. Given in greater detail from Walcott's original notebooks by Cross, W., Jour. Geology, vol. 16, 1906, pp. 105-106.
[e] Rept. U. S. Geog. Surveys W. 100th Mer., vol. 3, Geology, 1875, p. 177.

which lies 25 feet of impure shaly limestone of varying thickness and character, containing an extensive Permian fauna. This is the basal member of an upper division and is overlain by 300 feet or more of reddish-brown shale merging upward into drab or lavender-colored sandy and gypsiferous marls and shales, which in turn give place to ripple-marked, banded, reddish-brown and chocolate-colored arenaceous shales and sandstones. The latter are overlain unconformably by the "Shinarump" conglomerate. The total thickness of the upper division is 710 feet.

Newberry crossed the valley of the Little Colorado about 40 miles below Winslow and noted the principal features of the Permian rocks. He stated [a] that they begin at a point about 3 miles west of the river, where the Carboniferous limestone passes conformably beneath them, dipping at the rate of at least 100 feet to the mile. The lowest beds, which are deep blood-red in color, are so soft that they are eroded into fantastic forms. Next above are soft red argillaceous shales, with layers of red and green, foliated, ripple-marked, fine-grained micaceous sandstone. On the east side of the river these rocks are capped by red shales, above which are conglomerates. Newberry termed these rocks, including 100 feet of overlying red shales and sandstones, the "Saliferous series," or "red sandstone series," with a total thickness of about 500 feet.

The "Moencopie formation," as described by Ward, consists of 500 to 700 feet of reddish-brown saliferous and gypsiferous laminated shales with interbedded sandstones. It terminates, however, at the base of the "Shinarump" conglomerate and appears to be a definite stratigraphic unit throughout a wide area. Ward [b] gives the following general section:

Section of "Moencopie formation" in Little Colorado Valley, Arizona.

	Feet.
Dark chocolate-brown shales devoid of grit and highly charged with salt and gypsum	200
Dark-brown soft argillaceous sandstone	100
Dark-brown shale, highly saliferous and with gypsum layers; becomes calcareous below	200
Shale, mostly white	100
Brown shale, similar to those above; saliferous	100
Carboniferous limestone.	

The sandstones occur at various horizons and locally attain a thickness of 100 feet, with more or less intercalated shale. They are mostly soft, and weather in irregular rounded ledges. The gypsum occurs largely in thin veins, crossing the strata at various angles. Toward the base of the formation the shale is calcareous and nearly

[a] Report upon the Colorado River of the West, explored in 1857–58 by Lieut. J. C. Ives, pt. 3, Geologica report, 1861, p. 75.

[b] Am. Jour. Sci., 4th ser., vol. 12, 1901, p. 403; Mon. U. S. Geol. Survey, vol. 48, pt. 1, 1905, pp. 44–45.

everywhere includes a bed of limestone that merges into the inclosing strata.

The outcrop of the "Moencopie formation" extends along both sides of the Little Colorado Valley from Holbrook to Winslow and thence to a point 12 miles below Tanners Crossing, where the canyon in the Kaibab limestone begins. A low anticline also brings up this limestone for a short distance 5 miles below the mouth of Moencopie Wash. The formation extends for some distance west of the river to Black Tank, according to Ward, and to Black Point, according to Robinson.[a] The thickness near Winslow is estimated by Ward as 500 feet. The only fossils which he reported were impressions of coniferous twigs and stems, apparently from trees of the type to which the petrified wood belongs. They were found in flagstones on Little Colorado River, 3 miles below Tanners Crossing, at a horizon a short distance below the conglomerate.

A brown sandstone member at the base of the formation south and southeast of Winslow constitutes a long dip slope gradually rising to the south. It extends 20 miles to the south from Holbrook and ends in a low escarpment known as the Pink Cliffs. Some buff sandstone and red sandy shale are included in this member. The upper member of the formation extends for some distance up the Puerco Valley east of Holbrook, and far up the valley of the Little Colorado. The latter stream flows on red sandstone 3 miles east of Holbrook and also 5 miles west of that place. To the north, however, the "Moencopie formation" passes beneath the overlying conglomerate in low cliffs just north of the railroad. The formation extends for some distance west of Winslow, nearly to Canyon Diablo, where it ends in a zone of scattered outliers. Near Sunset siding a basal member of massive buff-red sandstone is quarried to some extent. Next above are red and green shales merging upward into red sandstone.

Outliers of the "Moencopie formation" occur at various localities on the limestone plateau to the west, generally protected by lava caps. Robinson has found 400 feet of the red shale and sandstone under the lava on the east side of Anderson Mesa. It has 5 feet of fine-grained red conglomerate at the base, and some conglomerate at the top, which may be "Shinarump." Farther south, on the east side of the mesa, 550 feet of the formation is exposed. In the walls of Sycamore Canyon Robinson found 300 to 400 feet of red beds with conglomerate at top. As noted by Gilbert, there is probably 700 feet of the formation in San Francisco Mountain, mostly covered by lava, but with its orange-red cross-bedded sandstone appearing at a few points. The highest exposure in the mountain shows red rocks 700 feet higher than the adjoining plateau. The pink sandstone is quarried near the base of this mountain just east of Flagstaff. A

[a] Am. Jour. Sci., 4th ser., vol. 24, 1907, p. 112.

sample of the rock from the quarry was analyzed by T. M. Chatard in the laboratory of the United States Geological Survey with the following result:

Analysis of brown sandstone from quarry near Flagstaff, Ariz. (No. 1144).

Silica and insoluble	79.19
Alumina (Al_2O_3)	1.30
Iron oxide (Fe_2O^3)	2.45
Magnesia (MgO)	.23
Lime (CaO)	7.76
Carbonic acid (CO_2)	5.77
Water at 100° C	.32
Water above 100° C	2.94
	99.96

The thickness of the formation exposed at the quarry is about 150 feet, consisting of sandstones above and red shale below. The shale, about 25 feet thick, extends to Flagstaff. The high buttes in Sunset Pass southwest of Winslow show about 700 feet of "Moencopie" beds lying on limestone and capped by lava. The upper strata include drab, gray, and red mottled clays and much light-colored sandstone. Below these are 30 feet of brown sandstone, moderately fine and soft, 200 feet of red shale with thin gypsum beds, and at the base 4 feet of cream-colored sandstones lying on light-buff Kaibab limestone. At old Rock station, on the Santa Fe trail, a short distance to the north, the basal beds are exposed. At this place there are 40 feet of red sandstone and shale, 10 feet of pale pinkish-buff massive sandstone, and 10 inches of red and buff shale lying on buff limestone (Kaibab) with pink spots, of which 6 feet is exposed. Robinson reports an outlying area of "Moencopie formation" at the Cedar ranch, northeast of Kendrick Peak. It is capped by lava and "Shinarump" beds 365 feet thick and consists of 280 feet of shale, mostly red.

Red Butte, 14 miles south-southeast of Grand Canyon station, is another remnant of the "Moencopie formation." According to L. F. Ward its thickness here is 600 feet to a capping of 210 feet of "Leroux formation," protected by 125 feet of basalt. I am informed by Mr. F. E. Matthes that Cedar Mountain, 10 miles south-southeast of the mouth of the Little Colorado, is made up of "Moencopie formation," capped by a hard mass of conglomerate. Newberry mentioned an outlier of red sandstone on the limestone plateau between Diamond and Cataract creeks, which is probably a thin remnant of "Moencopie."

The "Moencopie formation" is brought to the surface in the Fort Defiance uplift in Bonita Valley, but no study was made of the exposures. According to Newberry the red and green foliated sandstones and shales of his "Saliferous series" appear in Pueblo Colorado Wash, east of Oraibi, and continue to Fort Defiance Valley, 400 to 500 feet

of the formation being exposed in Bonita Valley. A low anticline west of Houck brings up the red sandy shales, which are probably at the top of the formation and are capped by 20 feet of conglomerate. The borings at Adamana penetrated the formation for 305 feet, as shown by the record on p. 79.

The following statement regarding the fauna of the Permian in Arizona was kindly prepared for me by G. H. Girty:

> The fossils of the Permian fauna are largely new. They consist almost entirely of pelecypods. Walcott cites several brachiopods, but rhynchonelloid shells, representing possibly not more than a single species allied with *Pugnax utah* are alone abundant. Occasionally a fragment of a large nautiloid is found, and very rarely an ammonoid, while a few specimens of *Pleurotomaria* and other gasteropods occur. Of the pelecypods the genus *Myalina* is especially abundant, but is probably represented by no more than two or three species. Shells having the general aspect of *Pteria* are also abundant at some localities. They probably belong to the genus *Bakewellia*. Beside the genera mentioned, *Aviculipecten*, *Pseudomonotis*, *Pleurophorus*, and *Schizodus* occur.

ZUNI UPLIFT.

The "Moencopie formation" is brought to the surface in a narrow zone encircling the Zuni uplift, but on the east and south sides the rocks are hidden by lava flows. This outcrop was shown on Dutton's map, limited below by the Carboniferous limestones and above by a bed of conglomerate believed to represent "Shinarump." The rocks are stated to be sandy shales containing much gypsum and thin local beds of limestone. The bright and highly variegated colors are characteristic, presenting chocolate, maroon, and dark brownish reds, alternating with pale ash-gray or lavender. The upper beds contain numerous silicified trunks of large coniferous trees. Near Fort Wingate Dutton found "several specimens of *Bakewellia* and an attenuated form of *Myalina* corresponding to the forms of the latter genus which are common in the Permian." He stated that the beds are distinctly separable from the underlying Carboniferous limestone.

I found the formation well exposed in the hogback range a few miles northwest of Bluewater. At the base is a thin mass of brown-red conglomeratic sandstone lying on the Pennsylvanian limestone. It is overlain by about 500 feet of soft shale of gray, buff, reddish, and purplish tints, containing beds of sandstone from a few inches to 20 feet thick. These sandstones are mostly red in the lower beds, but at the top they are of lighter color and more or less cross-bedded. One hard bed constitutes the crest of the hogback range, and locally is 100 feet thick. A peculiar limestone conglomerate about 3 feet thick occurs in the shale series about 50 feet above its base and is traceable westward to a point beyond Fort Wingate. The strata vary from place to place, especially in the color of the shale and the

thickness and character of the included sandstones. Numerous limestone concretions and fragments of petrified wood are included. In many exposures the basal shale is dark red, maroon, or purple in color. An exposure south of Guam shows at the base 30 to 40 feet of gray sandstone, followed by 50 to 70 feet of red shale, 30 feet of the peculiar conglomerate with many limestone pebbles, and 120 feet of maroon to green massive shale with three gray sandstone members in its upper half. The top sandstone, 30 to 40 feet thick, occupies the hogback ridge which extends for many miles a short distance south of the railroad. It is locally conglomeratic and is supposed to represent the "Shinarump" conglomerate, so that it should be regarded as the base of the next formation above the "Moencopie." It is overlain by sandy shales with scattered thin beds of impure limestone at the base of the Triassic underlying the wide valley that extends to the foot of the red cliffs on the north.

OJO CALIENTE.

In the uplift near Ojo Caliente the Pennsylvanian shale is overlain by red sandstones and purple shales several hundred feet thick, capped by a conglomerate similar to the "Shinarump" conglomerate of other regions.

SAN JOSE REGION.

The lowest beds which I observed in this general region were in the axis of an anticline 8 miles west of Rio Puerco station. A weak warm spring issues at this locality. The rocks comprise about 20 feet of greenish-gray sandy shales with thin sandstone layers and an inch of coal at the top. The fossils obtained here were identified by G. H. Girty, as follows:

Myalina permiana.
M. perattenuata.
Aviculipecten cf. A. whitei.
Bakewellia? sp.
Bulimorpha near B. nitidula.
Spirorbis sp.

These are related to the Permian of the Mississippi Valley. The fossiliferous beds are overlain by 300 to 400 feet of red sandstone and shale lying nearly level and capped by lava to the west. On the east is a succession of soft buff cross-bedded sandstones and shales, in part red or brown, with some limestones, 1,000 feet or more thick, dipping 50° to 60° E.

JEMEZ REGION.

According to Herrick and Reagan, Permian beds appear extensively in the sides of the Nacimiento uplift west of Jemez, overlying limestone of Carboniferous age.

TRIASSIC SYSTEM.

LITTLE COLORADO VALLEY.

WARD'S CLASSIFICATION.

The most extensive study of the Triassic rocks in northern Arizona was an examination made by L. F. Ward in 1899 and 1901 of the region adjoining the Little Colorado. An important collection of fossil bones obtained near Tanners Crossing indicated the Triassic age of at least part of the deposits. The rocks lying between the Permian ("Moencopie formation") and the Cretaceous sandstone, 2,800 feet in thickness, were divided into two formations, as shown in the following table:[a]

Section of Triassic rocks in Little Colorado Valley.

[By L. F. Ward.]

Formation.	Rocks.	Thickness.
		Feet.
Painted Desert (1,200 feet)	White sandstones	100
	Brown sandstones	200
	Variegated sandstones, regularly stratified and brilliantly colored, presenting a banded appearance and forming the "Painted Cliffs"	800
	Red-orange sandstones	100
Shinarump (1,600 feet)	Leroux member:	
	Calcareous marls, sometimes worn into small white, blue, or purple buttes	200
	Mortar beds with impure flintstones	80
	Limestone, stratified	20
	Sandstone with black petrified logs, local	100
	Variegated marls, chiefly argillaceous but somewhat calcareous, often in small scattered buttes; white, pink, or red, banded. Bones of belodonts and dinosaurs	400
	Lithodendron member:	
	Conglomerates and cross-bedded coarse sandstones, often with pink and white striped clay lenses, interstratified with gray argillaceous shales and variegated marls, the latter locally much thickened. Forms brilliant banded cliffs	800

Newberry[b] classed these Triassic rocks partly in the top of his "red sandstone series" and partly in the "variegated marls," the latter estimated at 1,500 feet in thickness, comprising the "Painted Desert formation," the "Leroux formation," and most of the "Lithodendron formation."

"LITHODENDRON FORMATION."

The "Lithodendron formation" was named from Carrizo (Lithodendron) Creek, which empties into the Puerco at Carrizo, 5 miles west of Adamana. According to Ward, its thickness ranges from 300 feet near Moencopie Wash to 700 or 800 feet in the belt extending from a point north of Winslow to the Petrified Forest. Sandstone and conglomerate are the most conspicuous rocks, but they are believed

[a] Am. Jour. Sci., 4th ser., vol. 12, 1901, p. 413; Mon. U. S. Geol. Survey, vol. 48, pt. 1, 1905, p. 45.

[b] Report upon the Colorado River of the West, explored in 1857–58 by Lieut. J. C. Ives, pt. 3, Geological report, 1861, pp. 74–80.

to occur at various horizons separated by light-colored shales and "marls." The formation begins with a deposit of conglomerate, but it was not ascertained whether or not this is continuous at the same horizon throughout. The conglomerates grade into cross-bedded sandstone and both are of light color, contrasting strongly with the red rocks of the underlying "Moencopie." No unconformity was noted in the succession of beds, and although sandstones predominate below, they are often found in the medial beds, and sandstone locally grading into conglomerate occurs in places at the top of the formation. The shales vary in character and are intercalated between the deposits of sandstone and conglomerate, even where the formation is only 300 feet thick, as in the lower valley of the Little Colorado. At the Petrified Forests "marls" constitute about half of the beds. They are largely of white and bluish-gray color, but show many darker tints, such as pink, purple, and buff. They are interstratified between conglomerates and cross-bedded sandstones, with numerous changes of succession within short distances. Ward states that in the lower part of the Little Colorado Valley calcareous clay lenses are included in the formation, the material taking the form of white stripes from 10 to even 20 feet in length but in places occurring in short pieces and small balls. They were not noted to the southeast, but are numerous in Red Butte, where the inclosing clay is of a bright-red color. Ward states that 210 feet of the "Lithodendron formation" remains on this butte, protected by basalt. It consists of 60 feet of conglomerate and cross-bedded sandstone, 100 feet of shale, and 50 feet of sandstone lying on 600 feet of the "Moencopie formation." The shale resembles the "Moencopie formation," but the underlying sandstone, which is cross-bedded and very coarse, includes clay pellets believed to be characteristic of the "Lithodendron formation." This apparent transition has suggested to Ward that these two formations are parts of one great series.

Newberry described some features of the "Moencopie formation," which, as stated above, he included partly in his "red sandstone series" and partly in the "variegated marls." He noted the conglomerate in the bluffs along the east side of the Little Colorado Valley below Winslow, where he found it to be 20 to 40 feet thick and to contain quartz pebbles varying in size from that of a pea to that of an egg. It lies on laminated sandstones or sandy shales, mostly red or pinkish. A representative section 10 miles above Winslow was given as follows:

Section of part of Triassic-Permian rocks at the mouth of Cottonwood Wash, near Hardy, Ariz.

Variegated marls:	Feet.
Light-orange marl	15
Green and purple magnesian limestone, calcite concretions	5
Pinkish-purple marl	22

	Feet.
Variegated marls—Continued.	
Brown shelly sandstone	⅔
Purple marl with silicified wood	16
Purplish-green cherty magnesian limestone in several layers, alternating with bands of marls	8
Purple and cream-colored marls	30
Greenish magnesian limestone in thin layers, with bands of marl	12
Yellow, red, and purple marl	40
Green magnesian limestone, thin layers with bands of marl	3
Red, purple, pink, green, lilac, brown, and blue marls with silicified wood	350
Red sandstone series:	
Green foliated sandstone	20
Purple shales with some silicified wood	50
Red sandstone and shale	45
Conglomerate	26
Dark-red laminated sandstone, with salt spring.	
	643

An immense amount of petrified wood was noted, but not in place.

E. E. Howell traced the conglomerate outcrop for several hundred miles from Utah into New Mexico, and states:[a]

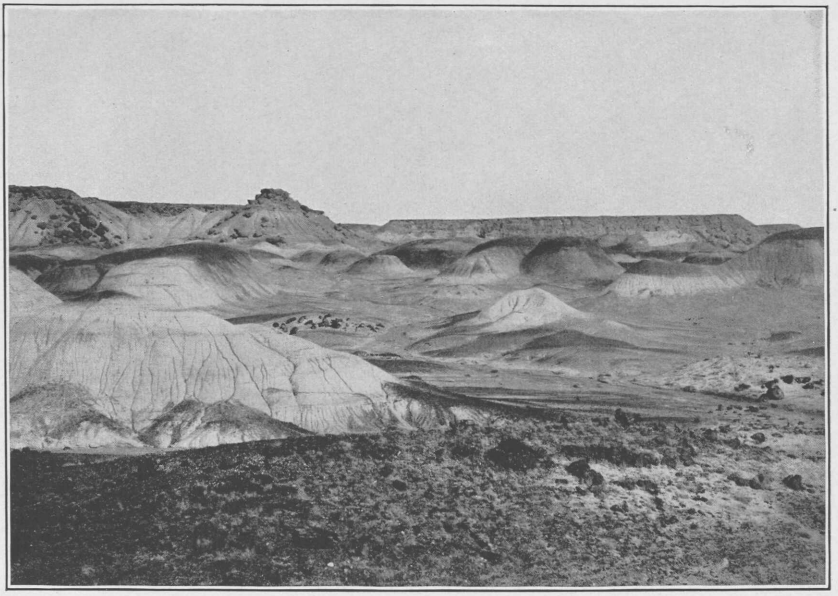
> The conglomerate bed to which Powell has given the name Shinarump is a very singular formation, * * * having a maximum thickness at St. George of 100 feet. It seldom exceeds 40 or 50 feet to the east, but is coexistent so far as I know with the Trias of the Colorado Plateau. Occasionally it is little more than a coarse sandstone, and sometimes thins out to 8 or 10 feet, but never have I passed that horizon without seeing it. One of its constant features, almost as constant as its existence, is the great amount of silicified wood which it contains.

Gilbert[b] described the lower portion of the Triassic as consisting of—

> variegated saliferous and gypsiferous clays with a persistent bed of conglomerate in the middle of them. The lower shales are somewhat eroded by the current which spread it, as is shown by the inequality of the surface on which it rests. Its thickness is variable, and it is not universally present; but its persistence over large areas is nevertheless such as to excite wonder. In the conglomerate and the superjacent clays are silicified tree trunks in great numbers.

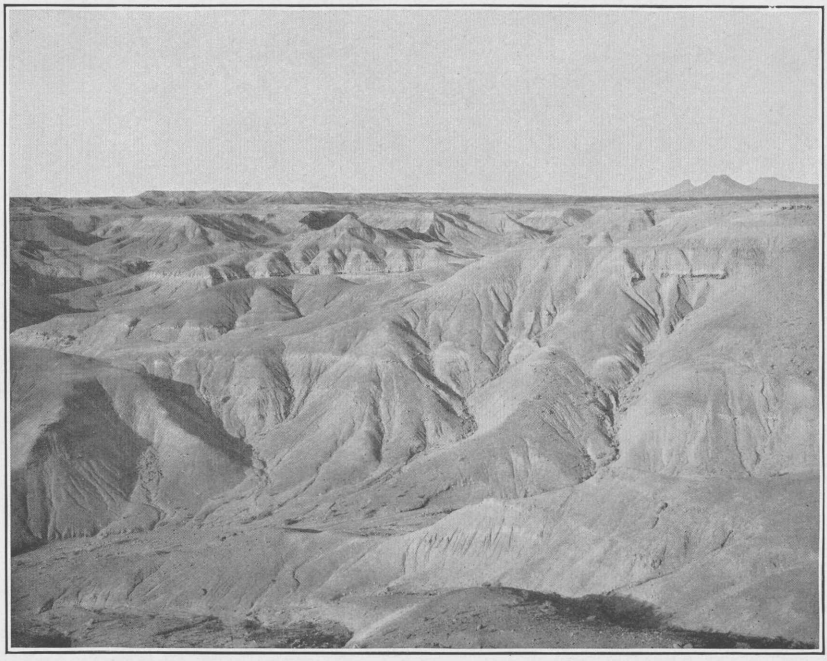
I found this conglomerate at the base of the "Lithodendron formation," well exposed 5 miles northeast of Winslow, associated with two beds of sandstone and containing a large amount of petrified wood. It was traced along the north side of the Little Colorado Valley to Holbrook and thence up the Rio Puerco to a point considerably beyond Adamana. I did not notice that the conglomerate occurs at various horizons, as stated by Ward, but made no careful observations in that connection. The conglomerate appears again in the anticline west of Houck, in the walls of Quirino Canyon. The ledge here is 20 feet high, of hard brownish-buff cross-bedded conglomerate and pebbly sandstone, with much petrified wood. Robinson

[a] Rept. U. S. Geog. Surveys W. 100th Mer., vol. 3, Geology, 1875, p. 283. [b] Idem, pp. 175–176.



A. CLAYS CAPPED BY CONGLOMERATIC SANDSTONE IN PETRIFIED FOREST, ARIZONA.

The logs occur in the sandstone. Photograph by W. T. Lee.



B. BADLANDS IN "LEROUX" SANDY CLAYS 12 MILES NORTH OF HOLBROOK, ARIZ.

Buttes of red sandstone and basalt in distance.

reports this conglomerate 35 feet thick lying in red shale of the "Moencopie formation" at the Cedar ranch, northeast of Kendrick Peak. It contains pebbles up to 3 inches in diameter, and petrified wood. It is overlain by 170 feet of marl and shale, 25 feet of sandstone, and 135 feet of shale and sandstone capped by lava.

Petrified wood occurs in great abundance everywhere in the "Lithodendron formation" notably at the upper and lower Petrified Forests, but there is a vast amount of it at many other places. The principal species is *Araucarioxylon arizonicum*, described by F. H. Knowlton[a] from two trunks collected in 1879 on Lithodendron Creek. The wood occurs in the conglomerate, but as the beds are eroded it accumulates on the surface at various levels. The trunks appear in many exposures, but are all drifted logs, so far as recorded.

"LEROUX FORMATION."

The "Leroux formation," which constitutes the upper half of Ward's "Shinarump formation," was named from Leroux Wash, which enters the Little Colorado 2 miles west of Holbrook. It is on this wash, about 15 miles north of Holbrook, that the formation probably attains its maximum thickness of 800 to 900 feet, according to Ward; near Moencopie it is 600 feet thick and east of Tanners Crossing and north of Winslow it is 700 feet thick. The lower half consists of variegated "marls" or massive shales, mostly white or bluish but in part pink or red and beautifully banded. The outcrop zone is characterized by bare buttes 3 to 30 feet high, in the form of haystacks, scattered over the plains. This feature occupies a belt 3 miles wide on Leroux Wash, as shown in part in Plate VIII, *B*. In the Petrified Forests the variegated "marls" appear half a mile east of the lower forest, but in the northern part of the region they lie somewhat farther east, the middle forest being in the midst of them. The same material occurs in the "Lithodendron formation" between the coarser deposits, and it was the belief of Ward that there is a regular gradation from one member to another, probably at somewhat different horizons in different parts of the area. Accordingly a sandstone which might be regarded as the topmost bed of the "Lithodendron" at one locality finally thins out and disappears, bringing the underlying and overlying bodies of variegated "marl" into continuous succession. These "variegated marls" of Ward are succeeded by a variety of beds. Near Black Falls, in the lower valley of the Little Colorado, there is at least 100 feet of sandstone containing black petrified logs. Next above are "mortar beds" which contain flint and also a bed of stratified limestone. These calcareous materials, from 200 to 300 feet or more in thickness, constitute the upper portion of the member. In the Leroux Wash region the

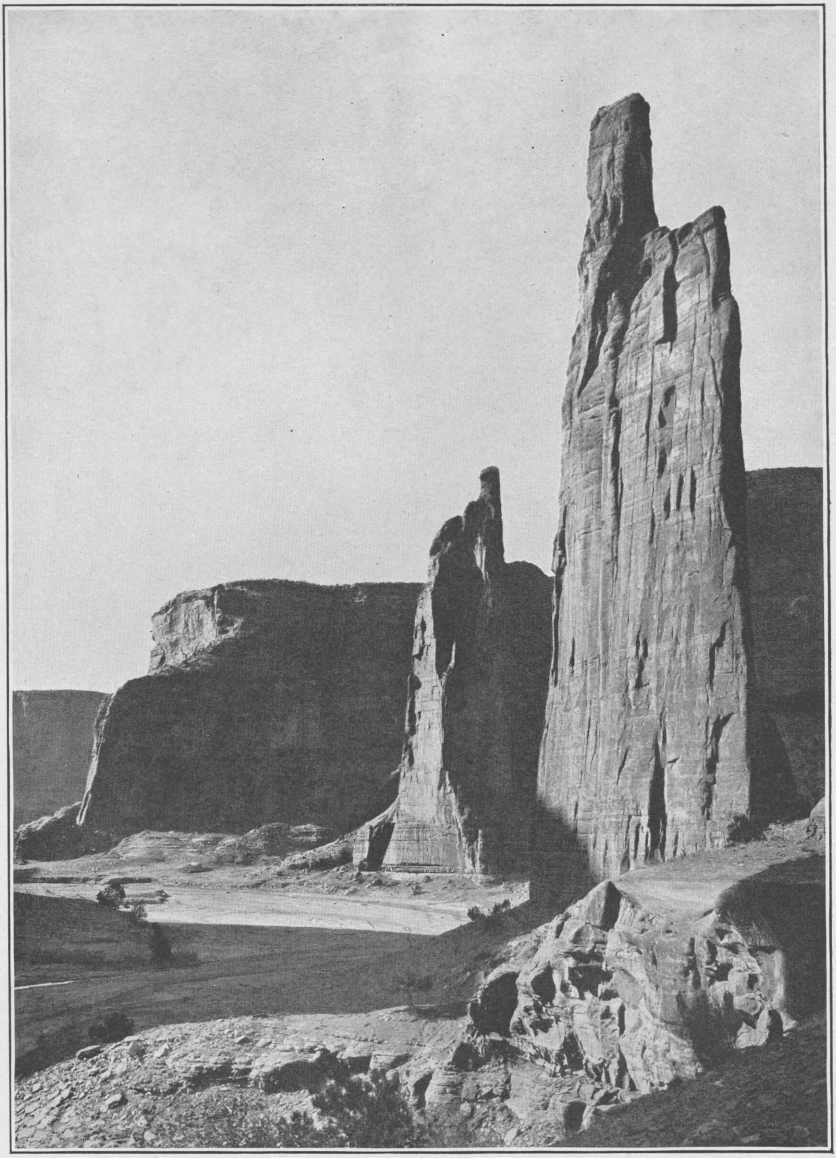
[a] Proc. U. S. Nat. Mus., vol. 5, 1882, pp. 1–3.

lower limit of this series is indefinite, for the deposits differ from the underlying beds only in the presence of carbonate of lime, which finally develops into a bed of limestone locally 10 feet thick. Over the latter lie 200 feet of very heavy beds of calcareous massive shales weathering at the top of the member into badlands buttes, in whole or in part of deep blue or lively purple color. The features are similar in the Petrified Forests region, but the development of the calcareous series is much less extensive. In the Fort Defiance uplift, beginning 50 miles east of Oraibi, Newberry found at this horizon 400 feet of buff, orange, purple, lilac, olive-green, and blue marls, with deposits of gypsum closely similar to the beds near the Little Colorado but with less dolomite. Fossil wood occurs in many places in the "Leroux formation," notably at the middle forest in the Petrified Forests, but also at various horizons to the top. (See Pl. VIII, *A*.) Most of the logs appear to have been drifted, but at one locality east of Tanners Crossing Ward found numerous stumps in place in an area of 30 to 40 acres. In 1899 Ward discovered vertebrate remains in the "variegated marls" a short distance east of Tanners Crossing, and further collections were made in 1901. They were obtained at a horizon near the middle of the series, or 200 to 300 feet above the top of the conglomerates. The material was examined by F. A. Lucas,[a] who found that the principal species was the belodont *Heterodontosuchus ganei*, two scutes from the belodont *H. episcoposaurus*, a new species of a very large labyrinthodont, *Metoposaurus frassi*, and a new cotylosaurian named *Placerias hesternus*. These remains are regarded as typical of the Triassic. The genus *Metoposaurus* is characteristic of the Keuper of Europe, which has a similar mixed fauna of belodonts and labyrinthodonts.

"PAINTED DESERT FORMATION."

The "Painted Desert formation" of Ward consists of about 1,200 feet of bright-colored, regularly stratified sandstone which constitutes the high cliffs extending along the northeast side of the Little Colorado Valley. At the base is 100 feet of orange-red sandstone, which contains much clay and is so soft that it is eroded into fantastic buttes and chimneys. It presents these same features on Leroux Wash and east of the Petrified Forests. The overlying sandstones are banded with various bright colors and attain a thickness of about 800 feet. Next above are more massive sandstones, mostly pure white and cross-bedded, but in the vicinity of Moencopie the lower 200 feet of these is soft, brown, and somewhat argillaceous, while the upper portion is white sandstone 100 feet or more thick. On the latter the Cretaceous beds lie unconformably. Ward regarded this white sandstone as Triassic, but presented no evidence for his belief;

[a] Science, new ser., vol. 14, 1901, p. 376; Proc. U. S. Nat. Mus., vol. 27, 1904, pp. 193–195, Pls. III, IV.



WINGATE SANDSTONE IN CANYON DE CHELLY, ARIZONA.

Photograph by J. K. Hillers.

it appears to be the same bed that was traced by Howell from Utah as part of the Jurassic.

In the steep slopes of a high basalt-capped mesa 35 miles south-southeast of Oraibi the following section of upper Triassic beds was measured by Newberry:

Section of upper Triassic beds halfway between Oraibi and Holbrook, Ariz.

	Feet.
Green, reddish-brown, and drab soft calcareous sandstone	60
Green, purple, red, and yellow marls and calcareous sandstones	150
Magnesian limestone, pinkish, cherty	5
Thick bedded light brown, pink, purple, and banded calcareous sandstone	50
Orange, yellow, and red marls	140
	405

The top of this section extends to or nearly to the base of the Cretaceous.

FORT DEFIANCE UPLIFT.

The Triassic rocks are extensively exposed in the Fort Defiance uplift in a broad belt extending for many miles along the eastern margin of northern Arizona and passing into New Mexico from Manuelito to Zuni and beyond. Along the Santa Fe Railway and southward this area is continuous with the exposures in the Little Colorado Valley. They are deeply trenched by Canyon de Chelly, as shown in Plate IX, and by Canyon del Muerto. Newberry [a] described the rocks along his route where they first rise in the valley of Pueblo Colorado Wash, 50 miles east of Oraibi. Here the upper beds are thicker and harder than in the region to the southwest, being soft thick-bedded sandstones varying in color from white to blood-red. Next below are about 400 feet of buff, orange, purple, lilac, green, and blue marls, with gypsum deposits ("Leroux formation"), closely similar to the deposits near the Little Colorado but containing less dolomite, although some of this rock still characterizes the lower portion of this member. The wash also cuts into 100 feet or more of underlying red and green foliated sandstones and shales, the upper part of the "red sandstone series," containing a conglomerate member like that near the Little Colorado. These lower beds are at the surface along the crest of the anticline for 20 miles to Fort Defiance, where they pass below overlying beds on the steep easterly dip. The succeeding beds are soft sandstones 400 to 500 feet thick, mostly massive, white or greenish white toward the top and a uniform rose-red in the lower two-thirds. Next above is 100 feet of yellow sandstone, succeeded by shale and sandstone carrying Cretaceous fossils. These Triassic rocks are extensively exhibited near the railroad about Manuelito, capped unconformably by the brown Creta-

[a] Report upon the Colorado River of the West, explored in 1857–58 by Lieut. J. C. Ives, pt. 3, Geological report, 1861, p. 89.

ceous sandstone. The upper member is soft, cross-bedded sandstone, white or greenish white at the top and banded pink and gray below, about 500 feet thick. It lies on about the same amount of dark red, very massive sandstone, closely resembling the Wingate sandstone on the north side of the Zuni uplift.

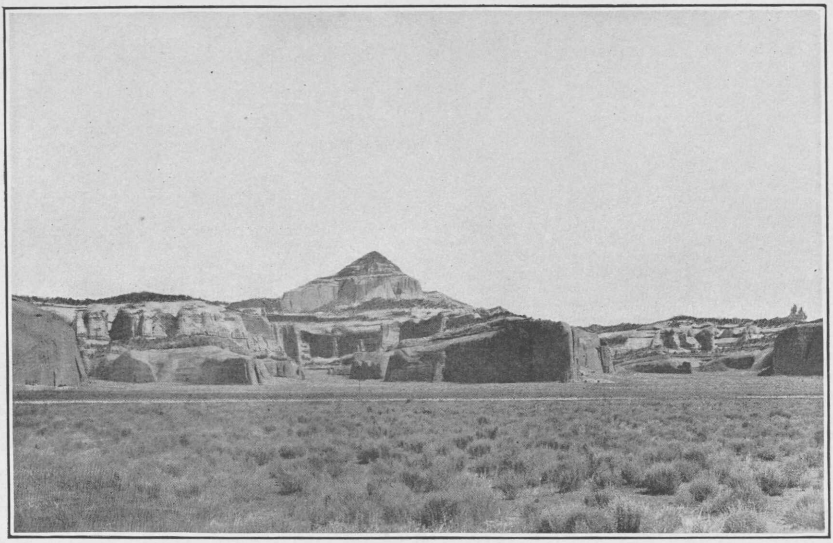
ZUNI UPLIFT.

DUTTON'S CLASSIFICATION.

The supposed Triassic rocks in the Zuni uplift have been described by Newberry, Marcou, and Dutton. Dutton [a] has subdivided them into the Zuni sandstone at the top, 1,100 feet thick, possibly of Jurassic age; the Wingate sandstone, 450 feet thick, presumably equivalent to the Vermilion Cliff sandstone of southern Utah; the "Lower Trias," 1,600 feet thick, with the supposed equivalent of Powell's "Shinarump" conglomerate provisionally at the base. The conglomerate lies on 450 feet of sandy shales, believed to be of Permian age, as described on a previous page. The "Shinarump" is referred to as a "well-marked coarse sandstone" and as a "very coarse conglomeratic sandstone." Next above are "about 650 feet of dark, strongly-colored sandy shales, abounding in selenite and silicified wood. These shales resemble so exactly the Permian below that it is quite impossible to distinguish them lithologically. In color, texture, bedding, and variegation they are absolutely the same." Accordingly, the presence of the conglomerate is the only basis for subdivision. These dark shales yielded plants classed as Triassic by Newberry and a few saurian bones classed in the same system by Cope. Above them is a "series of lighter-colored pale dull-red shales," not well exposed for measurement, but about 800 to 900 feet thick. Two thin beds of hard limestone 3 and 4 feet thick are included.

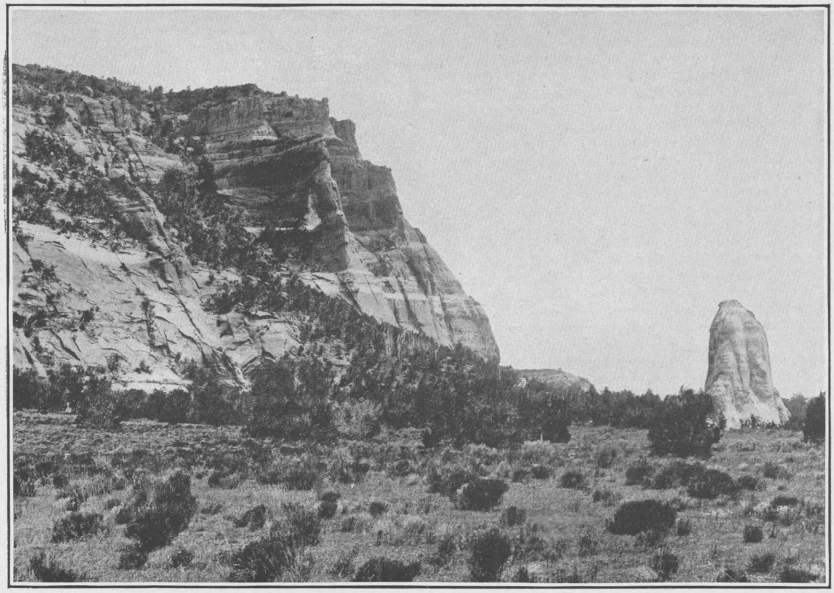
The Wingate sandstone of Dutton in the Zuni uplift region is a massive bright-red sandstone 450 feet thick, which outcrops in high cliffs in part of the area. These brilliant red walls extend parallel to the railroad and about 2 miles north of it, from a point near Navajo Church eastward nearly to Bluewater. They also extend from Fort Defiance past Manuelito to the region about Zuni. In many places there are no bedding planes, and the entire formation appears to be one massive bed, but locally there is banding, this feature being especially prominent 9 miles east of Zuni, where the bedding is thin and there are shale and gypsum partings, in great contrast to the very massive structure near Guam. (See Pl. X, *B*.) Dutton regarded the Wingate sandstone as equivalent to the Vermilion Cliff sandstone of southern Utah. (See Pl. X, *A*.)

[a] Sixth Ann. Rept. U. S. Geol. Survey, 1885, pp. 135 et seq.



A. RED WALLS OF WINGATE SANDSTONE CAPPED BY ZUNI SANDSTONE AT PYRAMID PEAK AND NAVAJO CHURCH, NEW MEXICO.

Looking north across the Santa Fe Railway.



B. WINGATE SANDSTONE NORTH OF GUAM, N. MEX.

The Zuni sandstone in the Zuni uplift was described by Dutton as consisting of "sandstones and sandy shales, with occasional masses of gypsum." The thickness varies, ranging from 800 to 1,300 feet. The formation also varies in color and bedding, and in many places it is wonderfully banded and variegated. In some places it is very massive, like the Wingate sandstone, but this is exceptional. Dutton says:[a]

> Between Wingate and Zuni, around the southwestern flanks of the Zuni Plateau, it is texturally solid and homogeneous and yet is divided up into alternating bands of bright red and white. * * * Around Zuni the whole mass is of a nearly uniform creamy-white color, suggestive of the White Cliff sandstone of southern Utah. In Pyramid Valley south of Manuelito it is of a uniform leaden color. * * * North of Fort Wingate it is broken up into a series of variegated beds of all conceivable colors. Yet the materials of these strata are the same throughout, fine sand with a calcareous and gypseous cement, with an occasional band or even a thick member of gypsum. The gypsum is most abundant near the top of the series, where it occurs sometimes in very heavy masses. Silicified wood is also abundant.

The top member is a highly colored, variegated, shaly sandstone, below which are more massive sandstones, white or yellow in color.

LOCAL FEATURES.

I examined the Triassic rocks along the north side of the Zuni uplift from a point east of Gallup to Bluewater and made a number of local sections. Exposures of the middle and lower beds are rare, for their outcrop zone underlies the valley followed by the railroad across the Continental Divide, where there are extensive coverings of surficial deposits. On the south side of this valley is a long line of low hogback ridges, due to the sandstone which Dutton regarded as the "Shinarump." Two miles or more to the north is the high red wall of Wingate sandstone, surmounted by slopes and cliffs of Zuni sandstone capped by the Cretaceous Dakota sandstone. The Dakota constitutes the long dip slope descending into the valley of the overlying shales farther north.

The following section gives the principal beds outcropping near Guam and for some distance east and west:

Section of Triassic rocks at north end of Zuni uplift, near Guam, N. Mex.

	Feet.
Hard buff sandstone (Dakota), unconformable on—	
Zuni:	
Red to greenish-gray sandy clays and soft light-colored sandstone	100
Soft, very massive, coarse sandstone, in part gray, but in places containing many red grains	220
Alternating red and gray sandy shale and soft shaly sandstones, banded	100
White, soft, cross-bedded sandstone (of Navajo Church)	200
Very soft brown to red sandstone, banded	140
Limestone, massive at top, thin and sandy below	10

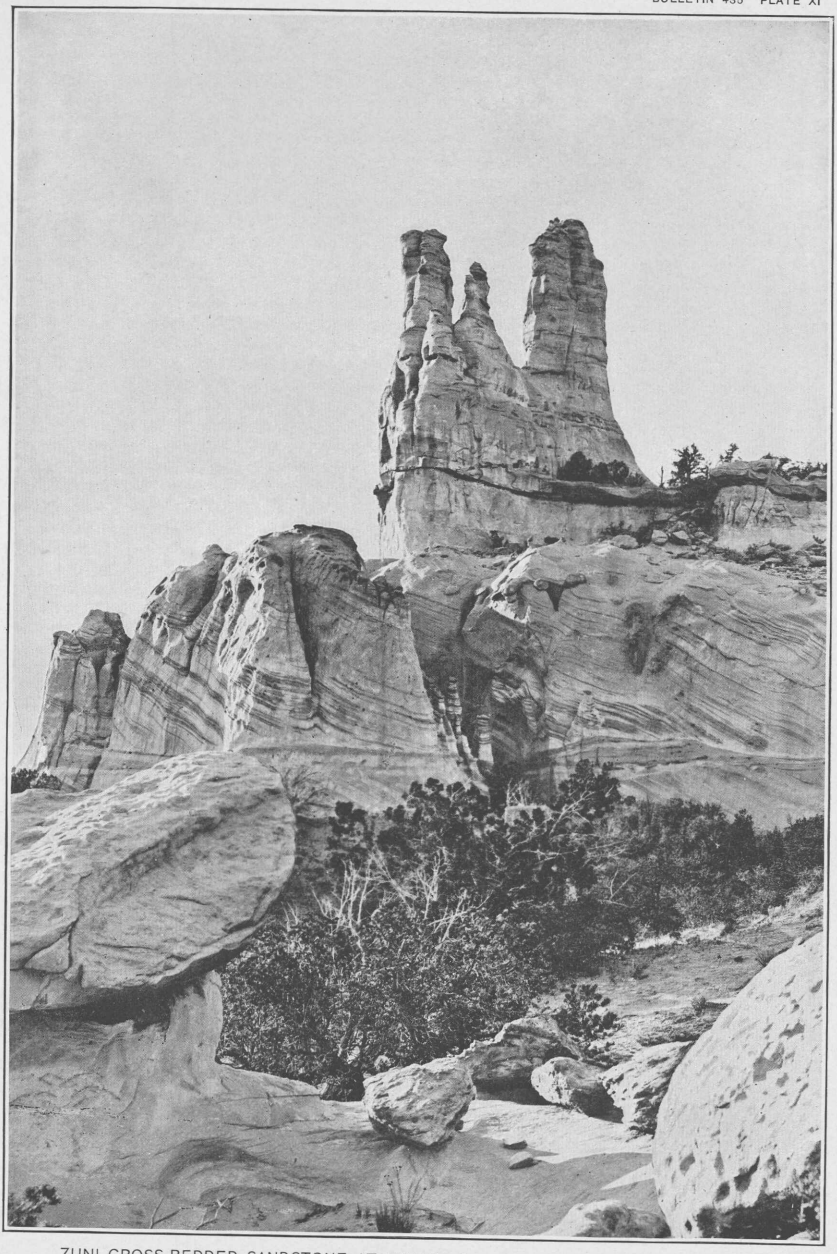
[a] Op. cit., p. 137.

	Feet.
Wingate: Very massive, fine-grained red sandstone, cross-bedded.	400
Leroux:	
Calcareous sandstone and sandy shale, purple to gray, with many bone fragments in lower half	12
Red and maroon sandy shale in bad-land slopes	150+
Hard, purplish-brown, very thinly bedded sandstone	12
Red and maroon sandy shales	100
Covered for 2 miles, average dip probably 4°	700+

These beds show considerable uniformity in character for several miles east and west. Toward Gallup the upper portion of the Zuni sandstone is white and soft and the middle and lower portions are predominantly light greenish gray, banded with reddish and darker tints, with local developments of soft, pale red and buff sandstone, in part argillaceous. A measurement of thickness 8 miles southeast of Gallup gave 800 feet. Here the upper half is soft white and pale greenish-white sandstone, with much red banding, and the lower half is gray sandstone, with considerable light-red banding. The unconformity with the overlying Cretaceous is conspicuously marked by the strong contrast between the fine-grained white Zuni sandstone below and the brown or buff coarse Dakota sandstone above. Locally there is suggestion of an erosional break in the middle of the Zuni sandstone. The thin limestone member at the base of the formation near Guam extends for some distance to the west, capping the red Wingate escarpment. I found no fossils in it, but did not have opportunity to make a thorough search. (See Pl. XI.)

The Wingate sandstone is uniform in character in the region east and southeast of Gallup, where its thickness is close to 400 feet, possibly with slight decrease near Guam and farther east. At the base of the Wingate there is a thin but very persistent stratum of calcareous sandstone and shale of purplish tint, containing bone fragments. This stratum was not followed east of Guam, but it was traced westward to a point near Navajo Church and thence over the end of the anticline and southward for 8 miles. Its thickness, which is 12 feet near Guam, decreases to 2 feet in a section measured 8 miles southeast of Gallup. It is 4 feet thick just south of the railroad 7 miles east of Gallup, where it is underlain by 80 feet of red to purplish-red sandy clays and overlain by the massive Wingate sandstone. Unfortunately the bone fragments which I obtained were too much broken to be determinable.

The deposits below the Wingate sandstone have a thickness of about 1,000 feet. They are sandy clays or massive shales, largely of reddish and maroon tints, with thin deposits of sandstone. One bed of sandstone, having a dark-purplish color, about 200 feet below the horizon of the bone bed, was traced from a point near Guam to



ZUNI CROSS-BEDDED SANDSTONE AT NAVAJO CHURCH, EAST OF GALLUP, N. MEX.

Photograph by J. K. Hillers.

a point 8 miles southeast of Gallup. These beds were regarded as Lower Triassic by Dutton, and doubtless represent the "Leroux member" of Ward, although they are much redder in this region than in the Little Colorado Valley. Next below is the series of locally conglomeratic sandstones, called Shinarump by Dutton, which constitute the low hogback extending along the south side of the valley from Bluewater westward.

G. K. Gilbert [a] describes the Triassic rocks on the northwest side of the Zuni uplift. Near the railroad east of Gallup he found, next below the Cretaceous, 1,000 feet of massive cross-bedded sandstones. At the top is 400 feet of soft sandstone variegated with green, sienna, and ocher-yellow, lying on 500 feet of pale-red to white sandstone; these two represent the Zuni sandstone. Next below is 100 feet of brick-red sandstone at the top of the Wingate. In a section north of Bear Spring, near Fort Wingate, between Guam and Gallup, Gilbert measured the following beds:

Section of Triassic-Permian rocks near Fort Wingate, N. Mex.

	Feet.
9. Purple to white conglomerate (overlain by Cretaceous coal measures)	80
10. Pink and variegated arenaceous shales	30
11. Massive cross-bedded sandstone (712 feet):	
(*a*) Pale purple; white at top	90
(*b*) Pale pink; friable	80
(*c*) Cream-colored; incoherent	120
(*d*) Red and white; banded	200
(*e*) Crystalline limestone	2
(*f*) Red and compact, with white band near base	220
12. Red and variegated shales	100
13. Purplish limestone	6
14. Variegated gypsiferous clays with beds of sandstone (975 feet):	
(*a*) Variegated clays	450
(*b*) Pale-purple cross-bedded sandstone	15
(*c*) Variegated clays	150
(*d*) Coarse white sandstone	25
(*e*) Purple and white clays	125
(*f*) Red and purple clays	50
(*g*) Coarse brown conglomerate	10
(*h*) Red, purple, and white clays	90
(*i*) Gray sectile sandstone	10
(*j*) Red, purple, and white clays	50
15. Calcareous chert on Carboniferous limestone	25

Beds 9 to 13 are probably Zuni sandstone, and 14*a* is an argillaceous phase of the Wingate sandstone. If 14*g* is the so-called Shinarump conglomerate, the underlying "Moencopie formation" is only about 150 feet thick.

[a] Rept. U. S. Geog. Surveys W. 100th Mer., vol. 3, Geology, 1875, pp. 551-553.

Gilbert's section near Nutria Pueblo, 20 miles northeast of Zuni, is as follows:

Section of Triassic rocks near Nutria, N. Mex.

	Feet.
1–6. Cretaceous sandstones and shales with coal.	
7. Massive cross-bedded sandstone, red and white and weathering brown	535
8. Conglomerate	10
9. Red arenaceous shale	240
10. Purple brecciated limestone	2
11. Variegated clays with sandstone beds (1,585 feet):	
(*a*) Purple and variegated clays	800
(*b*) Pale-red sectile sandstone	5
(*c*) Red clay	70
(*d*) Pale-red sectile sandstone	10
(*e*) Variegated clays	700

ZUNI REGION.

The Triassic rocks outcrop in a wide area about the pueblo of Zuni, where the flat, widened prolongation of the Fort Defiance anticline is deeply eroded by the drainage system of Zuni River. On the east side of this area an easterly dip carries these rocks beneath the Cretaceous. The Zuni sandstone constitutes buttes and wide tabular areas in the Zuni region and is very massive, appearing in cliffs of uniform creamy-white or pale-gray color, very different from its character on the north side of the Zuni uplift. In the outcrops 9 miles northeast of Zuni, however, there is much red banding. The Wingate sandstone also changes considerably and the bedding becomes thin, with shales and gypsum partings, in great contrast to the massive red cliffs north of Guam. Howell[a] regarded the sandstone cap on the Zuni Buttes, 4 miles northeast of Zuni, as basal Cretaceous, but Dutton classed it as Zuni sandstone. It consists of 130 feet of soft cross-bedded sandstone of a reddish-buff tint, with a suggestion of unconformity at the base. Similar relations exist at El Moro, or Inscription Rock, where the cap is about 75 feet thick.

ACOMA.

The Triassic rocks near Acoma are described by Gilbert[b] as follows:

Section of part of Triassic rocks at Acoma Pueblo, N. Mex.

Massive, friable, cross-bedded sandstone:	Feet.
(*a*) Pink, weathering brown; soft	30
(*b*) Yellow and firm; pebbly and banded with white near top	250
(*c*) Soft; olive-green with brown band 100 feet below the top	250
(*d*) Soft; red	150
	680

[a] Rept. U. S. Geog. Surveys W. 100th Mer., vol. 3, Geology, 1875, p. 280. [b] Idem, p. 55.

Bed *a* is capped by red and yellow shale, with a thin bed of coal at the base and several hundred feet of Cretaceous strata. I did not visit this pueblo, and the representation of the geologic boundaries in that vicinity on Plate I is compiled from very meager published descriptions.

REGION EAST OF LAGUNA.

The pre-Cretaceous rocks which appear in the uplift crossing the Santa Fe Railway between Laguna and San Jose are in general similar to those above described, but present some differences. From observations made east of Laguna, Newberry classed in his "variegated marl series" an upper member of soft red and white calcareous sandstone, 150 feet; gypsum, 80 feet; blue calcareous shale, 20 feet; and soft white calcareous sandstone, 40 feet. The underlying "salt group," 120 feet thick, was stated to consist of soft red calcareous sandstone on red and green foliated sandstone and blood-red shale. I found that the 80-foot bed of gypsum, which is well exposed in railroad cuts a little east of Rito station, varies considerably in thickness, down to 30 feet or less. The overlying sandstone is mostly red, and its upper half is hard and massive, strongly suggestive of the Wingate sandstone of the Zuni uplift. If it represents that formation, however, the Zuni sandstone is absent. Below the gypsum are 12 feet of thin-bedded dark, impure limestone, with thin layers of gypsum, and 40 feet of white massive cross-bedded sandstone, giving place abruptly at the base to light-brown or red massive sandstone, of which 40 feet is exposed in the crest of the anticline.

C. L. Herrick and H. N. Herrick have described some features of this region. They class the Triassic-Permian rocks in three divisions—the "Vermilion," "Chocolate," and "Red," with a thick gypsum deposit at the base of the second.[a] The lower or "Red" division is referred to the Permian from fossils found elsewhere. It usually contains beds of limestone or limestone breccia, which are characteristic, and has an average thickness of about 500 feet. The "Chocolate" division, about 600 feet thick, consists of gray and red sandstones, partly quartzitic. It merges gradually into the loose bright-red marls and clays of the "Vermilion" division. There is considerable local variation. In the San Jose Valley there is at the base "a comparatively small series of limestones and shales, followed by red sandstones and marls, pink sandy marls, and white sandy marls extending to the base of the gypsum deposits, which are irregular, often lenticular in shape. The 'Chocolate' beds of sandstones and shales

[a] Bull. U. S. Geol. Survey No. 223, 1904, p. 96.

are recognized by their characteristic color and are followed by the so-called 'Vermilion' division." The following section is given:

Section at El Rito, N. Mex.

	Feet.
Chocolate division:	
Massive sandstone	100
Bedded sandstone	75
Sandstone	25
Gypsum	25
Red division:	
Vermicular shale	3
Red sandstone, limestone, ironstone	30
Massive sandstone	75
Conglomerate	5?
Friable sandstone	35?

The gypsum ranges in thickness from 25 to 75 feet. The underlying vermicular shale is of widespread occurrence. In another description C. L. Herrick states that this shale, 10 feet thick and gypsiferous, is underlain by 45 feet of loose sandstone, white below, yellow above, 75 to 100 feet of fine pink sand, and 25 feet of green and chocolate sandy shale lying on hard red sandstone that merges downward into limestone and lime breccias, which at other localities yield Permian fossils. The forms mentioned are *Bakewellia parva, Myalina attenuata, Pleurophorus subcuneatus*, etc., which occur in hard sandstone east of the Sandia Mountains.[a]

The "Vermilion" division, which overlies the beds given in the section above, appears in the steep face of the Mesa Gigante, which rises a short distance to the north. This red escarpment extends westward for some distance, and also reaches far to the south on the opposite side of the San Jose Valley. The lower beds outcrop in a wide zone at its foot, but they are in part covered by lava flows. The thickness of the division is not stated, but judging from a columnar section in Herrick's paper it is near 500 feet.

NACIMIENTO UPLIFT.

C. L. Herrick[b] has described some features of the red beds in the uplift southwest of Jemez. The "Vermilion" or upper division comprises a top member of sandstones banded with alternating bright vermilion and green shales, and a lower member about 250 feet thick, of yellow sandstone. The "Chocolate" division, which is not much over 500 feet thick, includes at the base a bed of gypsum and anhydrite, 50 feet thick in places, underlain by 10 feet of vermicular gypsiferous shale, as on the San Jose. The "Red" division consists of alternating sandstone and shale of various kinds, grading downward into fossil-bearing Permian rocks. The beds are well exhibited in slopes of the high mesa extending southward from the south end of the Nacimiento Mountains.

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[a] Jour. Geology, vol. 8, 1900, p. 115.

[b] Am. Geologist, vol. 25, 1900, p. 337.

M. K. Shaler[a] has described the gypsum deposits along the west slope of the Nacimiento Mountains. There is one thick bed which lies a short distance below the Dakota sandstone and appears to extend continuously from a point beyond Gallina to the south end of the uplift; locally it is overlapped by Tertiary deposits. At Gallina the Dakota sandstone, 80 feet thick, is underlain by 300 feet of red and green shale extending to the gypsum, which is 40 feet or more thick and which lies on 50 feet of soft yellow sandstone and 300 feet of red sandstone. Southeast of Cuba a bed of gypsum 54 feet thick lies beneath 600 feet of Dakota sandstone and shale and sandstone of unknown age. Next below are 50 feet of white limestone, 600 feet of red and yellowish-drab shale, and 750 feet of red sandstones and shales, all dipping steeply to the west.

Near the mine, 10 miles southeast of Cuba, massive white gypsum 60 feet thick is overlain by 40 feet of crystalline limestone, above which are shale and Dakota sandstone. Below the gypsum are 120 feet of pinkish sandstones and 300 feet or more of red sandstones, lying on the granite. At a point 12 miles northwest of Jemez the gypsum reaches its maximum thickness of 100 feet and is overlain by 500 feet of shales and Dakota sandstone. Below it are 250 feet of shale, 80 feet of sandstone, and 700 feet of red sandstone lying on granite.

SUMMARY OF THE TRIASSIC ROCKS.

The classification of the Triassic rocks in Arizona and New Mexico is still in rather an unsatisfactory condition, especially as to correlation with formations in other regions. In the first place, it is not improbable that the upper sandstones (the Zuni and the upper part of the "Painted Desert") are Jurassic or even Morrison, but the question can be decided only by extensive work continued from adjoining regions. There appears to be no doubt as to the Triassic age of the bone-bearing beds (lower "Leroux") near Tanners Crossing, and doubtless the lower red sandstones ("Moencopie formation") below are Permian. The formations in Little Colorado Valley, the Fort Defiance uplift, the Zuni uplift, and the region to the east are relatively uniform in character, but there are important minor variations which must be traced from one area to another before a uniform classification can be applied. Apparently the base of the "Painted Desert formation" and that of the Wingate sandstone are at the same horizon, and it is not unlikely that the basal conglomerate will also be found to be continuous. The names Zuni sandstone and Wingate sandstone are entirely satisfactory in western New Mexico, and the same subdivision may be practicable in Utah, so as to displace the poor term "Painted Desert formation." In fact, when the Vermilion Cliff sandstone is traced southeastward to the Zuni uplift it may, as

[a] Bull. U. S. Geol. Survey No. 315, 1907, pp. 260–265.

suggested by Dutton, prove to be the Wingate sandstone. In this case there would be no use for the name Wingate. The age of the Vermilion Cliff has been assumed to be Triassic, but this assumption rests on no direct evidence and the formation may be Jurassic, together with the overlying White Cliff sandstone, which apparently is traceable into fossiliferous deposits.

The formation which Ward has termed "Leroux" appears to be recognizable throughout the area treated in this paper, and to be the same as the "Lower Trias" of Dutton in the Zuni uplift. It is not, however, so clearly recognizable in the region described by Herrick in central New Mexico. The "Lithodendron member" of Ward is somewhat enigmatical. Its characteristic feature is a conglomerate and sandstone member which is stated to range through an interval of 800 feet or more in the Petrified Forest of the Winslow region. It appears to me, however, as to others, that this member is really thin and usually consists of one or two beds without great interval. Whether or not this deposit of coarse material is at the same horizon throughout has not been proved, but it appears to be, and if so it supplies a most important datum. Ward has suggested that the "Leroux" and "Lithodendron" be regarded as the "Shinarump formation," but this term was definitely applied by Powell[a] to the group of strata lying between the Carboniferous limestone and the base of the Vermilion Cliff sandstone, so that its use in the new sense (to exclude "Moencopie") is unwarranted. Moreover, such a grouping is not desirable, for the formations are separable. Ward's use of the name "Shinarump" for the conglomerate division alone is not in accordance with the existing Survey regulations for nomenclature, and his later name, "Lithodendron formation," is used for the present.

Whitman Cross[b] has presented an extended review of the stratigraphy of the Triassic portion of Powell's Shinarump group. He compares it with the Dolores formation of the San Juan region of Colorado, which is probably of Upper Triassic age with a great unconformity and hiatus at the base. In tracing the formation into the Plateau region in Utah it has been found that this hiatus is so great that in places 1,500 to 2,000 feet of probable Paleozoic rocks are gone. The basal member of the formation consists of 200 to 300 feet of conglomeratic beds containing the same vertebrate fauna as that obtained by Ward in the "Leroux formation" near Tanners Crossing. This conglomerate is characterized by small round gray limestone pebbles, almost pisolitic in appearance and rarely reaching an inch in diameter. It is scattered through cross-bedded sandstone in beds from a few inches to perhaps 30 feet thick. The upper part of the Dolores for-

[a] Report on the geology of the eastern part of the Uinta Mountains: U. S. Geol. and Geog. Survey Terr., 1876.

[b] Jour. Geology, vol. 16, 1908, pp. 97–123.

mation thickens to the west, and Cross confidently correlates it with the Vermilion Cliff sandstone. Cross suggests, also, that in Arizona with the thickening of the Triassic the conglomerate becomes more widely separated from the Vermilion Cliff sandstone, which would account for the presence of several hundred feet of the "Leroux formation" that intervenes in that region. Powell noted the presence of 800 feet of beds resembling the "Leroux" overlying the typical "Shinarump" conglomerate on Kanab Creek, and these rocks, as well as the soft sandstones and shales below, were found to extend to and along the Uinta Mountains.[a]

Dutton[b] calls attention to the wide extent of the great deposit of marly shales with a conglomerate in the middle. He noted that many of the pebbles were of silicified wood, and in later publications the unconformity at the base of the conglomerate is recognized.

It seems not unlikely that the basal member of the Dolores when traced into Arizona will be found to comprise the "Shinarump" conglomerate member of the "Lithodendron formation" and also the "Leroux beds" that yield the fossil bones near Tanners Crossing. Doubtless this conglomerate locally expands somewhat in the Petrified Forest region, but I think it will be found to be in a formation much less than 800 feet thick. Whether or not it is at the same horizon in the Zuni uplift region also remains to be determined. It is possible, as suggested by Cross, that the horizon of the basal Dolores in that region may be much nearer the base of the Wingate sandstone than the conglomeratic sandstone in the ridges south of the railroad, described on page 52.

JURASSIC SYSTEM.

While there is no direct evidence as to the existence of Jurassic rocks in the region treated in this paper, it is possible, as suggested by Dutton,[c] that the Zuni sandstone is of that age. In southern Utah 500 to 1,000 feet of shales and sandstones are assigned to the Jurassic, because a portion of them contain the characteristic molluscan fauna. The upper portion of the "Painted Desert formation" consists of bright-colored sandstones, strongly suggestive of the White Cliff sandstone or Jurassic of Utah, and evidently regarded as such by Howell,[d] who traced them for many miles through the region. He found that they thinned toward the south, but appeared to be unmistakable near Moencopie, while between White Rock Spring and Pueblo Colorado, Ariz., east of Oraibi, he observed 20 or 30 feet of red marls which he thought might be Jurassic. He stated also that in the region south and east of Mount Taylor a series

[a] Report on the geology of the eastern part of the Uinta Mountains: U. S. Geol. and Geog. Survey Terr., 1876, p. 54.

[b] Geology of the high plateaus of Utah: U. S. Geol. and Geog. Survey Rocky Mtn. Region, 1880.

[c] Sixth Ann. Rept. U. S. Geol. Survey, 1885, p. 138.

[d] Rept. U. S. Geog. Surveys W. 100th Mer., vol. 3, Geology, 1875.

of beds about 125 feet thick held the proper position and closely resembled the Jurassic as seen in Utah. No fossils were obtained.

Newberry[a] collected plants from carbonaceous shales overlying the red beds near the Hopi pueblos about Oraibi which he regarded as Jurassic, but Howell regarded the horizon as basal Cretaceous.

CRETACEOUS SYSTEM.

Rocks of Cretaceous age underlie the greater part of northwestern New Mexico and occupy an area of several thousand square miles in northeastern Arizona. They lie unconformably on the red beds, as shown in Plate XII, *A*. It is believed that the rocks are all of later Cretaceous age, ranging from Dakota to coal measures and other strata considerably younger than Fox Hills. Possibly some earlier Cretaceous sandstones and the Morrison formation are present locally, and, as already suggested (p. 51), it is even possible that the Zuni sandstone may represent the Morrison.

HOPI REGION.

Cretaceous rocks lying in a broad, shallow syncline constitute the region of high mesas about and to the north of Oraibi. The Hopi pueblos are built on high bluffs of sandstone. Newberry was the first to describe these rocks, and the following two sections are from his report:[b]

Section of basal Cretaceous rocks 10 miles south of Walpi, Ariz.

	Feet.
Coarse yellowish sandstone with concretions of oxide of iron and scattered quartz pebbles	16
Impure coals alternating with bands of bituminous shale and fine clay containing fossil plants—*Clathropteris*, *Cyclopteris*, *Sphenopteris*, *Pecopteris*, etc., all new species	12
Fine clay and shale	3
Coarse compact white concretionary sandstone	6
Green marl	25
Bright red marl	22
White soft saccharoidal calcareous sandstone to base.	

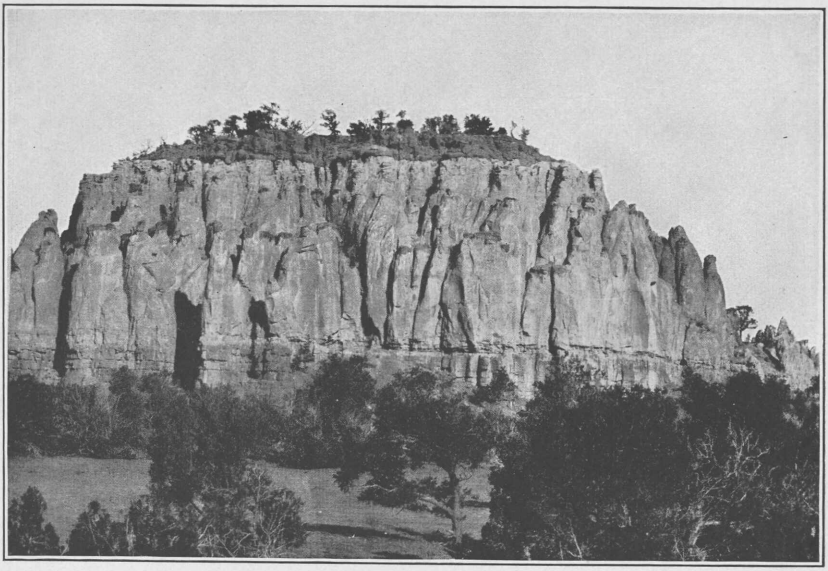
The plants were regarded as Jurassic. In the high bluffs on which the Hopi towns are built the section is extended up as follows:

Section of Cretaceous rocks near Mishonginivi and Oraibi, Ariz.

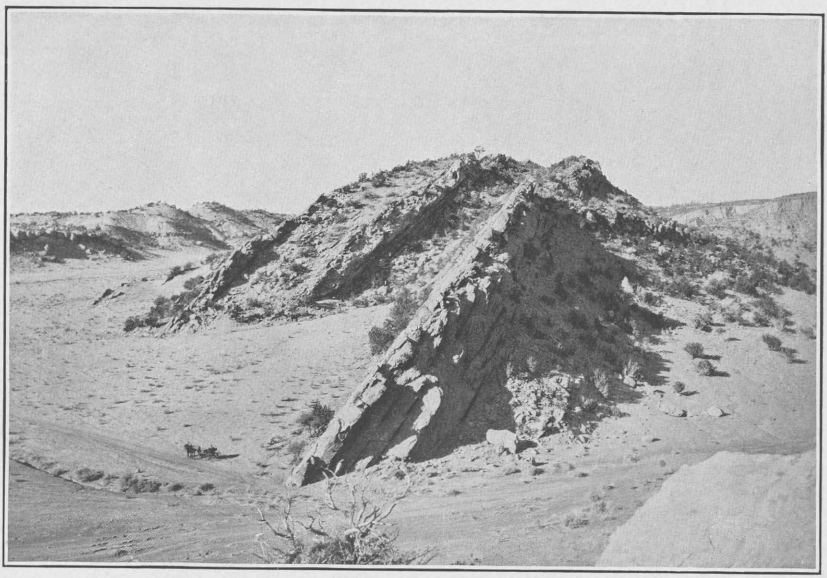
	Feet.
Soft coarse yellowish sandstone	25
Green shale	12
Blue shale with pinnules of *Neuropteris angulata*	1
Lignite	18
Green shale	2
Cellular sandstone	5

[a] Report upon the Colorado River of the West, explored in 1857–58 by Lieut. J. C. Ives, pt. 3, Geological report, 1861, pp. 82–83, 129–131.

[b] Idem, pp. 84–85.



A. CRETACEOUS SANDSTONE ON ZUNI RED SANDSTONE AT TARQUE, SOUTH OF ZUNI, N. MEX.



B. HOGBACK OF CRETACEOUS SANDSTONE ON NORTHWEST SLOPE OF ZUNI UPLIFT NORTHEAST OF GALLUP, N. MEX.

Horizontal Cretaceous coal measures to left; Zuni sandstone in distance to right.

	Feet.
Brown ferruginous shale	4
Green shales	28
Coarse yellow or white sandstone	80
Green shales with bands of sandstones; in some localities all soft greenish-yellow sandstones	60
Coarse light-yellow or whitish massive sandstone	120
Green shales with bands of ferruginous sandy limestone and beds of lignite, *Pinna? lingula* n. sp., *Gryphæa pitcheri*, and impressions of *Platanus*, *Alnus*, *Quercus*, and *Sphenopteris*	90
Green, blue, and gray argillaceous shales with bands of brown or yellow siliceous limestone containing *Ammonites percarinatus*, *Inoceramus cripsii*, and *Gryphæa pitcheri* var. *navia*	160
Coarse yellowish sandstone (basal Cretaceous)	25
Lignite (Jurassic?) to base.	

According to E. E. Howell,[a] the mesas about the Hopi pueblos are capped by 100 to 300 feet of cream-colored sandstone and shale lying on dark shale, in part carbonaceous, 300 to 500 feet thick. The adjacent valleys are floored with soft white sandstone, stated to be Jurassic. The rocks underlying the sandstones of the mesas are alternating shale and sandstone in beds 30 to 50 feet thick, the shales varying from light to dark in color. The thick bed of underlying shales includes a few sandy and sandstone layers. Coal is mined in small amounts not far from the pueblos, and 25 miles northwest of Oraibi Howell measured one bed 8½ feet thick and another at a lower horizon 4 to 5 feet thick; at a locality 2 to 3 miles farther north one bed is stated to have a thickness of about 25 feet. The area of the coal field is about 2,500 miles. Most of the boundary of this area, as given on Plate I, was furnished by H. E. Gregory from observations made in 1909.

GALLUP BASIN.

In the vicinity of Gallup the thickness of the Cretaceous rocks is about 2,000 feet. The rocks have been studied by F. C. Schrader [b] and M. K. Shaler,[c] who subdivided them into the Dakota sandstone, Mancos shale, and Mesaverde formation, all in conformable succession. They contain deposits of subbituminous coal in beds from a few inches to 8½ feet thick. The Dakota is stated to be 150 to 300 feet thick and consists mostly of hard sandstone, locally conglomeratic. In places it includes dark shale, which develops into coal. The Mancos is dark drab soft shale, in part sandy, with limy concretions, about 750 feet thick. Thin sandstones and a coal bed occur in its upper portion. Coal 40 inches thick, mined between Nutria and Black Rock, is believed to be in the upper part of the Mancos formation. Colorado fossils were found in the lower beds. The Mesa-

[a] Rept. U. S. Geog. Surveys W. 100th Mer., vol. 3, Geology, 1875. p. 279.
[b] Bull. U. S. Geol. Survey No. 285, 1906, pp. 241–258.
[c] Bull. U. S. Geol. Survey No. 316, 1907, pp. 376–426.

verde formation consists of a thousand feet or more of sandstones and interbedded drab shales with important coal deposits. This coal is in the upper and lower members, which are separated by about 500 feet of barren strata. The Weaver mine, 3 miles north of Gallup, is the largest producer in the region. A section at this place, based largely on diamond-drill borings, is as follows:

Section of upper Mesaverde coal-bearing rocks at Weaver mine, 3 miles north of Gallup, N. Mex.

	Feet.
Coal	1
Fire clay	2
Coal, dirty (No. 1)	3½
Sandstone and shale	14
Coal	½
Fire clay	7
Coal (No. 2)	4½
Sandstone and shale	24
Coal (No. 3)	4
Fire clay	2
Sandstone	5
Slate	1½
Coal (No. 3½)	6¼
Fire clay	2½
Sandstone, shale, and thin coal layers	20
Coal with many shale partings (No. 4)	3
Sandstone	20
Coal (No. 5)	6½
	127¼

At the Clark mine, 4 miles west of Gallup, drill holes have shown five beds in the same measures 2½ to 8½ feet thick. Coal in the lower Mesaverde beds is mined at various points northeast and south of Gallup. The following section at the Otero mine, about 3 miles east and 1 mile north of Gallup, is given by Shaler:

Section of lower Mesaverde coal beds in Otero mine, near Gallup, N. Mex.

	Ft.	in.
Coal (Crown Point bed)	3	5
Shale		8
Coal	1	5
Sandstone	11	
Coal (Thatcher bed)	4	
Shale and sandstone	6	
Shale	9	
Coal (Black Diamond bed)	1	6
Sandstone and shale	88	
Coal	1	2
Shale		9
Coal (Otero bed)	3	2

The rocks vary considerably in thickness and succession. The lower Mesaverde beds are brought to the surface by the anticline near Defiance switch, 8 miles west of Gallup, and they rise again on the slope of the Fort Defiance uplift, along a zone passing a short distance east of Manuelito. The Mesaverde formation has been found to terminate at the south in the high ridges on the north side of Nutria Creek, 15 miles northeast of the Zuni pueblo. The syncline east of Zuni holds Dakota sandstone overlain by Mancos shale.

I examined the basal Cretaceous beds at several places in the extensive exposures along the steeply dipping upturn east of Gallup. The lowest member is a hard buff sandstone, in part coarse and massive, lying unconformably on soft white Zuni sandstone. The two formations show no discordance in dip, but there is an abrupt change in materials, considerable slight channeling, and local conglomerate deposits. The Cretaceous sandstone forms the crest and west slope of the ridge which rises steeply above the red-bed slopes. It varies in thickness from 60 to 115 feet and is followed by 700 to 800 feet of shale (Mancos). The shale is in part sandy, and sandstones occur in its upper half. Some of the sandy beds are highly fossiliferous down to a horizon within 20 or 30 feet of the base of the formation. *Exogyra columbella* Meek is a very abundant species. The following is a typical section near the railroad east of Gallup:

Section of lower beds of Cretaceous system 3 miles east of Gallup, N. Mex.

	Feet.
Sandy shale, reddish sandstone, and green shale	100
Sandstone, buff	20
Sandy shale	80–100
Massive sandstone; gives rise to second ridge (basal Mesaverde)	100
Sandy shale (Mancos)	500±
Sandstone, massive to slabby	15
Gray shale, in part sandy; many fossils	300
Hard sandstone; highly fossiliferous near top	20
Soft sandstone and sandy shales; fossils	30
Dark shale	25
Hard buff sandstone lying on white Zuni sandstone	50

Another section, 2 miles farther north (Pl. XII, *B*), shows at the base 20 to 40 feet of buff sandstone, 30 feet of dark shale, and 40 feet of sandstone that is hard and highly fossiliferous at the top. The Mancos shale, following, is about 500 feet thick and is capped by the basal sandstone of the Mesaverde, which here, as all along the uplift, gives rise to a sharp ridge lying 100 rods west of the ridge due to the basal sandstone, a valley of Mancos shale intervening. The lower Mesaverde beds at this locality consist of 280 feet of sandstone with some shale, 45 feet of dark carbonaceous shale, 40 feet of dark sandy shale, and 20 feet of buff massive sandstone. In a section 8 miles

southeast of Gallup the Dakota sandstone, 250 feet thick, is capped by a hard, highly fossiliferous sandstone, followed by Mancos shale 800 to 900 feet thick with a sandstone deposit about 800 feet above the base and more or less thin-bedded sandstone in its upper portion. The deep artesian-well borings at Gallup probably penetrate the lower sandstones. (See record on p. 78.)

ZUNI UPLIFT TO NACIMIENTO MOUNTAINS.

J. H. Gardner [a] has recently reviewed the Cretaceous stratigraphy from Gallup to San Mateo, at the foot of Mount Taylor. The upper part of the Mesaverde formation constitutes an escarpment along Rio Chaco and is succeeded by the Lewis and Laramie formations. The lower part of the Mesaverde, 1,000 feet thick, forms the high escarpment 40 miles farther south and consists of massive sandstone alternating with thin shales and bearing workable coal deposits. The underlying Mancos shale, 800 feet thick, consists of 500 feet of massive sandstone and shale with local coal beds and 300 feet of shale with thin sandstone layers. This lies on Dakota sandstone 200 feet thick, consisting of light-gray sandstone at the top and bottom with some alternating thin beds of shale and sandstone and a few irregular coal beds of no great value.

Gardner gives detailed sections of the coal deposits in the Mesaverde and Mancos beds. This same observer [b] has described the Cretaceous and Tertiary formations in the region between Raton Spring and the Nacimiento Mountains. At the top is the Laramie formation, 900 feet thick, extensively overlapped by Tertiary deposits to the northeast and containing coal from longitude 107° to Raton Spring. Next below in the Lewis shale, which is 2,000 feet thick near the north end of the Nacimiento Mountains, but thins to 250 feet in the vicinity of Raton Spring. The Mesaverde formation, below the Lewis, carries important coal beds and ranges from 200 to 900 feet in thickness. The underlying Mancos shale, 500 to 1,000 feet thick, contains a prominent bed of sandstone toward its top and considerable sandstone alternating with the upper shale. The Dakota sandstone forms a prominent hogback along the west slope of the Nacimiento Mountains. It consists mainly of very hard sandstone with intercalated shale toward the top, but near the base it becomes reddish and softer.

RIO PUERCO REGION.

The Cretaceous rocks in the Rio Puerco valley east of Mount Taylor have been studied by C. L. Herrick,[c] who has published the section following.

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[a] Bull. U. S. Geol. Survey No. 341, 1909, p. 366.
[b] Idem, pp. 335–351.
[c] Am. Geologist, vol. 25, 1900, pp. 8–9.

Section of Cretaceous rocks in Rio Puerco valley, in the San Ignacio region, New Mexico.

[By C. L. Herrick.]

	Feet.
Massive white and irony sandstone; marine fossils in lower part; shark's teeth and other vertebrate remains in upper part	500–600
White massive sandstone with bands of shale from 25 to 75 feet thick; three prominent beds; deciduous leaves; lignite	250+
Yellow fine-grained sandstones and shales (Prieta sandstone)	1,200+
Shales and flags; about	100
Fossiliferous sandstone (Punta de la Mesa sandstone)	25–50
Shale	80–100
Sandy flags with concretions (cephalopod zone)	25
Shales with occasional flags	100+
Massive yellow sandstone with large concretions (Tres Hermanos sandstone)	75
Sandstones and flags; highly fossiliferous (gasteropod zone)	25
Dark and yellow sandstone, in part pulverulent, on red beds	75±

Further details of this succession and of the overlying beds near San Ignacio and San Francisco, in the Rio Puerco valley, are given by C. L. Herrick[a] and D. W. Johnson in a paper on the Albuquerque quadrangle.

The basal sandstone lying on the red beds is white and in part soft for 25 to 50 feet; the upper portion is harder and of buff color. "Farther to the westward this band reposes on the Dakota sandstone or may perhaps be said to form a part of it." The overlying shales are in part lignitic and near the top contain iron-stained flaggy beds carrying *Ostrea translucida, Exogyra læviuscula, E. columbella, Liopistha concentrica, Camptonectes symmetricus, Baculites gracilis,* and *Prionocyclus woolgarii.* Next above are 10 feet of flags, and 75 to 100 feet of yellowish-gray shales, grading up into the yellow "Tres Hermanos sandstone," about 75 feet thick. In the lower layers of this sandstone and the upper sandy part of the shale are many large iron concretions. The top of the sandstone is a pinkish rock of granular texture, nearly pure white when fresh. Next above is a thick series of very variable sandy shales with thin layers of ironstone containing many large ammonites, *Pinna,* and baculites. The overlying shales are dark yellow and earthy, are 100 feet thick, and are capped by 50 to 75 feet of sandstone, called "Punta de la Mesa sandstone," which is believed to be Fox Hills. Above this sandstone lies an extensive series, called the "Prieta sandstone," mostly loose yellow sandstone with shaly phases. The fossils in this series seem to be mostly the same as those from the "Punta de la Mesa sandstone," but some of them have not been found at a lower horizon. This series is estimated to be 1,000 feet thick and is well exposed in low hills east of Punta de la Mesa, on the east side of Rio Puerco. It is followed by a lignite-bearing series which is best exposed northeast of San Ignacio. The

[a] Bull. Sci. Lab. Denison Univ. No. 11, and Bull. Univ. New Mexico, vol. 2, 1900, pp. 13-16.

beds of this series comprise about 50 feet of white sandstone with ferruginous layers, 35 to 40 feet of lignitic beds, 5 feet of white sandstone, 35 to 50 feet of beds with brown lignite, 30 to 40 feet of white sand with lignite beds, 75 feet of lignitic beds with iron layers containing impressions of leaves and fruits, 10 feet of yellow sandstone, 25 feet of white sandstone, 2 feet of irony sandstones with many fossils, 25 feet of loose white sandstones with fossils, and, finally, 300 feet of white and irony sandstones extending to a fault, beyond which the relations are not clear. The fauna of the sandstone above the lignite appears to be closely allied to if not identical with that in the "Punta de la Mesa sandstone." It is marine and of Fox Hills age. The leaves in the lignitic beds are not identifiable with familiar Laramie species.

Some observations made by H. W. Shimer[a] in 1907 in the Rio Puerco region northeast of Mount Taylor afford additional data as to the Cretaceous stratigraphy. Fossils were collected at intervals for 16 miles southwest and 9 miles southeast of Cabezon. They represented several horizons, apparently all in the upper Benton. Possibly some of the highest sediments may belong slightly higher "without the presence of a typical Niobrara fauna," and may even reach the Pierre at one locality southeast of Cabezon. Two zones of concretions were noted, with distinct fauna.

I measured the following section of the lower members of the Cretaceous in the southern edge of the mesa northeast of Laguna:

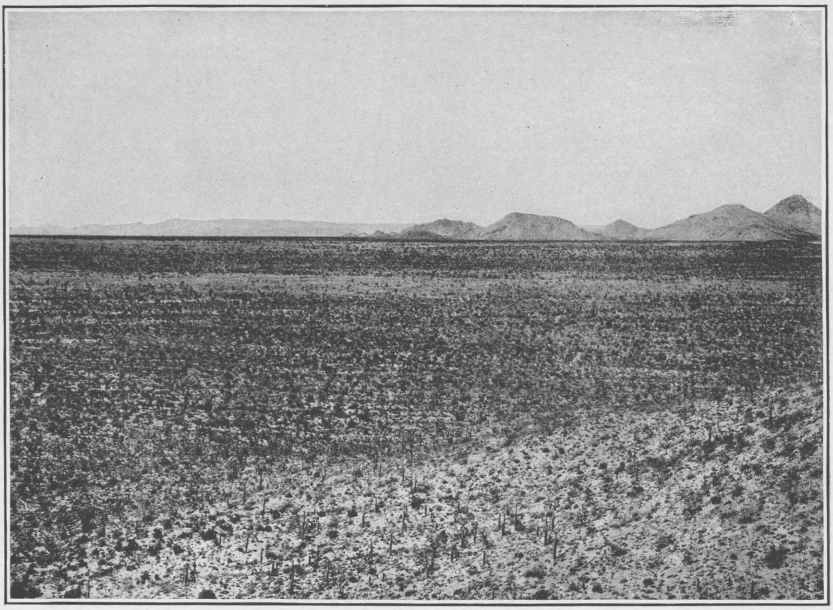
Section of part of Cretaceous rocks 2 miles northeast of Laguna, N. Mex.

	Feet.
1. Lava.	
2. Sandstone	25
3. Shale	60
4. Sandstone, buff, massive, moderately soft	40
5. Shales with sandstone layers, very fossiliferous	60
6. Sandstone, massive, hard, light buff	40
7. Shale, dark gray to gray-green, sandy layers, fossiliferous	60
8. Sandstone, hard, red, irony	5
9. Sandstone, white, massive, part coarse	80
10. Shale, greenish gray, sandy above	235
11. Sandstone, hard, buff, massive	40
12. Soft shale	30
13. Sandstone.	

No. 13 is a part of the basal bed of the Cretaceous which lies on red beds a short distance to the east. The following fossils were collected from bed No. 5:

Exogyra columbella Meek (abundant).
Gryphæa sp., probably a variety of G. newberryi.
Avicula gastrodes Meek?.
Cardium, Panopea, Turritella, Rostellites, and Fusus sp.

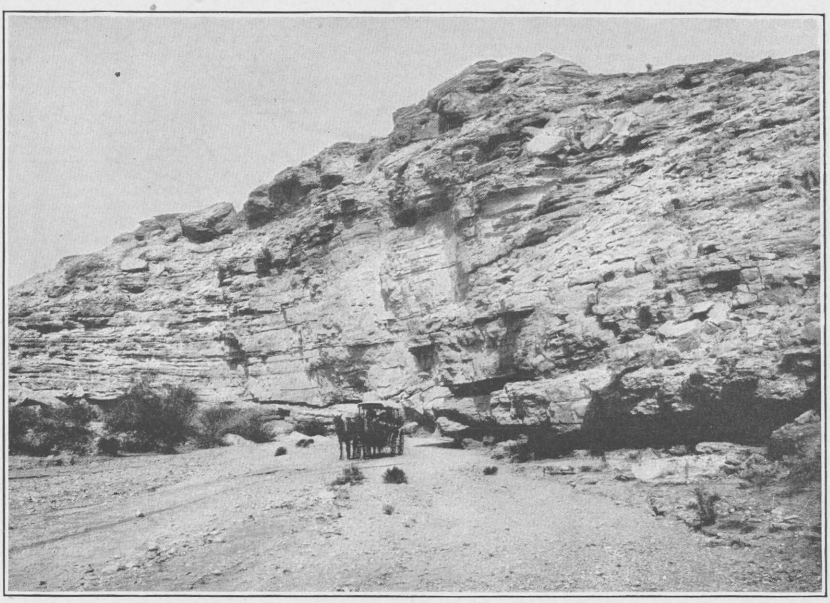
[a] Shimer, H. W., and Blodgett, M E., Stratigraphy of the Mount Taylor region, New Mexico: Am. Jour. Sci., 4th ser., vol. 25, 1908, pp. 53–67.



A. TYPICAL DESERT VALLEY BETWEEN GRANITE RIDGES, NORTHWESTERN ARIZONA.

Looking north from north end of Hualpai Mountains.

Photograph by W. T. Lee.



B. TERTIARY LIMESTONE, IN PART CONGLOMERATIC, HUALPAI WASH, ARIZONA.

Photograph by W. T. Lee.

In bed No. 7 the following were found:

Exogyra columbella Meek (few).
Pecten sp.
Prima petrina White.
Inoceramus?, Leda, Cardium, and Lucina? sp.
Isocardia n. sp.
Cyprimeria? sp., Corbula sp.
Liopistha (Psilomyra) concentrica Stanton.
Turritella whitei Stanton.
Tritonium kanabense Stanton.
Actæon, Cinulia, Turrilites?, or Heteroceras sp.

These fossils were determined by T. W. Stanton, who reported that they indicate a horizon in the Benton formation with a faunal facies like that developed in southern Colorado and southern Utah.

TERTIARY AND QUATERNARY SYSTEMS.

I made very few observations on the Tertiary and Quaternary rocks in the region examined, and their boundaries as shown on Plate I were mostly compiled.

SEDIMENTS.

The principal area of Tertiary sediments is in the broad, deep basin of the Rio Grande, which has been described by C. L. Herrick.[a] It extends to the Rio Puerco Valley west of Albuquerque. Cope classed the upper member, the Santa Fe marl, as Miocene, but Herrick regarded it as Pliocene or later.

The Choiskai Hills are capped by sands, sandstones, and conglomerates of early Tertiary age. Shaler[b] found outliers of unconsolidated pinkish sand, drab mud shale, and conglomerates with sandy matrix capping the hills 10 miles southwest of Gallup. Newberry[c] noted supposed Tertiary deposits on the high plains between Walpi and Pueblo Colorado, but their identity is doubtful.

The wide, flat desert valleys in western Arizona (Pl. XIII, *A*) are filled with very thick deposits of sand and gravel, many features of which have been described by W. T. Lee.[d] He discovered some thick bodies of Quaternary or Tertiary limestone in Hualpai Wash (Pl. XIII, *B*) and along Colorado River near Pierce Ferry; and I am informed by D. W. Johnson that there are similar limestones in Verde Valley east of Jerome. The limestone in Verde Valley contains fossils and is associated with extensive deposits of sand, gravel, and marl. The only evidences of glaciation found in the region are on San Francisco Peak, a cirque and moraine on which have been described by W. W. Atwood[e] and D. W. Johnson.[f]

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[a] Am. Geologist, vol. 22, 1898, pp. 26–43; Bull. Univ. New Mexico, vol. 1, pp. 94–97; vol. 2, pt. 1, pp. 3–8.
[b] Bull. U. S. Geol. Survey No. 316, 1907, p. 378, map.
[c] Report upon the Colorado River of the West, explored in 1857–58 by Lieut. J. C. Ives, pt. 3, Geological report, 1861, pp. 87–88.
[d] Bull. U. S. Geol. Survey No. 352, 1908.
[e] Jour. Geology, vol. 13, 1905, pp. 276–279.
[f] Tech. Quart., vol. 19, 1906, p. 410.

VOLCANIC ROCKS.

A large portion of north-central Arizona is covered by volcanic rocks of various kinds, and there are also areas of considerable extent in western New Mexico. I gave but little attention to these rocks, except to map the boundaries at some localities, as shown in parts of Plate I. The largest areas of volcanic rocks are on the Coconino Plateau, on Mogollon Mesa, about Mount Taylor, and on the Aquarius Plateau south of Truxton. The larger, thicker masses usually consist of acidic rocks, flanked by later outflows of basalts in thin but widespread sheets. Mount Taylor and San Francisco Mountain and surrounding peaks present these relations. Bill William Mountain is shown in Pl. XIV, *B*. Large flows of basalt occur along the east and south sides of the Zuni uplift, on the mesa north and west of Isleta, and on the plateau west of Acoma. That these lavas are of various ages is shown by their relations to the topography and by the superposition of flows.

W. T. Lee [a] has described many relations of these volcanic rocks in northwestern Arizona, and in the same publication A. Johannsen has described the petrography of numerous samples collected by Lee. A. R. Marvine [b] noted the features observed on his trip across west-central Arizona, and scattered data are contained in reports by Newberry, Gilbert, Howell, and Davis. D. W. Johnson [c] in crossing the Coconino Plateau from Oak Creek canyon northward found lava extending from the Verde Breaks escarpment to a point within 7 miles of Flagstaff, where the limestone appeared at intervals. Thence northward to Hulls Spring there was lava practically all the way, and eastward nearly to the Little Colorado lava was observed filling many depressions and appearing in cascades over cliffs. The structure of a fine cone known as Red Mountain, 30 miles northwest of Flagstaff, has been described in detail by W. W. Atwood.[d] D. W. Johnson [e] has described a remarkable recent cone in the same region. One of these features is shown in Plate XIV, *A*. H. H. Robinson [f] has made a detailed survey of the San Francisco Peak igneous area and I am indebted to him for the boundaries of the igneous rocks there.

The volcanic features of the Mount Taylor region have been described by Dutton,[g] and further details will be given in a paper now in course of preparation by D. W. Johnson. The broader relations of this region and about the Zuni Mountains and Acoma Plateau were first noted by Howell and Gilbert. C. L. Herrick [h] has described

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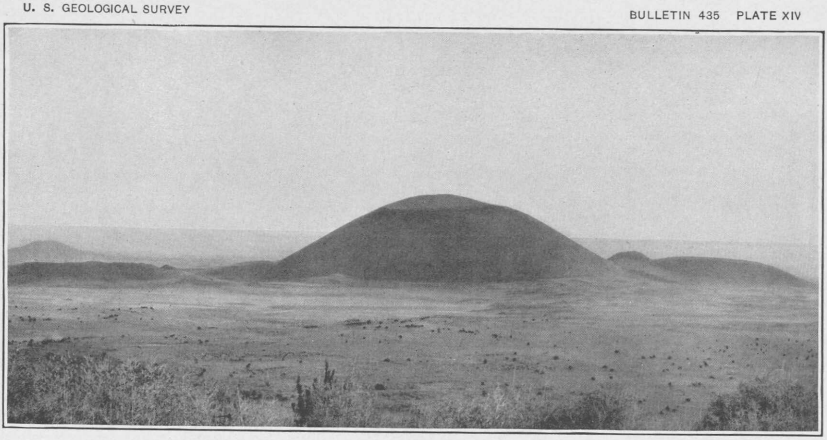
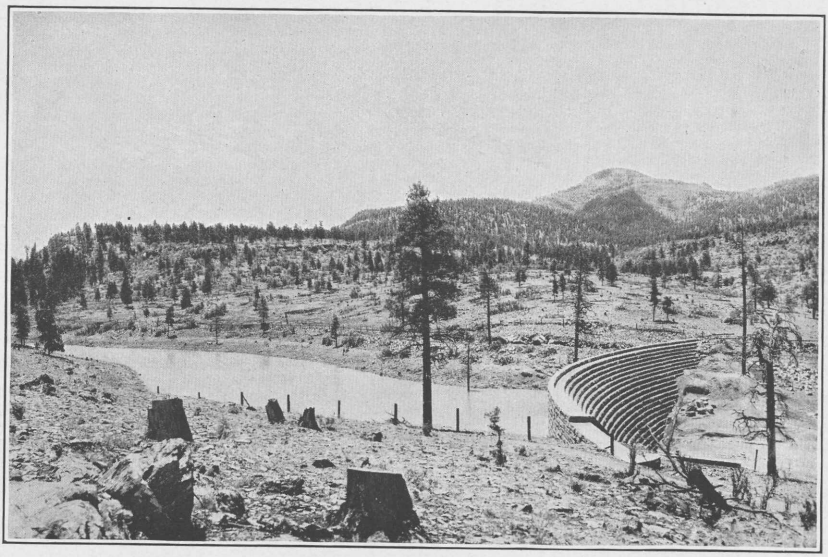
[a] Bull. U. S. Geol. Survey No. 352, 1908.
[b] Rept. U. S. Geog. Surveys W. 100th Mer., vol. 3, Geology, 1875.
[c] Letter to N. H. Darton.
[d] Jour. Geology, vol. 14, 1906, pp. 138–146.
[e] Bull. Geog. Soc. Philadelphia, vol. 5, 1907, pp. 6–11.
[f] Prof. Paper U. S. Geol. Survey (in preparation).
[g] Sixth Ann. Rept. U. S. Geol. Survey, 1885, pp. 164–182.
[h] Am. Geologist, vol. 22, 1898, pp. 26–43; Bull. Univ. New Mexico, vol. 1, pp. 94–97; vol. 2, pt. 1, pp. 3–8.



A. RECENT VOLCANIC CONE, NORTHWESTERN ARIZONA.

Photograph by G. K. Gilbert.



B. BILL WILLIAMS MOUNTAIN, ARIZONA, FROM THE EAST.

Reservoir for Santa Fe Railway in foreground.

the relations of the volcanic rocks in the Albuquerque region and southwestward. Several years ago I described the Zuni Salt Lake,[a] where there is a remarkable crater-like depression rimmed in part by Cretaceous sandstone and in part by lava, with two cinder cones near its center.

Twin Cones, a prominent butte a mile south of the railroad 6 miles west of Gallup, was found to be an irregular dike or neck of igneous rock flanked by a large amount of breccia. Microscopic examination by Mr. Johannsen showed that the rock is an augite minette of holocrystalline porphyritic texture. The phenocrysts, which constitute about 40 per cent of the material, consist of about equal parts of biotite and augite, but the rock differs from ordinary minette in having no very large biotites. The groundmass is made up of about equal parts of augite microliths and magnetite grains in a base of about 40 per cent orthoclase. The rock lies between minette and vogesite, and might also be called a biotite vogesite.

STRUCTURE.

GENERAL FEATURES.

The sedimentary rocks of the region treated in this paper are flexed and faulted to some extent and with the main structural features on a large scale. The salient features are shown in Plate XV and figure 4. In the limestone plateau the strata are nearly horizontal, with some broad, low undulations. To the east they descend into a wide, shallow basin extending to the Fort Defiance uplift near the eastern margin of Arizona. Next east are the Gallup syncline, the Zuni uplift, the Mount Taylor syncline, and the Nacimiento anticline. The dips are generally very low except on the west side of the Zuni and Nacimiento uplifts, where they approach the vertical, and on the east side of Fort Defiance uplift, in the Jemez region and near San Jose, where they are moderately steep. In many wide areas the strata have the appearance of lying horizontal. Some observers have attributed every line of cliffs in the plateau area to great dislocations, but most of them are not due to faults.

The well-known fault of the Grand Wash Cliffs is the most pronounced break, and next in order is another dislocation a short distance west, which crosses Colorado River in the vicinity of longitude 114°. The Hurricane and Toroweap faults have been described in detail by Dutton and others. They are shown in section A, Plate XV. There are smaller faults on Diamond Creek, at Bright Angel, at the mouth of the Little Colorado, at the foot of the escarpment east of Ash Fork, on Oak Creek, at Ojo Caliente, near Bluewater, and near San Jose. Doubtless there are many others which I did not observe.

[a] Jour. Geology, vol. 13, 1905, pp. 185–193.

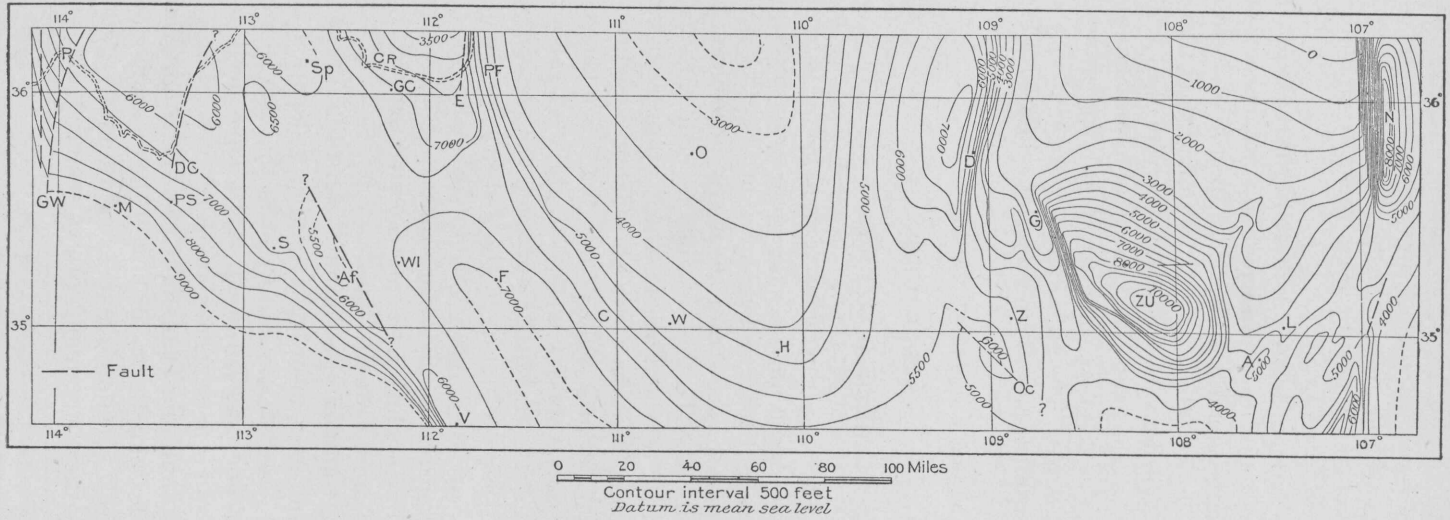
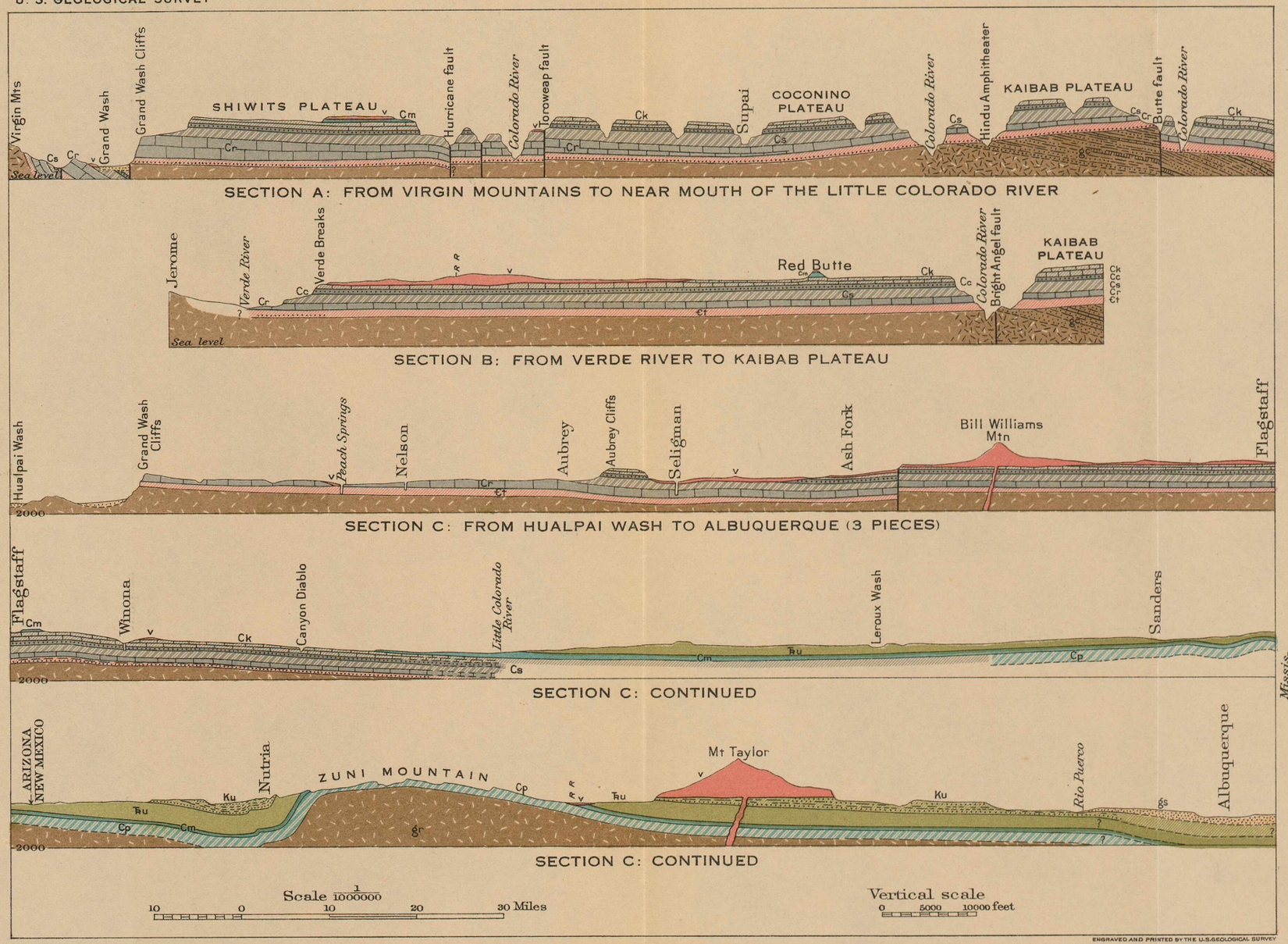


FIGURE 4.—Map showing structure of parts of Arizona and New Mexico by configuration of top of Carboniferous limestone. A, Acoma; AF, Ash Fork; GC, Grand Canyon station; C, Coon Butte; CR, Colorado River; D, Fort Defiance; F, Flagstaff; G, Gallup; H, Holbrook; L, Laguna; M, Music Mountain; O. Oraibi; P, Pierce Ferry; PS, Peach Spring; S, Seligman; Sp, Supai; W, Winslow; Wl, Williams; V, Fort Verde; GW, Grand Wash fault; DC, Diamond Creek fault; PF, Paria fold; E, East Kaibab fault; ZU, Zuni uplift; Oc, Ojo Caliente fault; N, Nacimiento uplift; Z, Zuni.



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SECTIONS ACROSS NORTH-WESTERN NEW MEXICO AND NORTHERN ARIZONA

By N. H. Darton

1909

LEGEND

- v — Volcanic rocks
- gs — Gravel, sand, and clay
- Ku — Undifferentiated
- Tru — Undifferentiated
- Cm — "Moencopie formation"
- Cp — Undifferentiated Pennsylvanian
- Ck — Kaibab limestone
- Cc — Coconino sandstone
- Cs — Supai formation
- Cr — Redwall limestone
- Ct — Tonto group
- Grand Canyon series
- gr — Granite, schist, etc.
- Fault

Permian; Pennsylvanian; Aubrey group; Mississippian

QUATERNARY AND TERTIARY; CRETACEOUS; TRIASSIC; CARBONIFEROUS; CAMBRIAN; PRE-CAMBRIAN

Pre-Cambrian faults are exposed in the Grand Canyon, and no doubt they traverse other portions of the region. I found no direct evidence of faulting at Music Mountain or in the Aubrey Cliffs, but there may be displacements at these places hidden by valley filling or lava.

LIMESTONE PLATEAU.

The Coconino Plateau, together with its southern extension and the wide steps on its west side, presents nearly horizontal strata, in which perceptible dips are rare. Some low undulations exist which are brought out in the cross sections on Plate XV, but owing to the exaggeration of the vertical scale in these sections (over 5 to 1) the relative dips are greatly magnified.

The structure of the plateau is typically exhibited by the Grand Canyon, of which a representative portion is shown by the topographic map, Plate XVI. Section B, Plate XV, shows the structure along a line passing north and south through the center of the area shown on this map and illustrates the wider relations. Figure 3 (p. 21) shows the succession of strata. The outcrops are so closely related to the topography that Plate XVI with the letter symbols for explanation clearly sets forth the geology and structure. There is a general rise of strata toward the north to the Kaibab dome, the general configuration of which is represented in figure 4 near the intersection of latitude 36° and longitude 112°. The dip is at an angle slightly more than 1°, so that the beds rise about 1,000 feet from Grand Canyon station to the south edge of the Kaibab Plateau, a distance of about 10 miles. The rise from west to east in this dome is shown in section A, Plate XV (relative dip magnified 5.3 to 1). This rise begins near Supai and attains a maximum near the east end of the Kaibab Plateau, beyond which it is cut off by the Butte fault. Some structural details along the canyon are illustrated by the altitude of the contact between the granite and the Tonto group. Northeast of Supai, in latitude 36° 20′, longitude 112° 27½′, this contact is 2,800 feet above sea level. It sinks to the river bank at an altitude of 2,100 feet 5 miles farther south and gradually rises again upstream, reaching 3,900 feet, or 1,450 feet above the river, opposite the mouth of Bright Angel Creek, a short distance northeast of Grand Canyon station. Thence eastward it sinks slightly and then rises to over 4,000 feet in the big bend near the mouth of the Little Colorado. The base of the Tonto group gradually rises 4,000 feet from the mouth of Grand Canyon southward to Music Mountain, a distance of 50 miles; but this is only an average dip of slightly over 1°. North of Music Mountain W. T. Lee observed a dip to the northeast of 11°. In the Juniper Hills near Juniper post-office he noted a dip of 3° N. in the Redwall limestone.

The Aubrey Valley is due to the red beds of the Supai formation, which extend to the railroad at the Yampai divide. Just west of this place there is a hill of Redwall limestone 200 feet high, which indicates a relatively steep rise of the strata locally. An easterly dip of 5° or more is indicated by the relations of the Supai formation and Redwall limestone in outcrops west of Seligman and in the boring at Seligman. In Chino Valley south of Seligman the sandstone at the base of the Tonto lies on granite at an altitude of 5,000 feet; and the well at Seligman, 1,479 feet deep, which ended near the bottom of the Redwall limestone at an altitude of 3,620 feet, indicates that the base of the Tonto group is here about 2,700 feet above sea level. This would require a dip to the north of 2,300 feet in 3 miles, or over 8°. In the ridge north of Seligman the outcrops show dips of 4° to 5° NE. On the west slope of Picacho Butte a block of Redwall and associated strata is tilted by lava so that it dips 30° E. East of Seligman the sedimentary rocks are covered by lava nearly to Ash Fork. Southwest of Ash Fork there is a regular succession of beds from Tonto apparently to Kaibab, descending on a gentle northeasterly dip into a shallow syncline at Ash Fork. This syncline is cut off on the east by the fault which uplifts the beds into the high escarpment 6 miles east of that place. The top of this escarpment is the Coconino Plateau. Apparently the strata rise slightly to the east into a faint anticline, which crosses the railroad near Belmont. Along the eastern margin of the Coconino Plateau there is a decided descent of the strata to the east, which is strongly marked in the region west of the lower part of the Little Colorado Valley, where it is part of the Paria fold. Along the railroad the dip is much less. It is indicated, however, by the fact that the base of the "Moencopie" is at an altitude of nearly 6,950 feet just east of Flagstaff and about 5,350 feet at Canyon Diablo, an average decline of 40 feet to the mile; but this monocline is somewhat flattened or even crenulated by a slight anticline near Winona.

Robinson has found several local uplifts in the San Francisco Mountain region. One is on the east side of Elden Mountain, where there is an uplifted block of strata from Redwall to Kaibab. Marble Mountain also shows these strata dipping 60°, and they appear in the dome-shaped uplift of Slate Hill with dips of 25°.

HOPI SYNCLINE.

The broad, shallow basin lying between the Coconino Plateau and the Fort Defiance uplift may be designated the Hopi syncline because the Hopi pueblos are situated in it. Its westward margin is the monocline just described, on which the Kaibab limestone passes beneath the "Moencopie formation" in the Little Colorado Valley northwest of Winslow. The basin pitches to the south at a moderately rapid rate in the region south of Winslow and Holbrook. Its

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MAP OF GRAND CANYON AT MOUTH OF BRIGHT ANGEL CREEK

Showing distribution of formations, especially in their relations to the topography

By N. H. Darton

Topography from Bright Angel quadrangle, Arizona, by F. E. Matthes

Scale $\frac{1}{48000}$

1 ½ 0 1 2 Miles

1 ½ 0 1 2 3 Kilometers

Contour interval 50 feet.

Datum is mean sea level.

Ck = Kaibab limestone; Cc = Coconino sandstone; Cs = Supai formation (*red sandstone and shale*);
Cr = Redwall limestone; Ets = Shales of Tonto group; Et = Basal sandstone of Tonto group;
Au = Unkar group (*red sandstone*); gr = Granites, etc. – – – Fault

descent to the north is sufficiently great, together with the rise of land, to carry the Triassic rocks beneath the shallow basin of Cretaceous rocks in the Oraibi region. The axis of this basin crosses the railroad near Holbrook, east of which very low westerly dips predominate for many miles. They are interrupted near Houck by a low, flat anticline which brings up the red sandy shale of the "Moencopie formation" for a few miles. There is a very shallow syncline east of Houck, which extends to the west slope of the Fort Defiance anticline. According to the observations of H. E. Gregory the strata north of Oraibi dip from 2° to 3° E., but in the region east of Walpi there is a general southeasterly dip at a low angle. At a point 10 miles north of Walpi the dip is due west. These facts indicate that the axis of the syncline passes between Walpi and Oraibi, trending north.

FORT DEFIANCE ANTICLINE.

Newberry, Howell, Gilbert, and Dutton have illustrated the salient features of the Fort Defiance anticline. It brings up the Triassic red beds along a zone of considerable width, which crosses the Santa Fe Railway near the eastern margin of Arizona, but a short distance to the south the anticline flattens and broadens into a wide flexure, passing through the Zuni region. It is most marked along the Bonita Valley (see Pl. XVII, *B*), in which the dips on its east side were found to be nearly vertical. Just west of Manuelito they are 30°, and near Zuni they are very low. According to Dutton the rate of dip is 9° to 10° in the ridges 9 miles east of Zuni. In the vicinity of Fort Defiance the dips are steep on the east side of the anticline, the top is broad and flat, and the west slope is a very wide zone of low dips. The Canyon de Chelly and Canyon del Muerto are in this zone. These canyons cut deeply into the Wingate sandstone, as shown in Plate IX.

GALLUP SYNCLINE.

The east limb of the Fort Defiance anticline descends steeply into the Gallup syncline, which holds about 2,000 feet of Cretaceous rocks in the vicinity of Gallup. The basin is flat bottomed, with steep dips on each side, especially on the east. Halfway between Gallup and Manuelito it is traversed longitudinally by a local anticline or elongated dome which brings up the lower sandstone of the Cretaceous. East of Zuni, where the basin is much shallower, only the Dakota and Mancos formations are present.

ZUNI ANTICLINE.

The Zuni Mountains are due to an uplift which in its more obvious features affects an area of about 3,500 square miles in west-central New Mexico. It trends northwest and southeast and is about 25

miles long. As is well known, the uplift has steep dips on its west side, low dips on the east side, and a wide, nearly flat crest. (See section C, Pl. XV.) Its higher portion is marked by a mountainous area of upper Carboniferous sandstone and limestone, with small ridges of the underlying grantite in its center. Lower on the slopes are elliptical outcrop zones of Permian to Cretaceous rocks. As shown by Howell, the steep dip on the west limb of the flexure is not accompanied by faulting and there is simply a sharp upturn of the beds from nearly horizontal to nearly vertical, as shown in figure 5.

The locality in which this upturn is best exhibited is just north of the railroad 3 miles east of Gallup. From most points of view on the railroad a fault appears to be present, but on examining the outcrops it is very easy to see that the sharp flexure is not attended by any notable fracturing of the strata, and there is a continuous stratigraphic succession of the lower coal measures. In this vicinity, and to the south along this steeply dipping limb, there may be more or less slipping in the upturned beds and local faulting in some of the beds, but I crossed the upturn along several lines and saw no evidence of dislocation. Howell has estimated that the vertical uplift due to this flexure is about 2,000 feet near Gallup, and Gilbert's estimate is 2,500 feet. Near Nutria, 20 to 25 miles farther south, where the maximum uplift is reached, the amount is about twice as great (Pl. XVII, *A*). About 2 miles west of Nutria there is an additional flexure by which the strata descend about 200 or 300 feet in the same direction. The maximum dip east of Gallup is 70°, northeast of Zuni it is 50°, and at Inscription Rock it is much less. The rate rapidly diminishes on the mountain slope and is very low on the crest of the anticline. On the northeast slope of the uplift the dips average about 3° near Guam, but farther east and south they increase on the mountain slopes to 10° or 12°. The structure is well exhibited in the canyon of Bluewater Creek, just west of Bluewater, where the eastward-dipping beds are cut by a fault of small throw.

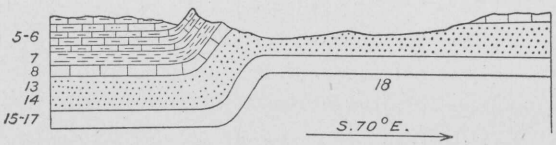
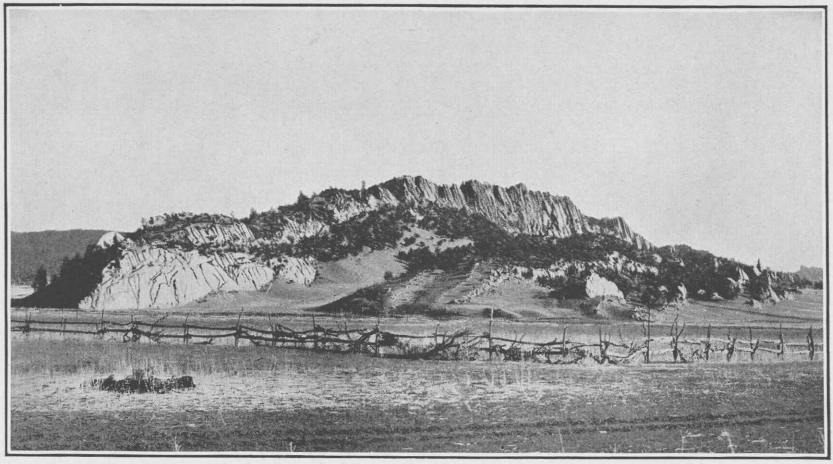


FIGURE 5.—Section of northwest side of Zuni anticline 3 miles east of Gallup, N. Mex., looking north-northeast. After E. E. Howell. 5-8, Cretaceous; 13-17, Triassic and Permian; 18, Carboniferous.

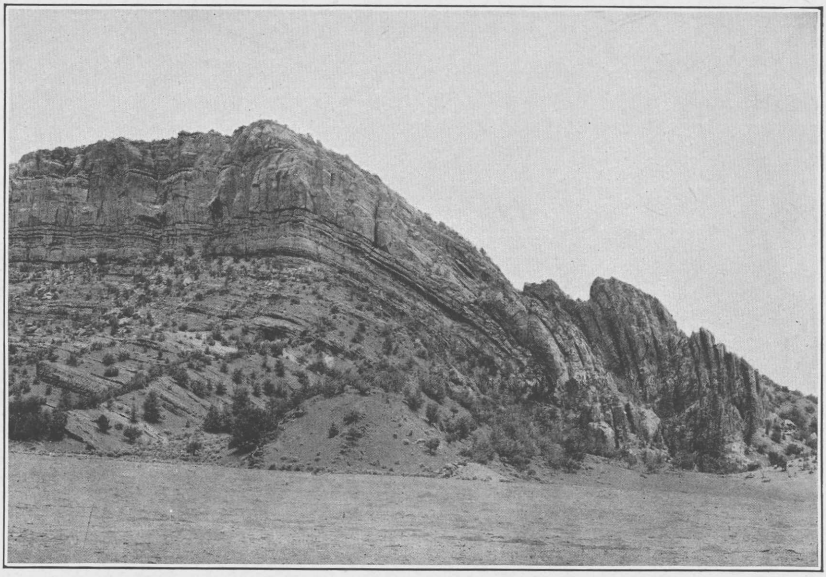
MOUNT TAYLOR SYNCLINE.

There is a well-marked basin lying east of the Zuni uplift, with its axis passing near Mount Taylor. The sides are steep, but the strata lie nearly horizontal in the middle, and its depth is such that it holds many hundred feet of Cretaceous strata surmounted by thick masses



A. CRETACEOUS AND UNDERLYING SANDSTONE ON SOUTHWEST SIDE OF ZUNI UPLIFT NEAR NUTRIA, NORTHEAST OF ZUNI, N. MEX., LOOKING NORTHWEST.

Zuni Mountain to the right.



B. FORT DEFIANCE ANTICLINE IN BONITA VALLEY, NORTHWEST OF MANUELITO, N. MEX., LOOKING NORTH.

of lava in the Mount Taylor area and southwest of Acoma. The Triassic rocks appear on both sides. Gilbert noted a steeply dipping monocline at Willow Springs, 25 miles north-northeast of Mount Taylor; and Dutton describes a similar feature passing a few miles northwest of Grants with dips of 16° to 18°. These relations are due to an anticline that was investigated by Schrader and Shaler and is shown in figure 4.

Toward the north the Mount Taylor syncline widens greatly and near latitude 36° it merges into a very wide undulating basin, which extends from the Fort Defiance anticline to the Nacimiento anticline. (See fig. 4.) It pitches gradually to the north and holds several thousand feet of Cretaceous and Tertiary strata.

NACIMIENTO UPLIFT.

Nacimiento Mountain is formed by granites and associated rocks overlain by Carboniferous limestones and sandstones, uplifted several thousand feet by a sharp anticline. (See fig. 4.) Along the west side the strata are nearly vertical and considerably crushed and faulted, but on the east side the dips are low. Owing to the steep dip on the west side of the uplift, the strata descend into a deep basin filled with a great thickness of Cretaceous and Tertiary rocks, which reach nearly to the foot of the mountain. East of the mountain, north of Jemez, there are broad flexures of the Carboniferous rocks and overlying red beds. A. B. Reagan [a] has determined the principal features of this area about Jemez. He represents the red beds as either faulted against or overlapping the granite at the south end and along part of the west side of the mountain.

The Nacimiento anticline pitches steeply at the south end of the mountain, but the uplift with diminished height continues far to the south. It crosses the San Jose Valley as a broad corrugated uplift exposing the red beds from Laguna nearly to Rio Puerco station. On Rio Puerco its axis passes about 10 miles above San Ignacio, where the valley reveals a small area of red beds. Near San Jose the beds are considerably flexed and probably faulted, and in the ridges 8 miles southwest of Rio Puerco one of the local flexures rises abruptly and exposes strata below the red beds. At this point the strata on the east side of the arch dip at angles of above 70°, but those on the west side are nearly horizontal. I did not have opportunity to study much of this region, but some details are given by C. L. Herrick,[b] who also states that Mesa Lucero, 10 miles southwest of San Jose, was found to be made up of red beds capped by Cretaceous.

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[a] Am. Geologist, vol. 31, 1903, pp. 67–110.
[b] Idem, vol. 25, 1900, pp. 331–346.

FAULTS.

The Grand Wash fault is the greatest displacement in northern Arizona, where it defines the western boundary of the plateau region. It marks the lower end of the Grand Canyon by dropping far beneath the surface of the rocks in which the canyon is cut. The strata rise a short distance to the west, however, but are again dropped by another great fault. The relations at the river, as determined by Gilbert [a] and by Lee [b] are shown in figure 6 and in a general way in section A, Plate XV.

As several faults in the plateau region have vertical planes it is assumed that this condition exists here. The amount of displacement can not be ascertained, owing to the deep filling west of the faults, but that of the eastern fault is at least 7,000 feet and that of the western fault 4,000 feet. These faults are traceable for some distance to the south, but finally they are all covered by valley fill in Hualpai Wash. The eastern one is marked by the Grand Wash Cliffs, nearly to latitude 35° 50′, but south of that place, where the cliffs

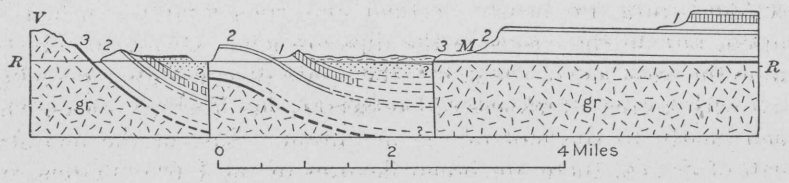

FIGURE 6.—Section of Grand Wash fault at Colorado River, at mouth of Grand Canyon. After Gilbert. M, End of Grand Canyon; V, Virgin Range. 1, Supai, Coconino, and Kaibab formations; 2, Redwall limestone; 3, Tonto group; gr, granites and schists. (The straight line R–R is the river grade. All below is hypothetical.)

fall back to the east, there is no direct evidence of faulting. Lee [c] shows a great fault defining the continuation of the cliffs, passing at the foot of Music Mountain, through Hackberry, and along the base of the Cottonwood and Aquarius cliffs, but I saw no convincing evidence of its existence.

The fault on Diamond Creek has been described and figured by G. K. Gilbert.[d] It is exhibited mainly in the Tonto beds and the underlying granite. It appears in a branch valley which heads 2 miles north of Peach Springs station, and, trending nearly due north, passes down Diamond Creek to its mouth and up the Colorado. Possibly it develops into or joins the Hurricane fault. The upthrow, which is on the west side, amounts to about 300 feet at the spring where the granite first appears, 10 miles north of Peach Springs, and to about 400 feet at the mouth of Diamond Creek. The principal features of this fault are shown in figure 7.

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[a] Rept. U. S. Geog. Surveys W. 100th Mer., vol. 3, Geology, 1875, pp. 17–187.
[b] Bull. U. S. Geol. Survey No. 352, 1908.
[c] Idem, Pls. I and V.
[d] Op. cit., p. 55.

The escarpment 6 miles east of Ash Fork is due to a fault of 800 to 900 feet throw, with uplift on the east side. It trends north-northwest. Lava, lower beds of Kaibab limestone, and upper beds of Coconino sandstone appear on the east side, but the relations on the west side are concealed by the sheet of lava dropped by the fault. This fault is shown in section C, Plate XV. In places the fault splits.

The fault which traverses the strata at the trail descending into the Grand Canyon at Grand Canyon station extends northeastward up Bright Angel Creek. Its throw near the trail is about 300 feet in places, with upthrow on the west side. Its presence has caused the breaks and talus which have made a trail practicable at this place. It is traceable on the plateau for some distance south from the trail by a line of low eastward-facing cliffs. F. L. Ransome[a] has noted certain features of this fault and of another one in a gorge 2 miles to the west. North of the river a wedge of the red sandstone of the Unkar group lying on granite and schist remains on a block between these two faults, dropped in pre-Tonto time. There has been later movement along the Bright Angel fault, with the uplift on the west side, showing the features mentioned above.

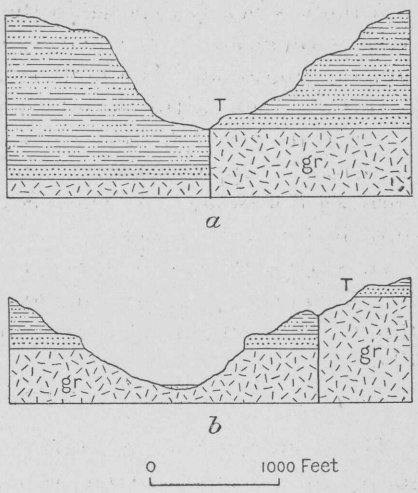

FIGURE 7.—Sections across Diamond Creek fault, looking north. *a*, Ten miles north of Peach Springs; *b*, near Colorado River. T, Sandstone of Tonto group; gr, granite.

D. W. Johnson[b] has described two faults exposed in the southern margin of the limestone plateau at Oak Creek canyon with drops of several hundred feet on the east side. One of them extends far north along Oak Creek valley. According to Robinson its displacement is 600 feet on the east side of Hull Mountain, 7 miles west-southwest of Flagstaff. This observer also finds a fault north of Hull Spring with 400 feet drop on the east side and a fault on the north side of Clark Valley southeast of Flagstaff, bounding Anderson Mesa and trending N. 65° W.

The Butte fault, described by Walcott,[c] extends north and south for 14 miles along the west side of Colorado River opposite the mouth of the Little Colorado. At the place where the displacement is

[a] Science, new ser., vol. 27, 1908, p. 668.
[b] Proc. Boston Soc. Nat. Hist., vol. 34, pp. 138–139.
[c] Bull. Geol. Soc. America, vol. 1, 1889, pp. 49–64.

greatest (2,200 feet) the base of the Kaibab limestone is brought into contact with the Chuar. As shown in section A, Plate XV, the downthrow is on the east side.

At Ojo Caliente, south of Zuni, there is a fault noted by Gilbert, Howell, and Shaler,[a] which brings Permian red beds into contact with Cretaceous sandstones for some distance. It trends northwest and southeast and has a displacement of about 2,000 feet, with upthrow on the northeast side. Southward from Zuni lower beds gradually rise to the surface in succession until at the fault at the warm spring there are sandy shales similar to those of the "Moencopie," south of Guam, while still lower beds with Carboniferous fossils appear half a mile farther southeast. On the opposite side of the fault are upper beds of the Mancos shale.

A fault is clearly exposed in the canyon of Bluewater River 4 miles west of Bluewater. It traverses Carboniferous gray sandstone overlain by limestone. The fault trends northeast and southwest, with upthrow on the northwest side amounting to about 150 feet, sufficient to bring to view 100 feet of red sandstone which underlies the gray sandstone. Apparently the higher red beds are cut by a fault 8 miles northwest of Bluewater, which Schrader[b] found extending northward into the Cretaceous rocks.

G. K. Gilbert[c] has described a faulted area in the limestone plateau 10 miles north of Canyon Diablo. The faults have from 10 to 50 feet throw, and from one of these extends a deep open fissure, shown in Plate VI, *A*.

COON BUTTE.

The well-known Coon Butte,[d] situated on the plateau 12 miles southeast of Canyon Diablo, is one of the notable phenomena of this country. Much has been written regarding it, but the papers by G. K. Gilbert,[e] D. M. Barringer,[f] and B. C. Tilghman[g] describe it fully. It consists of a bowl-shaped crater, about 3,900 feet in diameter and nearly 600 feet deep, encircled by a narrow rim rising from 120 to 160 feet above the plateau surface. The cross section, figure 8, shows the general structure.

The rocks in the adjoining plateau lie nearly horizontal over a wide area, but are sharply upturned all around the margin of the crater to the amount of 150 to 200 feet, with the angles of dip averaging 30°,

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a Bull. U. S. Geol. Survey No. 316, 1907, p. 383.

b Bull. U. S. Geol. Survey No. 285, 1906, Pl. VII.

c Jour. Geology, vol. 2, 1895, pp. 117–119.

d Some late writers have suggested other names for this feature, notably Meteor Crater, but the name Coon Butte is too well established by usage to be changed now. It is the old landmark for Coon Tank, a watering place some distance to the southeast.

e Science, new ser., vol. 3, 1896, pp. 1–13; and Presidential address, Geol. Soc. Washington, 1896.

f Proc. Acad. Nat. Sci. Philadelphia, vol. 57, 1906, pp. 861–886.

g Idem, pp. 887–914.

but varying from 10° to 80°; at one point the beds are slightly overturned. There is some local faulting and lateral crushing. The rocks upturned are basal "Moencopie" about 25 feet thick, Kaibab limestone 200 to 300 feet, and Coconino sandstone of undetermined thickness but probably less than 500 feet. The top of the sandstone is greatly crushed under the limestone; talus hides the relations at its base. The rim consists of an irregular ridge thickly capped by detritus from the crater, consisting of blocks of limestone and sandstone ranging from 30 feet in diameter to fine dust. The coarser material is predominantly limestone, and there is a large amount of very fine silica or "rock flour" at the base of deposit. The rim is about half a mile wide, but a thin sheet of fragmental material extends much farther, and scattered material is said to be found as much as 3½ miles distant. One 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. Numerous borings, one 1,100 feet deep, have found wash and pond deposits lying on broken rock and rock flour. Water

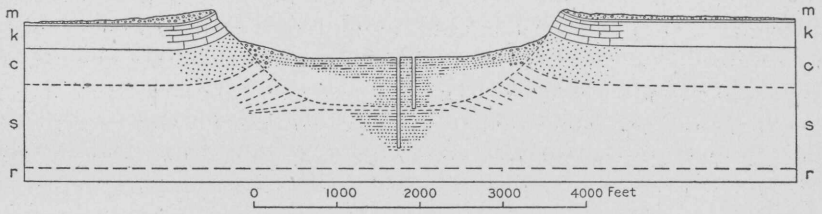

FIGURE 8.—Generalized section across Coon Butte, Arizona. m, "Moencopie formation;" k, Kaibab limestone; c, Coconino sandstone; s, Supai formation; r, Redwall limestone.

rises within 200 feet of the surface. Solid rock entered at 820 to 870 feet below the crater floor is yellow to red sandstone (Supai). Apparently it lies horizontal and presents no evidence of disturbance. This formation doubtless also extends for some distance up the sides of the crater, as shown in figure 8, for the Coconino sandstone probably is less than 500 feet thick. 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. Tilghman's estimate of the volume of the rim is materially less. Altogether the features suggest a great bubble with the top blown off and the ejected material piled up on the margin.

After an examination of the crater and consideration of all that has been written, I believe we have no evidence adequate to explain its origin. The hypothesis that it was caused by impact of a meteor, as urged by Tilghman, Barringer, Fairchild, and Merrill,[a] is in accordance with some of the features but does not accord with the all-

[a] Merrill, George P., The meteor crater of Canyon Diablo, Arizona: Smithsonian Misc. Coll., vol. 50, pp. 461–498.

important fact that no meteor is present, as has been demonstrated by many borings. The suggestion of Merrill that the meteor may have been partly volatilized by the heat of the concussion and its residue blown out of the crater by the explosion is difficult to accept. It is agreed that if there was a meteor it must have been at least 500 feet in diameter. The occurrence of the few tons of meteoric iron in the vicinity and mingled with some of the débris on the rim and in the crater is an enigma. The hypothesis of Gilbert that the crater and rim were produced by a volcanic steam explosion appeals to me most strongly, notwithstanding its purely gratuitous character. The competency of such a cause is well illustrated by explosion craters in various parts of the world. I reiterate Gilbert's statement that Coon Butte is in the midst of a volcanic region, and there are recent cones a few miles west and northwest. The crater of Zuni Salt Lake,[a] which is somewhat similar but has cinder cones in the center, is not far southeast.

An accumulation of superheated steam in the lower part of the gray Coconino sandstone and the underlying red sandstone of the Supai formation at a depth of 800 feet would have a pressure due to weight alone of more than 1,000 pounds to the square inch and a temperature of at least 280° C. This steam, permeating the pores of the sandstone, would on explosion rend the particles into rock flour such as that which exists in large volume in and about the crater, and it is difficult to understand how any other force could have produced so much fine material. The slight traces of metamorphism which some of the sandstone particles exhibit doubtless were caused by increased heat due to great friction along some of the zones of movement. It appears probable that about 500 feet of red sandstones of the Supai were involved in the explosion, and as but little of this material appears in the detritus there is a strong suggestion that steam and hot water may have bleached it so that it is now represented by part of the white rock flour.

MINERAL RESOURCES.

The principal mineral resources of the region treated in this report are coal and copper, but asbestos, gold, building stone, gypsum and limestone are of considerable importance. The very large copper mine at Jerome lies just outside of the area examined, as do also the metalliferous mines in the desert mountains and the copper mines near Copper City. The coal in the basin extending from Gallup to the Nacimiento Mountains has been described in reports by Schrader, Shaler, and Gardner, already cited, to which the reader is referred. The large coal field extending north and east from the

[a] Darton, N. H., Jour. Geology, vol. 13, 1905, pp. 185–193.

Hopi pueblos has not yet been surveyed but it is known to have an area of about 2,500 square miles and to contain a vast amount of coal. The small deposit of copper in the limestone in Grand Canyon has been described by S. F. Emmons, the copper prospects in Zuni Mountain by F. C. Schrader, and the asbestos in the Grand Canyon by J. H. Pratt and by J. S. Diller. Gypsum deposits have been described by H. N. Herrick and by M. K. Shaler. Turquoise has been found in Mineral Park, Mohave County, Ariz., and peridot about 10 miles north of Fort Defiance.

DEEP BORINGS.

A number of deep wells along the Santa Fe Railway in New Mexico and Arizona throw much light on the stratigraphy. The following data are all that were obtainable:

NEW MEXICO.

Rio Puerco.—At Rio Puerco two borings obtained salty water unfit for use. One is 193 feet deep and the other 1,015 feet deep; both are reported to be entirely in clay and gravel, but the deeper one doubtless penetrated Tertiary and Cretaceous strata.

Garcia.—This station is 7 miles west of Rio Puerco station. The boring, 855 feet deep, obtained only salty water. The strata penetrated were Triassic red beds, and probably the top of the Permian was reached. The following record was furnished by the drillers.

Record of boring at Garcia, N. Mex.

	Feet.
Red clay, streaks of blue clay	0–412
Gravel	412–432
Red sandstone	432–532
White sandstone	532–605
Blue clay	605–855

At 355 to 358 feet there was a coarse bed of "gravel" containing salt water.

San Jose.—The Frisco System has recently bored three wells in the valley of Lucero Creek in T. 8 N., R. 3 W., a few miles west of San Jose. Data regarding them were kindly supplied by Mr. J. S. Eldridge. The first, in section 19, is 235 feet deep. After boring through 225 feet of gray clay it entered red and gray clay and gravel, and at 235 feet found a flow which rose 6 inches above the casing. The water, which contains some sulphate of lime, was piped up 30 feet and flows about 50 barrels a day.

The second well, in section 15, found a flow of water at 235 feet in red sandstone. It flows 6 inches above the top of casing. The third well, in section 9, had the record following.

Record of boring in sec. 9, T. 8 N., R. 3 W., Valencia County, N. Mex.

	Feet.
Sand and clay	0– 85
Lava rock	85– 90
Clay with little water at base	90–155
Gray clay	155–190
Red sandy clay	190–290
Gray clay	290–325
Red clay	325–460
Gray clay	460–480

This boring was not a success.

Laguna.—Three borings have been made by the Frisco System in sec. 17, T. 8 N., R. 5 W., 9 miles south of Laguna, and one of them is still in progress. The following information was supplied by the driller, Mr. J. S. Eldridge:

The first boring, 275 feet deep, found only a little salty water at 125 feet. It entered red shale at 95 feet, under 92 feet of gray sandstone, and was in red materials to the bottom. Another boring, 382 feet deep, found water at 140 feet, which varies from salty to fairly fresh and pumps a 1-inch stream. The water was found under 45 feet of gray sandstone. This was overlain by 65 feet of red shale. The boring that is now in progress had the following record to April 29, 1910:

Record of deep boring in sec. 17, T. 8 N., R. 5 W., Valencia County, N. Mex.

	Feet.
Red clay, sandstone, and gravel	0– 90
Grayish sandstone, water at 140 to 160 feet	90–160
Red and brown clay with gray shale at 290 to 410 feet	160–560
Sandstone and red shale	560–590
Red sandstone	590–610
Hard sandstone with much salty water rising to −3 feet	610–613
Red shale; some sandstone and gypsum	613–700
Hard brown sandstone; much very salty water rising to −20 feet	700–705
Red shale; salty water rising to −7 feet at 737 feet	705–737
Red shale, harder at base	737–758
Light-red shale	758–785
Darker-red shale	785–830
Red shale (?) with sandstone layers; water less salty	830–853

Suwanee.—At Suwanee siding, 7 miles northwest of San Jose, are several flowing wells about 350 feet deep, the water of which contains much mineral.

Armijo.—At Armijo railroad siding, about halfway between San Jose and Laguna, a 942-foot boring obtained salt water only. Below valley filling, including a thin sheet of lava, it penetrated 760 feet of red sandstone and shales, and 42 feet of gray sandstone, doubtless all Triassic.

Record of boring at Armijo, N. Mex.

	Feet.
Sand and clay	0– 55
Lava	55–106
Sand or sandstone	106–140
Red rock	140–900
Gray sandstone	900–942

Chaves.—At Chaves, a station in New Mexico, halfway between Guam and Bluewater, a well was sunk in 1902 on my recommendation and obtained a flow of 50 gallons a minute of excellent water at a depth of 707 feet. It is entirely in the basal Triassic-Permian deposits as follows:

Record of artesian well at Chaves, N. Mex.

	Feet.
Red clay and sand, surficial	0– 50
Gravel	50– 52
Gray sandstone	52–195
Red clay	195–530
Blue clay	530–570
Gray sandstone	570–595
Black sand	595–600
Gray sandstone	600–700

Guam.—A well at Guam obtains a flow of 12 gallons a minute from a depth of 150 to 200 feet. The boring was continued to 600 feet without finding another water-bearing bed. The strata are all lower Triassic and Permian, on the north slope of the Zuni uplift.

Record of boring at Guam, N. Mex.

	Feet.
Surface sand	0– 10
Soft clay	10– 45
Sand and gravel	45– 55
Hard sandy clay	55– 75
Petrified wood and gravel	75– 76
Hard blue shale	76– 92
Soft white sandstone	92–103
Red shale	103–108
Hard red sandstone	108–135
Red shale	135–145
Sand and gravel (water)	145–155
Gray sandstone	155–210
Hard blue shale	210–410
Soft shale	410–540
Hard red sandstone	540–560
Hard red shale	560–600

The beds, from 155 to 600 feet, are in the "Moencopie formation."

Gallup.—Several years ago the railroad company sank a number of wells at Gallup from 295 to 540 feet deep and obtained moderate supplies of water from sandstones in the Cretaceous coal measures. In 1905 a boring 1,112 feet deep struck a flow of 15 gallons a minute of clear soft water. In July, 1907, the company completed another

artesian well which flows 100 gallons an hour from a depth of 1,241 feet and the same amount from 1,356 feet. The flow began at the rate of nearly a gallon a minute when the drill reached 1,235 feet. The following is the driller's record:

Record of artesian well at Gallup, N. Mex.

	Feet.
Clay and quicksand	0– 115
Gray sandstone	115– 256
White sandstone	256– 320
Dark shale	320– 365
Hard sandy shale	365– 377
Dark shale	377– 448
Shell of hard rock	448– 468
Dark shale with hard, lumpy layers at 610 and 645 feet	468– 820
Fossil shell layer	820– 827
White sandstone	827– 882
Dark shale	882– 925
White sandstone	925–1,145
Pink sandstone	1,145–1,167
White sandstone	1,167–1,356

It is probable that this boring penetrated the Zuni sandstone below 1,145 feet.

Manuelito.—Several wells 170 to 295 feet deep at Manuelito failed to obtain satisfactory amounts of water, but a 600-foot well sunk in 1901 yields a moderate supply. The boring was in valley filling 100 feet, white sandstone 492 feet, and red sandstone 8 feet. The two last are the Zuni sandstone.

Bluewater.—A 735-foot boring at Bluewater obtained at about 500 feet a small amount of water which rises within 120 feet of the surface. Some water also appeared at 275 feet.

Record of well at Bluewater, N. Mex.

	Feet.
Lava	0– 61
Tuff	61– 72
Red clay	72– 85
Lava	85– 90
Red clay	90–159
Blue clay	159–260
Gray soft sandstone	260–263
Blue clay	263–270
Gray hard sandstone	270–277
Red sandstone	277–291
Siliceous limestone	291–439
Black "quartz"	439–447
Limestone	447–455
White sandstone (water)	455–575
Red sandstone (bad water)	575–735

The boring began in a lava flow lying on the lower part of the "Moencopie formation," and at 291 feet passed into the Carboniferous limestone of the Zuni uplift.

ARIZONA.

Allentown.—At Allentown, 5 miles east of Houck, a 165-foot boring in red shale of the "Moencopie formation" obtained only a small supply of poor water.

Chambers.—At Chambers, 7 miles east of Navajo, a 635-foot boring did not obtain a satisfactory water supply. It passed through 225 feet of clay, 80 feet of sand, and 330 feet of sandstone, probably penetrating deeply into the "Moencopie formation."

Adamana.—A 305-foot boring at Adamana, entirely in the "Moencopie," yields a moderate flow of highly saline water. The flow is 25 gallons a minute and the head is stated to be sufficient to raise the water 19 feet above the surface. The following record was given to L. F. Ward[a] by the driller:

Record of artesian well at Adamana, Ariz.

	Feet.
Sand and sandy clay	0– 55
Sandstone	55– 58
Cement gravel	58– 59
Sandstone (slightly salt water at 88 feet)	59–108
Brown shale	108–151
Red shale	151–200
Hard brown and blue shale	200–205
Red shale	205–275
Sandstone	275–285
Hard brown shale	285–305

Manila.—At Manila, a siding midway between Holbrook and Winslow, a 305-foot boring obtains over 100 gallons a minute of excellent water. It passed through 20 feet of clay, 110 feet of sand, and 175 feet of white sandstone, all in the "Moencopie formation."

Holbrook.—A recent boring at the large cattle ranch east of Holbrook has the following record:

Record of boring east of Holbrook, Ariz.

	Feet.
Soil	0– 23
Quicksand	23– 61
Rock	61– 69
Red mud	69– 71
Rock	71– 76
Red mud and some gypsum; water, no flow	76–177
Gypsum	177–178
Red sandstone	178–229
White sandstone	229–435
Light-yellow sandstone	435–440

A moderate amount of good water was found in the sandstone from 178 to 300 feet, yielding about 700 gallons an hour. The boring is to be deepened to obtain a larger supply.

[a] Mon. U. S. Geol. Survey, vol. 48, pt. 1, 1905, p. 18.

Winslow.—A deep boring was made at Winslow many years ago by the Atlantic and Pacific Railroad Company, but no record is available. The depth is claimed to be 1,700 feet, which would have reached far into red beds of the Supai formation. No water was obtained.

Winona.—In 1902 a 657-foot boring was made at Winona to test the water resources of the Coconino sandstone. Unfortunately no water supply was found. The boring, which began low in the Kaibab limestone, reached the Coconino sandstone at 185 feet. The drill penetrated 456 feet of this sandstone and went 16 feet into the underlying red shale of the Supai formation. Another report gives the limestone at 285 feet, and this leaves but 356 feet for the sandstone.

Ash Fork.—An old boring at Ash Fork, reported to have been 1,025 feet deep, obtained no water. It probably passed through the Redwall limestone and into the shale of the Tonto group. If it had gone a few hundred feet deeper it would have reached sandstones of the Tonto and probably would have obtained water.

Seligman.—Several unsuccessful attempts have been made to complete a deep well at Seligman. One boring 1,479 feet deep nearly reached the base of the Redwall limestone after passing through 647 feet of that formation.

Record of boring at Seligman, Ariz.

	Feet.
Lava and cinders	0– 234
Red sandstone and shale (Supai)	234– 832
Limestone (Redwall)	832–1,479

According to other reports the volcanic rocks extend only to 170 feet or to 145 feet.

Aubrey.—A boring made by the Atlantic and Pacific Railroad Company at Aubrey is reported to have reached a depth of 936 feet and obtained no water. It began in the upper part of the Redwall limestone and may have reached the shale of the Tonto group.

Picacho.—On my recommendation the railroad company sank a well at Picacho (now Pica), a siding midway between Aubrey and Nelson to a depth of 1,546 feet. The boring first passed through valley wash underlain by a thin mass of basal Supai beds on Redwall limestone. After penetrating this limestone to a reported depth of 1,170 feet, it passed into water-bearing sandstones of the Tonto group. The yield is 30 gallons a minute, and the water rises within 781 feet of the surface. The total solids are 21 grains to the gallon, of which 12.3 grains were carbonates.

Record of deep well at Picacho, Ariz.

	Feet.
Sand, gravel, etc.	0– 95
Red sandstone (Supai)	95– 144
Limestone (Redwall)	144–1,132
Shale and sandstone	1,132–1,546

According to two other reports the limestone extended from 110 to 1,170 feet or from 140 to 1,289 feet.

Nelson.—On my recommendation a well was sunk at Nelson which obtains a moderate supply of good water from a depth of 1,041½ feet. It began below the middle part of the Redwall limestone, which extended to a depth of 396 feet according to one report and to 926 feet according to another; the remainder was in shale and sandstone of the Tonto group.

Peach Springs.—Two wells 924 and 1,013 feet deep have been sunk at Peach Springs. The record of the deeper one as reported by the driller is as follows:

Record of well No. 2 at Peach Springs, Ariz.

	Feet.
Soil	0– 12
"Cement" gravel	12– 215
Limestone	215– 590
Clay	590– 635
Sandstone	639– 935
Quartz	935–1,003
Granite	1,003–1,013

Water found at 430 feet rises within 402 feet of the surface and yields a small supply to pumping. Doubtless it is from sandstone. To judge by exposures in the valley a short distance north of this place there is but little if any limestone in this boring; if there was any it may even be above 215 feet. The limestone mentioned in the record is probably sandstone of the Tonto. This formation may have been penetrated for 800 feet. The identity of the "granite" was not established, but it is reasonable to expect it at the depth mentioned, and the overlying "quartz" is probably the quartzitic sandstone at the base of the Tonto.

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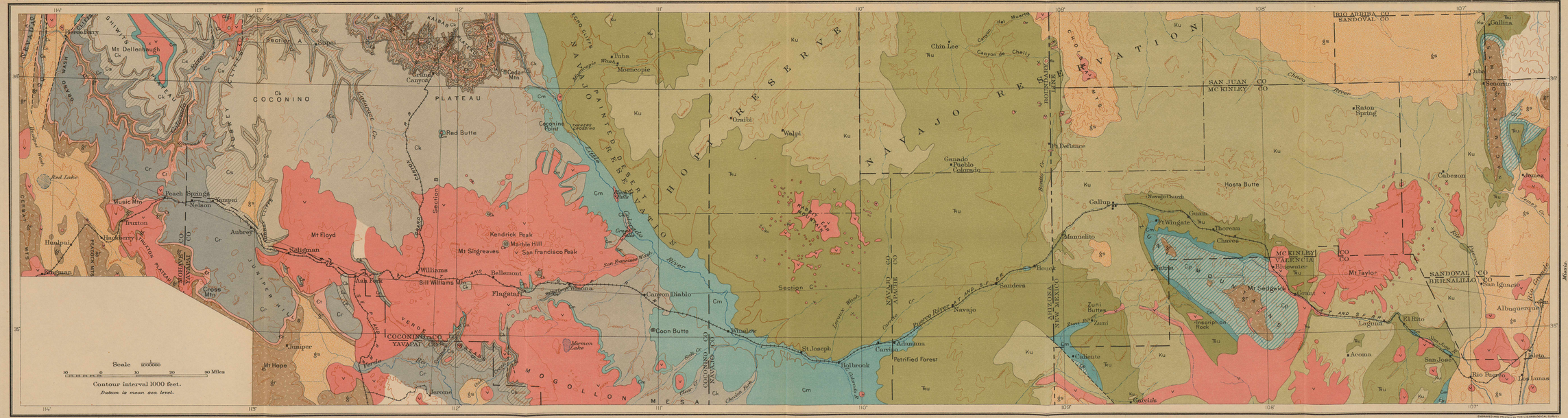

GEOLOGIC MAP OF PART OF NORTHWESTERN NEW MEXICO AND NORTHERN ARIZONA

By N. H. Darton

1909

Base compiled mainly from topographic maps by U. S. Geological Survey

Geology in part from maps by C. E. Dutton, H. H. Robinson, H. E. Gregory, A. C. Reagan, W. T. Lee, C. L. Herrick, C. D. Walcott, G. K. Gilbert, C. A. Fisher, L. F. Ward, M. K. Shaler, F. C. Schrader, and J. H. Gardner.

LEGEND

- Volcanic rocks — V
- Gravel, sand, and clay — Qs
- Undifferentiated — Ku
- Undifferentiated — Tu
- "Moencopie formation" — Cm
- Undifferentiated Pennsylvanian — Cp
- Kaibab limestone — Ck
- Coconino sandstone — Cc
- Supai formation — Cs
- Redwall limestone — Cr
- Temple Butte limestone (too thin to show on map) — Ct
- Tonto group — Ct
- Grand Canyon series — Sc
- Granite, schist, etc. — Gr
- Fault

QUATERNARY AND TERTIARY
TRIASSIC CRETACEOUS
CARBONIFEROUS
Permian
Pennsylvanian
Aubrey group
Marble canyon
DEVONIAN
CAMBRIAN
PRE-CAMBRIAN

Note: There are several small outliers of Triassic in the Moencopie area.