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GEOLOGIC RECONNAISSANCE OF A PART OF WESTERN ARIZONA

BY

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WITH NOTES ON THE

IGNEOUS ROCKS OF WESTERN ARIZONA

BY

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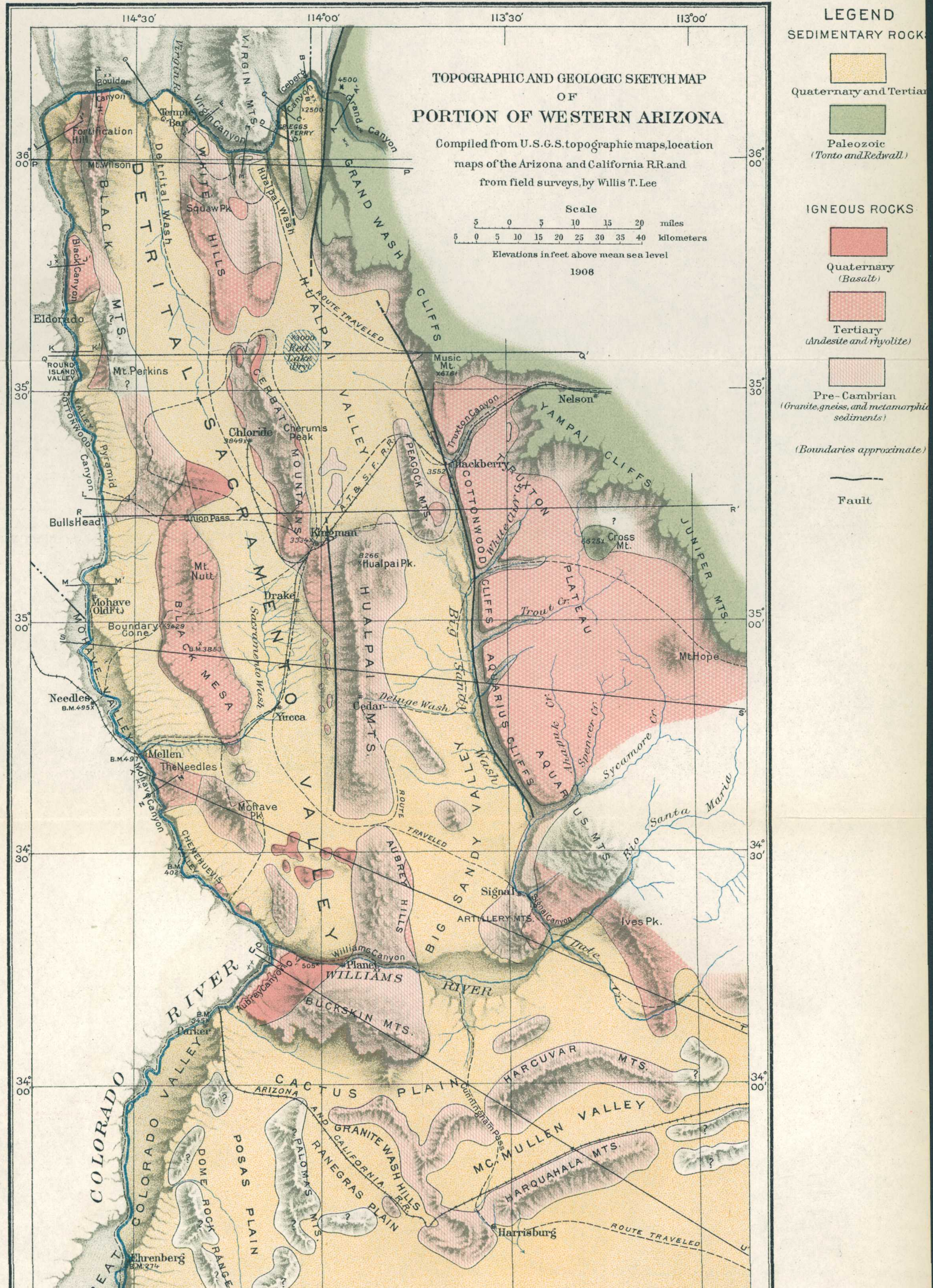

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GEOLOGIC RECONNAISSANCE OF A PART OF WESTERN ARIZONA.

By Willis T. Lee.

INTRODUCTION.

Purpose of the investigation.—The investigations described in this bulletin were made in western Arizona under the general direction of Mr. N. H. Darton. The region examined lies mainly west of the high plateau and north of latitude 33° 30′.

The original purpose was to investigate the water resources of the region and the extent to which they might be developed. This necessitated an examination of the geographic features with special reference to irrigable lands and the possibilities of getting water to them, and of the geologic formations with reference to their bearing on questions of underground water. Conditions were found so unfavorable for water development in this region that the economic results of the work are unimportant, or at best have negative value. On the other hand, the region proves to be one of great geologic interest. Many significant features were observed, and their bearing on important geologic problems was noted, but want of sufficient time as well as the desert condition of the region made it impossible to follow out many of the most interesting lines of investigation.

Extent and character of the investigation.—The observations were made during rapid reconnaissance trips. In the summer and autumn of 1903 the Hualpai, Detrital-Sacramento, Big Sandy, Chino, and Aubrey valleys were visited, and Colorado River was examined from Needles, Cal., southward to Yuma, Ariz., the object of the river trip being to examine the geologic conditions at the various reservoir sites of the Reclamation Service along lower Colorado River. During the spring and summer of 1904 a more extended reconnaissance was made, including a river excursion from the mouth of Grand Canyon to Needles, Cal., and several overland trips shown on the accompanying map (Pl. I).

The amount of territory covered necessitated for the most part very general observations, and as the investigation was undertaken in the interests of water development the evident impossibility of development in certain places rendered it impracticable to make extended geologic examinations where such examinations would have been of great scientific interest. For these reasons the fragmentary data here presented might perhaps be of little use if they related to a region fairly well known, but so little is known either of the geology or of the geography of this region that the information, confessedly incomplete, will, it is believed, be of value to many persons.

The northern third of the region is covered by the early reconnaissance maps of the United States Geological Survey, and the geographic features are well known. Little has been done, however, toward accurately mapping western Arizona south of the thirty-fifth parallel. The maps heretofore published were found erroneous, especially in the locations of mountain groups and lines of drainage. It is not claimed that the map accompanying this bulletin is errorless, but in the southern part, where previously published maps have been most incorrect, this map is believed to be measurably accurate owing to data acquired by recent railway surveys and furnished for use in this bulletin by W. A. Drake, engineer of the Santa Fe Railway system.

The geologic formations were mapped where practicable, and their general distribution over the greater part of the region was determined. Data concerning their character and occurrence were collected as far as time would allow, and special attention was given to the recent geologic history.

During the investigation it became evident that changes of a physiographic nature have occurred in recent geologic times, which have produced notable results. Changes in surface elevation and configuration and in climatic conditions have resulted in periods of aggradation and periods of degradation during which nearly the entire region was affected. The evidences of these changes are found in such phenomina as recently formed canyons, filled valleys, aggraded plains, and the deflection of streams.

The chief economic results of the examination have to do with the development of both surface and underground waters. Attention is also called to the mining districts of the region, and certain possibilities of development of the mineral resources are pointed out.

Summary of previous knowledge.—Little information has hitherto been published regarding the geology of this region. In 1856 Jules Marcou's notes were published in the Pacific Railroad Reports,[a] in which he briefly describes the geologic features along the route traversed, including the igneous and granitic rocks of the Truxton Plateau, the detrital filling of the Big Sandy Valley, and the gneiss and

[a] Marcou, Jules, Pacific Railroad reports, vol. 3, 1856, p. 155.

lava flows in the region of Williams Canyon. Again, in 1858, he makes brief mention of the region in his "Geology of North America."[a]

The first account of any considerable value is found in Lieutenant Ives's report on lower Colorado River, published in 1861. Part 3 of this report, by J. S. Newberry, describes the geology along the route traversed by the Ives expedition. Newberry ascended Colorado River to the mouth of the Virgin, and crossed the northern part of the region from Fort Mohave eastward to the Colorado Plateau. Later, Major Powell, in the course of his exploration of Colorado River, skirted the northern border as far as the mouth of the Virgin, and in the early seventies Gilbert and Marvine described its northern part in the final Wheeler reports.[b]

A few scattered references to the geology of the region are found also in various mining reports. In 1866 [c] Silliman visited certain mines near Fort Mohave, and described in a general way the volcanic rocks of Black Mesa. In 1863 Blake observed a deposit of iron ore near Planet, in Williams Canyon, and described the metamorphic strata with which it is associated.[d] This deposit, together with the copper deposits of the Planet district, have recently been described by McCarn [e] in a brief sketch of the geology of that locality, and Pratt [f] has described the occurrence of ore in the Socorro mine, near Harrisburg, Ariz.

GENERAL GEOGRAPHY.

RELATION TO SURROUNDING REGIONS.

Arizona is divided into three general geographic provinces,[g] known as the Plateau, the Mountain, and the Desert regions. The first province is well known through the writings of Powell, Gilbert, Dutton, Walcott, and others, as the Colorado Plateau; its western limit is very definitely marked in western Arizona by the Grand Wash Cliffs. Between the Plateau and the Desert regions is a mountainous belt comprising the second, or Mountain, region, which includes the greater part of the area described in this bulletin. The third, or Desert, region is mainly one of low-lying plains with more or less isolated mountain groups; it occupies the southwestern part of the Territory.

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[a] Marcou, Jules, Geology of North America, 1858, p. 23.

[b] U. S. Geog. Surv. W. 100th Mer., vol. 3, pts. 1, 2, and 5, 1875.

[c] Silliman, Benjamin, jr., On some of the mining districts of Arizona: Am. Jour. Sci., 2d ser., vol. 41, 1866, pp. 289-308.

[d] Blake, W. P., Iron regions of Arizona: Idem, vol. 40, 1865, p. 388.

[e] McCarn, H. L., The Planet copper mines (Arizona): Eng. and Min. Jour., vol. 78, 1904, p. 26.

[f] Pratt, J. H., Gold deposits of Arizona: Idem, vol. 73, 1902, p. 795.

[g] Ransome, F. L., Description of Globe district: Geologic Atlas U. S., folio 111, U. S. Geol. Survey, 1904, p. 1.

No definite line of separation can be drawn between the Desert and Mountain provinces in the area here described. In central and southern Arizona the distinction is well marked;[a] but in western Arizona the Mountain region, so prominent in the central part of the Territory, becomes a transition belt in which the descent of about 6,000 feet from the high plains of the Colorado Plateau to the low-lying plains of the Desert region of southern Arizona is accomplished through several mountain groups with gradually diminishing elevation. The transition becomes less marked northward until in northern Arizona the change in elevation is accomplished largely by fault scarps.

North of the area described Gilbert, in the Wheeler reports (and other geologists following him), makes but two general provinces, the High Plateau and the Great Basin, but states[b] that on account of an interlocking of characteristics along the borders their common boundary is not easily located. This division into two topographic provinces is a more natural one for northwestern Arizona than the threefold division of central Arizona. The basin ranges and broad gravel-filled valleys of Nevada extend southward into Arizona and bear the same general relations to the High Plateau that they do in southern Nevada and Utah.

TOPOGRAPHY.

General character.—The Colorado Plateau here enters into consideration only in so far as it forms the boundary of the area described. This bulletin is concerned chiefly with the low-lying area to the west.

In the Mountain region, south of the area described, the rocks have been deeply dissected by erosion, and great crustal movements have occurred. Near the escarpments bordering the plateau the mountains consist in some places of disturbed portions of the sedimentary formations of the plateau, let down to their present position by faulting. Mountains of this kind occur in the vicinity of Globe, Ariz.,[c] in the Tonto basin,[d] and within the region described near the mouth of Grand Canyon. In many places, especially at a distance from the edge of the plateau, sedimentary rocks are not found, and it is difficult to determine whether mountains composed entirely of crystalline rock are due to local elevation or are simply masses left by erosion during the general degradation of the region.

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[a] Lee, W. T., Underground waters of the Salt River valley, Arizona: Water-Supply Paper U. S. Geol. Survey No. 136, 1905.

[b] Gilbert, G. K., and Marvine, A. R.: U. S. Geog. Surv. W. 100th Mer., vol. 3, 1875, p. 57.

[c] Ransome, F. L., Description of Globe district, Arizona: Geologic Atlas U. S., folio 111, U. S. Geol. Survey, 1904. Also Geology of the Globe copper district, Arizona: Prof. Paper U. S. Geol. Survey No. 12, 1903.

[d] Lee, W. T., Underground waters of the Salt River valley, Arizona: Water-Supply Paper U. S. Geol. Survey No. 136, 1905, p. 117.

The mountain ranges throughout western Arizona, with a few notable exceptions, lie in general parallel to the border of the plateau. In general, also, the mountains become smaller and more completely isolated away from the plateau. In central Arizona, where the distinction between mountain and plain is most marked, rugged mountains extend from Mogallon Mesa to the Superstition Mountains, a distance of 70 miles, where they give place gradually through such isolated groups as the Phoenix Mountains, Estrella Mountains, etc., to the still smaller hills of southwestern Arizona. As the mountains become less prominent the valleys broaden and finally blend into a plain completely surrounding the isolated mountain groups. The topographic character of northwestern Arizona lies between these extremes, the area being about equally divided between mountain and plain.

Mountains.—The mountains of northwestern Arizona occur in four more or less distinct groups. The first consists of a series of cliffs at the eastern border of the region known as the Grand Wash, Cottonwood, Aquarius, and Yampai cliffs. The first three form a practically continuous escarpment, extending from Colorado River southward to Williams Canyon, a distance of about 125 miles. The Grand Wash Cliffs, extending from Colorado River to Music Mountain, a distance of about 50 miles, is composed of crystalline rock at the base, overlain by the sedimentary formations of the plateau region. At Music Mountain this escarpment divides, the lower or crystalline part continuing southward under the names of the Cottonwood and Aquarius cliffs and forming the edge of the Truxton Plateau, while the upper or sedimentary part recedes to the east, under the name of the Yampai Cliffs. With the lower group of cliffs may be included the Aquarius and Artillery mountains, which form the southward extension of the Aquarius Cliffs.

A second group, consisting of the White Hills, Cerbat, and Hualpai mountains and the Aubrey Hills, forms a broken range parallel to the cliffs at the west. The White Hills and the Aubrey Hills are inconspicuous as topographic features, but the two central sections are prominent. The Hualpai Mountains attain a maximum altitude of 8,266 feet in Hualpai Peak, and the Cerbat Mountains an altitude of somewhat more than 7,000 feet in Cherums Peak.

A third group, lying still farther to the west, is commonly known as the Black Mountain Range, and consists of the Black Mountains proper, Black Mesa, and the Mohave Mountains. This range is relatively low, except at its northern end, but is continuous from Colorado River southward to Sacramento Wash, where it is broken down for a few miles before attaining prominence again in the Mohave Mountains.

The fourth group of mountains, situated south of Williams River, does not correspond with the other three groups in geographic position or in regularity of arrangement. In place of the parallel arrangement of north-south ridges just described, this group is made up of three large east-west ranges and three small north-south ranges. The Harcuvar and Harquahala mountains are about equal in altitude and are the loftiest and most massive mountains in central western Arizona. The other groups are less conspicuous, though the Buckskin Mountains are moderately prominent, particularly at their eastern extremity.

Valleys and plains.—Three distinct kinds of lowland occur: First, the valleys and canyons now containing running water, such as the Colorado and Williams valleys, including Big Sandy Wash and Santa Maria Canyon; second, old débris-filled valleys, such as the Detrital-Sacramento, Hualpai, and Big Sandy valleys; and third, plains eroded from hard rock or built up by flows of igneous rock, such as the Truxton Plateau. Extensive detrital plains, such as Cactus Plain, Ranegras Plain, etc., which occur south of Williams River, are probably débris-filled valleys similar to those farther north, but their character is not certainly known.

DESCRIPTIVE GEOLOGY.

ROCK FORMATIONS.

The rocks of western Arizona are mainly pre-Cambrian crystallines, Tertiary eruptives, and probably Quaternary sediments. Sedimentary formations of Paleozoic age occur only at the eastern margin of the area described. The igneous rocks are described by Albert Johannsen (see pp. 81–92), but many of the details upon which this general description is based may be found in the following sections.

PRE-CAMBRIAN.

The oldest rocks of the region consist mainly of granites and gneisses. (See p. 81.) Coarse-grained granitic rock giving little or no evidence of gneissoid structure is found in many places throughout northwestern Arizona. It occurs beneath the Cambrian sandstone at the base of the cliffs in the eastern part of the region, forms the central core of the Black Mountains, and constitutes the main mass of the Cerbat and Hualpai mountains. Gneiss occurs in many places, either in extensive masses, as at the southern end of the Hualpai Mountains and in the Aubrey Hills, or in restricted areas where local movements have taken place, as near Hualpai Wash, at the northern end of the region. At the mouth of the Grand Canyon the granite, which had obviously been exposed at the surface prior to the deposition of the Cambrian sediments, is prevailingly red to a depth of

200 feet or more. A similar coloring of both the granite and the gneiss was noted in Black and Boulder canyons and in several places south of Williams River.

Metamorphosed sediments, consisting of quartzites, argillites, and limestones, occur in several localities in northwestern Arizona. These were observed in Virgin Canyon at the northern end of the region, in Williams Canyon, and in the Granite Wash Hills in the vicinity of Harrisburg. They are highly metamorphosed, faulted, tilted, and more or less included as blocks within the granites and gneisses. They were nowhere observed in contact with the Cambrian, but on account of their high degree of metamorphism and their intimate association with granites which, in the cliffs region, lie beneath the Cambrian sandstone, are here regarded as probably pre-Cambrian rocks.

CAMBRIAN.

According to the various writers who have described the Grand Canyon region, Cambrian rocks occur in Grand Canyon and are identical in character with those in the cliffs in the eastern part of the area described. They consist of a coarse-grained basal quartzite 80 to 100 feet thick, overlain by about 600 feet of yellowish-green arenaceous shale. The quartzite and shale together comprise the greater part of the Tonto formation of the Grand Canyon section.

CARBONIFEROUS.

Resting with apparent conformity upon the Tonto formation is the Redwall limestone (the Devonian of Grand Canyon described by Walcott[a] was not identified in the cliffs), which is 1,000 feet or more in thickness where examined.[b] From Music Mountain southward this limestone is separated more or less distinctly into an upper and a lower division. The upper part is massive, with little tendency toward separation into layers even in weathered surfaces. The lower part, although consisting mainly of limestone, is made up of distinct layers, often separated by thin seams of clay.

In Truxton Canyon two small collections of fossils were obtained from the Redwall limestone. These were examined by G. H. Girty, of the Geological Survey, who reports the following lists.

At Yampai, near the top of the exposed section, the following were obtained:

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

[a] Walcott, C. D., Am. Jour. Sci., 3d ser., vol. 20, 1880, pp. 221-225.

[b] G. K. Gilbert's section at the mouth of Grand Canyon shows a thickness of 2,675 feet in the Redwall limestone.

These fossils, according to Girty, indicate a Pennsylvanian or "Coal Measures" age.

Lower in the section, near Nelson, Ariz., Mississippian forms were obtained as follows:

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

Girty states that this is the Eomississippian fauna, which has a wide range over the West, correlating with the lower "Wasatch"[a] limestone of Utah, the Madison limestone of Yellowstone Park, and the Chouteau limestone of Missouri.

The Redwall limestone has been described by Gilbert[b] as consisting of "Upper Carboniferous" above and "Lower Carboniferous" below, and King[c] makes a similar division of the "Wasatch" limestone in Utah. It is probable that in the area here described the line of separation between the Pennsylvanian and the Mississippian is to be drawn between the upper massive and the lower laminated divisions of the Redwall.

TERTIARY.

Eruptive rocks.—If sediments of Triassic, Jurassic, or Cretaceous age were deposited in western Arizona, they were removed previous to the opening of the Tertiary period. The Tertiary rocks are principally effusive andesites and rhyolites, which occur in isolated mountain masses and in broad sheets having a maximum thickness of 3,000 feet or more. The oldest effusive rock is the andesite of the northern end of Black Mesa. (See p. 27.) It is a dark-colored porphyritic rock lying above the granite and beneath the rhyolites and later andesites.

The older andesite is overlain by extensive beds of rhyolitic ash, tuff, and flows, which extend over a large part of western Arizona, and which were in turn followed by extrusions of andesite. The rhyolites and younger andesites are closely associated and must at present be described together. (See pp. 83–87.) They are conspicuously exposed in the Black Mesa, White Hills, Kingman Mesa, and Aquarius Mountains, but extend eastward beyond the area mapped, and farther south occur in extensive masses in the Chocolate and Dome Rock ranges.

Some of the older basalt sheets of the region may also belong to the Tertiary, but this is not definitely known. They cut the rhyolites and andesites in dikes and overlie them in sheets. East of Chloride they

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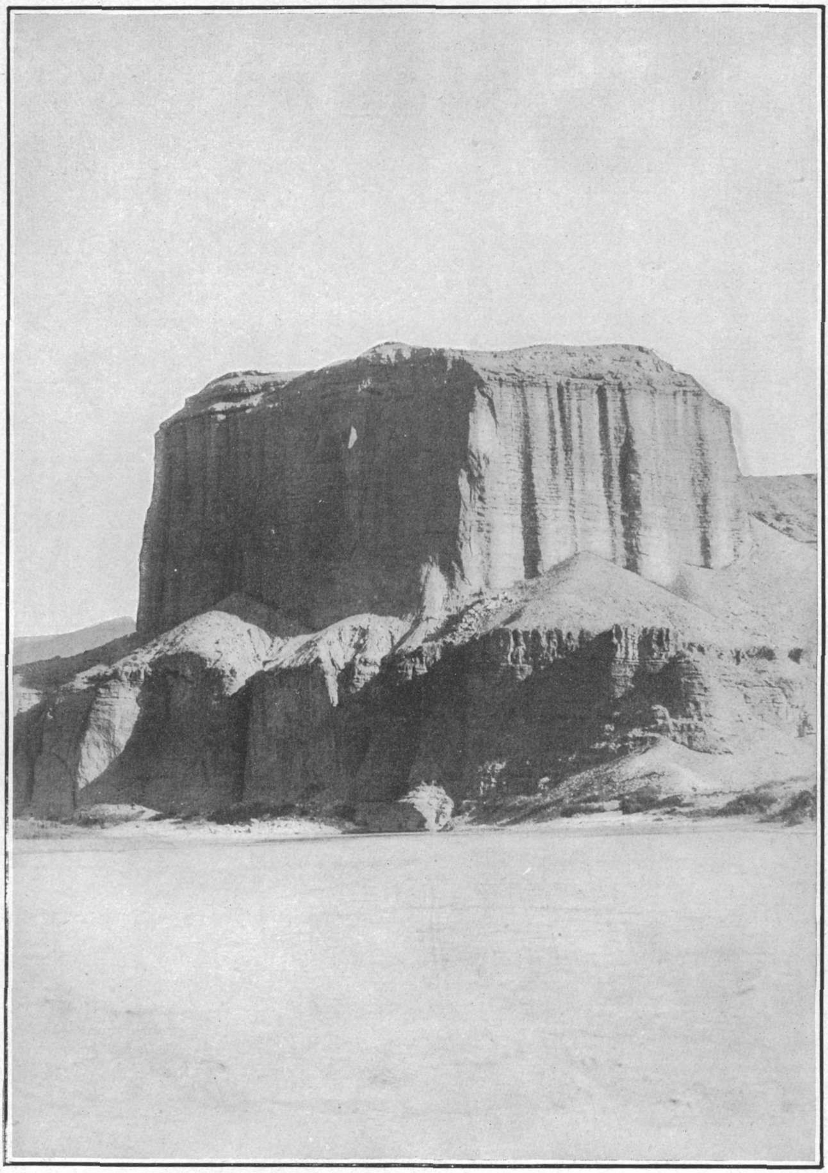
[a] Present usage of the Geological Survey restricts the name Wasatch to the Eocene formation. As soon as sufficient detailed work can be done, another name will be assigned to the Carboniferous formation.

[b] Gilbert, G. K., Final Rept. U. S. Geog. Surv. W. 100th Mer., vol. 3, 1875, pt. 1, p. 178.

[c] King, Clarence, Final Rept. U. S. Geol. Explor. 40th Par., vol. 1, p. 155.



TEMPLE BAR CONGLOMERATE AT TEMPLE BAR.

occur within the Detrital-Sacramento Valley, which was presumably excavated in late Tertiary time.

Greggs breccia.—The Greggs breccia, so called from Greggs Ferry, at the northern end of the region, is a name here given to a detrital formation filling the Grand Wash Trough and having an exposed thickness of about 1,400 feet. It is composed of coarse unassorted and poorly stratified material, consisting largely of blocks of crystalline rock, similar to the granite and gneiss of the Virgin Mountains to the west. Toward its top the detrital material is cemented with lime carbonate, and in places the upper 200 feet consists of travertine containing few rock fragments. This travertine is best exposed south of Colorado River and east of Greggs Ferry, where it caps conspicuous cliffs, which rise 1,400 feet or more above the river.

The formation contains no fossils, so far as observed, and its reference to the Tertiary is based largely on the physiographic evidence given in detail in the description of the Grand Wash Trough and later in the section on "Geologic history." Briefly stated, the accumulation of the breccia antedates the cutting of Grand Canyon, which apparently began either in the latter part of the Tertiary or at the beginning of the Quaternary.

QUATERNARY.

Temple Bar conglomerate.—Temple Bar conglomerate is a name here given to a sand and gravel formation having wide distribution in western Arizona. It occurs in the Colorado and other valleys of that region, filling the low places generally to an altitude of 3,000 feet or more. The conglomerate is typically exposed near the mouth of Virgin River at Temple Bar, from which it takes its name. At this point it consists of slightly consolidated sand and gravel exposed in nearly perpendicular cliffs (Pl. II), in which are included sheets of basalt.

Where exposed along the Colorado, the Temple Bar conglomerate is evidently a river deposit, but it merges laterally into deposits of angular mountain wash in some places, and possibly into lacustrine deposits in others. It rests unconformably upon the Greggs breccia and older formations, and is apparently equivalent in age to the widespread detrital accumulation filling the low places of the Southwest generally and forming the desert plains of Arizona and parts of southern California.

No fossils have been found in the conglomerate, and there are no means known at the present time by which it may be definitely correlated with other formations. In composition, geologic and physiographic relations, and general appearance it is similar to the Gila conglomerate described by Gilbert[a] from the Gila Valley; by Ransome[b] from the vicinity of Globe, Ariz.; by Lindgren[c] from eastern Arizona, and by the present writer[d] from the Salt River Valley in central Arizona. The greater part of the Temple Bar conglomerate, however, is not usually so well consolidated as the Gila conglomerate, although in places, especially where the older portions are exposed, it is as firmly cemented.

In constitution and general appearance the formation resembles the Lake Bonneville beds of Utah described by Gilbert[e] as Quaternary. The correlation, however, is based mainly on physiographic evidence, the discussion of which is included under "Geologic history," and, for the sake of clearness, is placed after the section on descriptive details.

Chemehuevis gravel.—Chemehuevis is here applied to a series of gravels that lie unconformably upon the Temple Bar conglomerate in the terraced bluffs along Colorado River from Grand Canyon to the Gulf. In the open valleys south of Black Canyon they form the conspicuous bluffs seen in characteristic development from Bulls Head southward. The name is derived from the Chemehuevis Valley, south of The Needles. The gravels are about 700 feet in maximum thickness, but occupy a measurably narrow belt along the river, having been deposited as valley filling during an aggrading stage of Colorado River. (See p. 65.) Their unconformable relations with the Temple Bar conglomerate and their unconsolidated condition render it probable that they are of late Quaternary age.

Basalt flows.—Included in the Temple Bar conglomerate in many places, and sometimes overlying that conglomerate, are sheets of basalt from a few feet to 800 feet in thickness, in some places occupying large areas. These are younger than the basalts which were described on page 16 as having perhaps been outpoured at the close of the Tertiary and which underlie the Temple Bar conglomerate.

GEOGRAPHIC AND GEOLOGIC DETAILS OF HIGHLANDS.

GRAND WASH CLIFFS.

Location.—The Grand Wash Cliffs, located in the northeastern part of the area described, form an escarpment extending from Music Mountain northward beyond Colorado River. They constitute the boundary between the High Plateau or Grand Canyon district to the east and the low-lying Basin region to the west.

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[a] Gilbert, G. K., U. S. Geog. Surv. W. 100th Mer., vol. 3, pt. 5, 1875, p. 540.

[b] Ransome, F. L., Geology of Globe copper district, Arizona: Prof. Paper U. S. Geol. Survey No. 12, 1903, pp. 47–51.

[c] Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Arizona: Prof. Paper U. S. Geol. Survey No. 43, 1905, pp. 75–77.

[d] Lee, W. T., Underground waters of the Salt River Valley, Arizona: Water-Supply Paper U. S. Geol. Survey No. 136, 1905, pp. 111–114.

[e] Gilbert, G. K., Lake Bonneville: Mon. U. S. Geol. Survey, vol. 1, 1890.

Topographic features.—The Grand Wash Cliffs are very precipitous, as shown in section *P-P′*, Pl. V, rising 4,000 feet or more above the plains to the west. The drainage of the plateau near the cliffs is northward to Colorado River, and the continuity of the westward-facing escarpment is broken by few canyons.

The lower or granitic portion of the cliffs, though not so nearly perpendicular as the upper or limestone portion, is steep, and the slopes meet the detrital surface of the Hualapai Valley at high angles. Numerous detrital cones have formed at the foot of the escarpment, but they are comparatively small. In a few places the cones join laterally, forming an alluvial slope, but in general the escarpment rises abruptly from the nearly level floor of the valley.

Rock masses.—At the mouth of Grand Canyon the cliffs are composed principally of Carboniferous limestone (Redwall) and Cambrian sandstone and shale (Tonto), with a little granite exposed at the base. In Music Mountain, at the southern end of the Grand Wash Cliffs, the same series occurs, but the granite is more extensively exposed, the base of the Tonto being about 4,000 feet higher than at the mouth of Grand Canyon.

The granite is coarse grained and is intersected by dikes and sheets of intrusive rocks which terminate abruptly at the contact between the granite and the overlying sandstone of the Tonto. This contact, as seen in the face of the escarpment, is a practically straight line and represents a base-leveled surface upon which the Cambrian sediments were deposited.

The sandstone at the base of the Tonto at the mouth of Grand Canyon is 80 feet thick and the overlying shale is about 600 feet thick. About 12 miles southwest of the mouth of the canyon, at the base of the tilted block through which Iceberg Canyon is cut, the sandstone is again 80 feet thick, but the overlying shale is only 200 feet. A few miles north of Music Mountain, in the pass occupied by the road from the Hualpai Valley to the plateau, the sandstone was found to be 50 feet thick and the overlying shale 300 to 400 feet thick.

The Devonian of the Grand Canyon region, described by Walcott,[a] was not identified by the writer in the Grand Wash Cliffs. The highest formation observed was the Redwall limestone, which forms the rim of the cliffs, and though more or less eroded, still has a thickness of 1,000 feet or more, according to locality.

COTTONWOOD AND AQUARIUS CLIFFS.

Location.—At Music Mountain the escarpment divides, the upper or sedimentary part receding toward the east and the lower or granitic part continuing southward under the names of the Cottonwood and the Aquarius cliffs. The Cottonwood Cliffs extend from Music

[a] Walcott, C. D., Am. Jour. Sci., 3d ser., vol. 20, 1880, p. 222.

Mountain to Trout Creek, and are best observed in Truxton Canyon, through which the Santa Fe Railway descends from the high plateau to the lowlands farther west. The Aquarius Cliffs extend from Trout Creek southward to the Aquarius Mountains.

Topographic features.—The Cottonwood and the Aquarius cliffs are lower and less precipitous than the Grand Wash Cliffs. Alluvial cones and slopes are developed to some extent at the base of the Cottonwood Cliffs north of Truxton Canyon, but from that canyon southward to Signal the Big Sandy flows close to the cliffs and prevents the formation of cones.

The continuity of the escarpment formed by these cliffs is interrupted in several places by canyons, chief among which are Truxton, White Cliff, Trout, and Sycamore creeks. The canyons are narrow and steep and the streams torrential in character.

Rock masses.—The Cottonwood Cliffs are composed principally of granite, 2,500 feet of which is exposed near Hackberry. The granite is covered by a comparatively thin sheet of andesite which forms the cap rock of the cliffs and thickens southward, connecting with the great masses of igneous rock in the Aquarius Mountains.

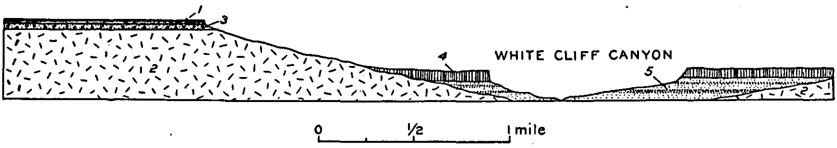


FIG. 1.—Sketch section across White Cliff Canyon, showing relation of the andesite of the Truxton Plateau to the younger basalt at the foot of the cliff. 1, Andesite flow; 2, granite; 3, andesite tuff; 4, basalt flow; 5, stratified volcanic ash.

In White Cliff Canyon the plateau is covered by andesite 200 feet thick, the lower half consisting of tuff and the upper half of a columnar flow. Near the mouth of the canyon a younger mass of volcanic rock occurs in an erosion embayment about 1,200 feet lower than the lava capping the cliffs. The younger mass is basalt and consists of several layers of ash, tuff, and flow. (See fig. 1.)

YAMPAI CLIFFS.

Location.—A series of irregular cliffs extends from Music Mountain in a general southeasterly direction to the southern end of the Juniper Mountains, where they turn northward, forming the western bluffs of the Chino Valley, which lies directly east of the area here described. These are locally known as the Yampai Cliffs.

Topographic features.—The Yampai Cliffs resemble the Grand Wash Cliffs in being precipitous and composed of hard limestone strata, but differ from them in being much more irregular in outline. They vary in altitude from about 6,000 to 6,700 feet and rise 1,000 or more feet above the Truxton Plateau. In their sinuous outlines, large reentrant angles, and detached outlying portions Yampai

Cliffs exhibit the characteristic features of an erosion escarpment, the steep face being maintained by the hard Redwall limestone at the top.

Rock masses.—Pre-Cambrian granite occurs in the base of the cliffs. It was observed by the writer in four localities—at Music Mountain, in Truxton Canyon, near Cross Mountain, and at the southern end of the Juniper Mountains. As in the Grand Wash Cliffs, it terminates above in a base-leveled plain, upon which the Cambrian sediments rest.

The Cambrian rocks described continue uninterruptedly southward from the Grand Wash Cliffs, the basal sandstone being about 100 feet and the shale about 225 feet thick at the southern end of the Juniper Mountains.

The Redwall limestone continues southward as the highest formation of the cliffs, and on account of its superior hardness maintains the precipitous face. It thins southward, probably owing to erosion, until at the southern end of the Juniper Mountains it is only 450 feet thick.

The section near Nelson, in Truxton Canyon, yielded the fossils previously described, showing that the Redwall limestone is partly of Mississippian and partly of Pennsylvanian age. Although examined with considerable care, no fossils were found in the limestone at the southern end of the Juniper Mountains.

TRUXTON PLATEAU.

Location.—Lying between the Yampai Cliffs on the east and the Cottonwood and Aquarius cliffs on the west, is a comparatively level plain extending from Music Mountain southward to the Aquarius Mountains. The writer crossed it in two places near the northern end, as shown by the routes of travel delineated on Pl. I. In the vicinity of Truxton Canyon it is locally known as the Truxton Plateau, and this name may be used to designate the entire area.

Topographic features.—The plateau, which lies about 5,000 feet above sea level, consists of eroded granite, nearly covered with eruptive rock, which fills the depressions, leaving the higher granite points exposed above the lava. In other words, the Truxton Plateau is a lava-covered peneplain which has been slightly dissected by a few streams that have cut narrow canyons. Back from the edge of the plateau these are shallow, but they deepen rapidly as they near the cliffs to the west, a fact indicative of comparatively recent uplift.

Rock masses.—The rocks of the plateau are pre-Cambrian granites overlain by Tertiary rhyolite and andesite, together with basalt of more recent origin. The plateau was not visited south of Trout Creek, but, seen from a distance, the igneous rock apparently extends continuously southward to the great masses of rhyolite and andesite of the Aquarius Mountains.

AQUARIUS MOUNTAINS.

Location.—The Aquarius Mountains, located in the east-central part of the region, form a group of considerable size at the southern end of the Truxton Plateau, and extend in a southeasterly direction across the course of Rio Santa Maria and Date Creek.

Topographic features.—South of the mouth of Deluge Wash the Aquarius Cliffs gradually lose their scarplike character and finally merge into the general westward slope of the Aquarius Mountains. These mountains were visited only at their southern and western extremities, but from the west at a distance they appear as lofty mountains, comparable in altitude with the Hualpai Mountains to the west, and the Harcuvar and Harquahala mountains to the south.

The southern part of the group is carved into rugged, irregular hills. Rio Santa Maria has eroded a narrow canyon deep into the lavas, and smaller streams have cut less deeply. Date Creek has cut through the end of the ridge, instead of following an apparently easy course a few miles farther south.

Rock masses.—The granite of the Truxton Plateau extends southward to the Aquarius Mountains, and was examined in Signal Canyon. The southern part of the group, however, is composed of andesites and rhyolites, presumably of Tertiary age. South of Santa Maria Canyon the mountains, 3,000 to 4,000 feet high, are composed of effusive rock, which has been dissected by erosion to a depth of about 3,000 feet.

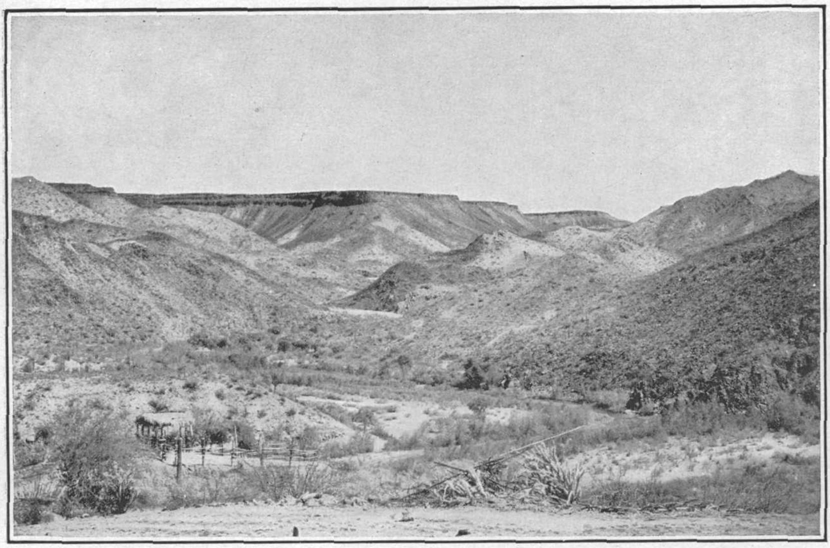
Within valleys eroded in the Tertiary lavas small sheets of basalt occur, in some places capping gravels of probable Quaternary age, as in Signal Canyon (Pl. III, *A*), and in other places occurring within these gravels, as in Santa Maria Canyon near the mouth of Big Sandy Wash.

ARTILLERY MOUNTAINS.

Location.—The Artillery Mountains form a small group near the head of Williams River. They are separated from the Aquarius Mountains by Signal Canyon only, and are virtually an outlying group of those mountains.

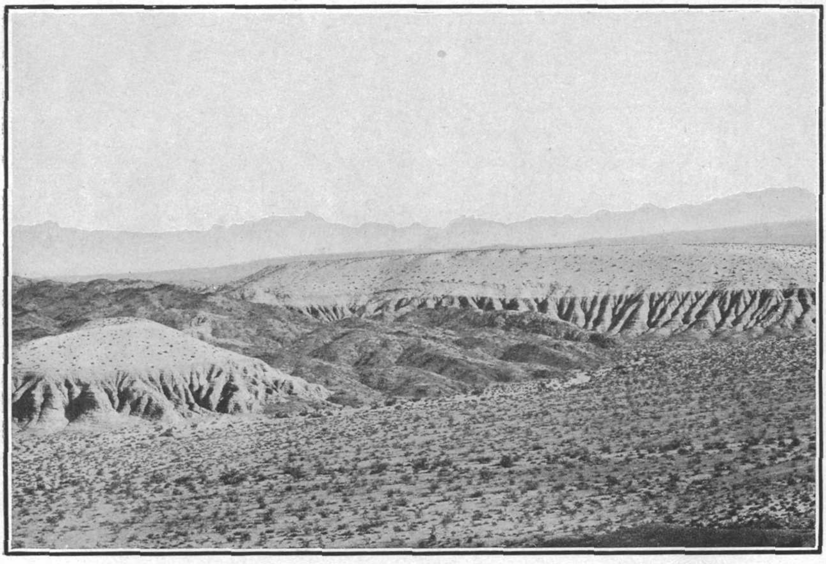
Topographic features.—The Artillery Mountains are small and comparatively low, the only conspicuous peak being a sharp pinnacle of igneous rock, apparently a volcanic neck, which, on account of its altitude and pointed summit, is visible and easily identifiable from great distances. The rocks are deeply dissected by erosion on the east and south near Big Sandy and Williams rivers, but to the north and west the mountain flanks are buried by the detritus of the Big Sandy Valley.

Rock masses.—The main rock mass of the Artillery Mountains is coarse-grained granite, mineralized in places, although the mineral



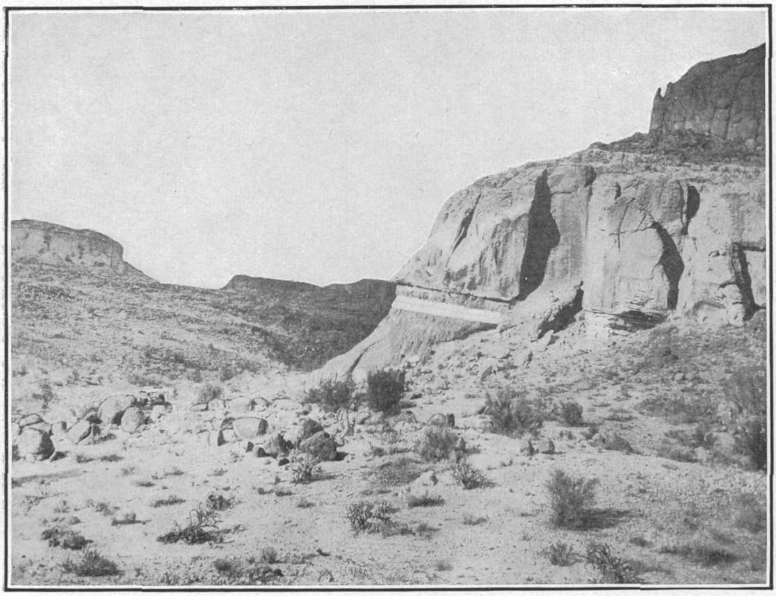
A. SIGNAL CANYON, AQUARIUS MOUNTAINS.

Showing lava-capped gravel and sand filling.

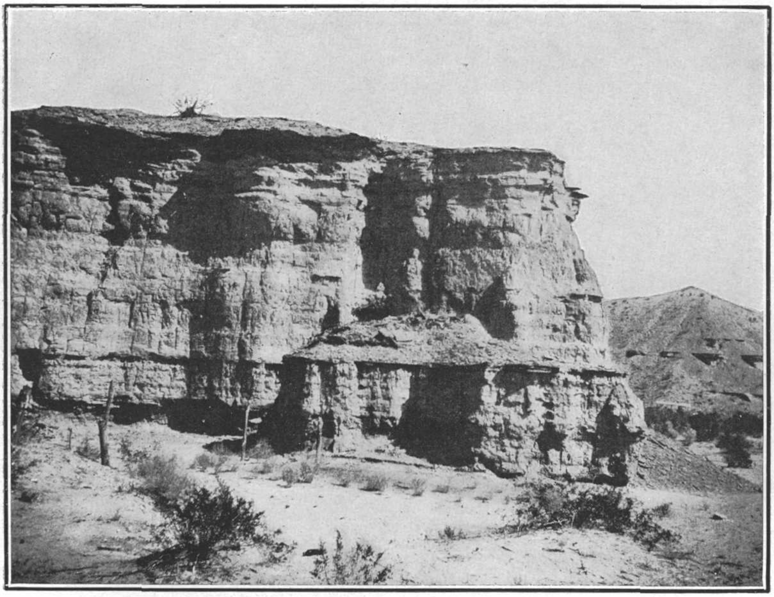


B. CHEMEHUEVIS GRAVEL NEAR BULLS HEAD.

Overlying granite at left. Showing upper and lower divisions of gravel.



A. RHYOLITIC ASH NEAR KINGMAN.



B. DETRITUS AT MOUTH OF DELUGE WASH.

prospects have not been extensively developed owing to the inaccessibility of the region.

Overlying the granite south of Artillery Peak occur thick masses of effusive rock similar in appearance to the older effusives of the Aquarius Mountains to the east, but separated from them by erosion. Quaternary lavas also occur in small quantities included in and overlying the gravels in Signal and Williams canyons.

WHITE HILLS.

Location.—The White Hills, located in the north-central part of the region described, are the southward continuation of the Virgin Mountains of southeastern Nevada, and are separated from them by Virgin Canyon.

Topographic features.—The White Hills consist of many more or less isolated peaks and groups of hills rising a few hundred feet above the plains on either side of them, and are inconspicuous as compared with neighboring highlands.

Rock masses.—Granite similar in general appearance to that beneath the Cambrian formation of the Grand Wash Cliffs occurs in these hills, and is more or less mineralized, several gold prospects having been developed in it. Quartzites and argillites, apparently of pre-Cambrian age, occur in the hills south of Virgin Canyon. The Tertiary rhyolites and andesites are found from Squaw Peak to the southern end of the White Hills, and occur as light-colored beds of tuff and ash and as flow sheets.

CERBAT MOUNTAINS.

Location.—The Cerbat Mountain range, about 30 miles long, lies south of the White Hills, between the Hualpai and the Detrital-Sacramento valleys.

Topographic features.—The mountains are high, attaining a maximum altitude of about 7,000 feet in Cherums Peak, and have been deeply eroded. At the southern end of the range they break down and merge into a dissected plateau.

Rock masses.—The Cerbat Mountains are composed mainly of granitic rock similar in general appearance to the pre-Cambrian granites of the cliffs region to the east. These are intersected and more or less completely surrounded by effusive rocks.

Along the western base of the range rhyolite and andesite occur at intervals, but are frequently eroded away or covered with wash. Near the southern end of the mountains they overlie the granite in extensive beds of ash, tuff, and flow, originally 1,000 feet or more in thickness. The igneous rocks are evidently due to a long series of eruptions, flows, and beds of tuff alternating (see Pl. IV, *A*), and both being cut by dikes and covered by younger effusives.

These effusives are megascopically and microscopally the same as the rhyolites and younger andesites of Black Mesa to the west, and form a part of the lava sheet supposed to have once extended continuously across the Detrital-Sacramento Valley. At the northern end of the range sheets of olivine basalt occur at the crest of the ridge, tilted eastward. (See section Q-Q′, Pl. V.) In several places along the eastern base similar sheets occur, dipping steeply to the east and passing beneath the detrital filling of the Hualpai Valley.

Structure.—The eastward inclination of the lava sheets along the eastern base of the Cerbat Mountains suggests an eastward tilting of the surface similar to that shown in Iceberg Canyon to the north and in the Hualpai Mountains to the south (fig. 2).

HUALPAI MOUNTAINS.

Location.—The Hualpai Mountains are situated between the Sacramento Valley on the west and the Big Sandy Valley on the east, in the central part of the area described.

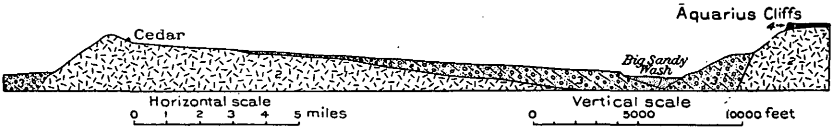
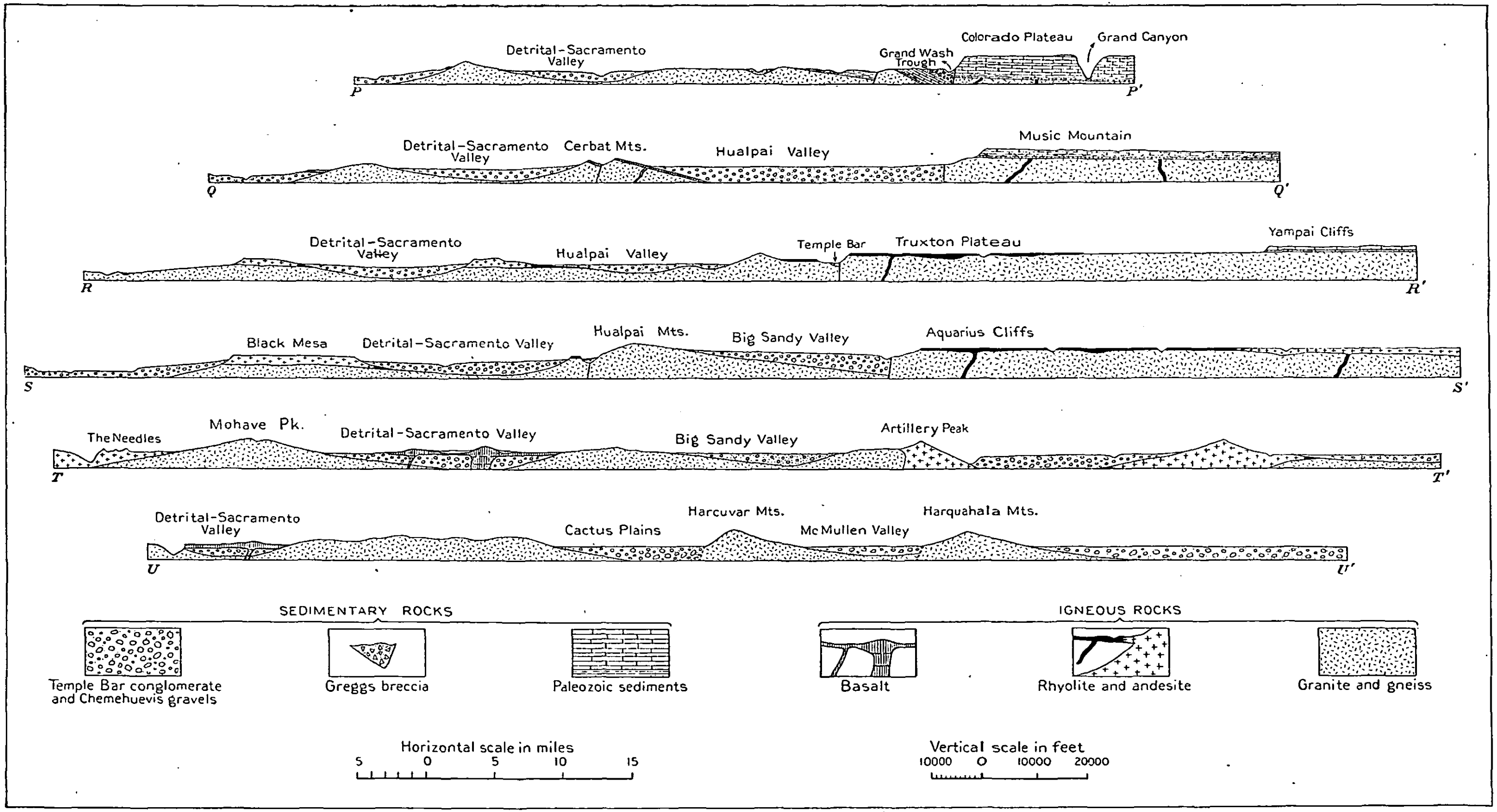


FIG. 2.—East-west section across Big Sandy Valley, showing the tilted Hualpai block and the unconsolidated gravel beds inclined toward the face of the Aquarius Cliffs. 1, Chemehuevis (?) gravel; 2, granite; 3, Temple Bar (?) conglomerate; 4, andesite.

Topographic features.—The range is about 35 miles long, with a general altitude of about 7,000 feet and a maximum altitude of 8,266 feet, attained in Hualpai Peak. The western slope is very precipitous down to an altitude of about 3,000 feet, where it meets the detrital plain of the Sacramento Valley at high angles. Along its base occur small flat-topped lava-covered hills, rising a few hundred feet above the surrounding plain. These are most numerous at the north, near the lava fields of the Kingman area, but extend southward nearly to the southern end of the range. Detrital material has accumulated in alluvial fans and slopes to some extent, but in general the steep mountain face meets the plain at high angles.

The eastern slope of the mountains is not so precipitous as the western. At altitudes of nearly 6,000 feet the crystalline rocks begin to disappear beneath a corrugated detrital slope of comparatively low gradient, which extends eastward to Big Sandy Wash, a distance of 10 to 15 miles. In this distance the descent is about the same as that attained in the western slope in a much less distance. (See fig. 2.)

At the southern end of the range the mountains cease rather abruptly, giving place to low isolated hills separated by broad passes occupied by the detrital accumulation of the plains. To the east are several comparatively small spurs and detached mountain groups, such as Owens Peak, Peacock Mountains, etc.



GEOLOGIC SECTIONS. FOR LOCATION SEE PL. I.

Rock masses.—The Hualpai Mountains, so far as observed, are composed mainly of coarse-grained granitic rock, becoming gneissoid at the southern end of the range. They are highly mineralized in places, and dikes and quartz veins are numerous. At Cedar, near the summit of the range, mining operations have been successfully carried on for a number of years. The lavas capping the foothills to the west are outlying portions of rhyolites and andesites of the Kingman area (see p. 16), and the small masses in the Peacock Mountains are probably parts of the lavas covering the Truxton Plateau that have been let down to their present position by faulting. The detrital material of the eastern slope is part of the detrital accumulation described under the caption "Big Sandy Valley."

Structure.—The Hualpai Range was apparently formed by the upheaval and tilting eastward of a large crust block, the movement taking place along faults west of the range and at the Cottonwood and Aquarius cliffs. The evidence of block tilting in addition to that given of faulting along the cliffs rests on the steep, scarplike western face of the range, the high angles at which the mountain slope meets the surface of the Sacramento Valley, and the gently inclined débris slope of the eastern face.

AUBREY HILLS.

Location.—South of the Hualpai Mountains and lying between the Sacramento and Big Sandy valleys is a small group known as Aubrey Hills.

Topographic features.—The Aubrey Hills are low, rising but a few hundred feet above the plains on either side. They are separated from the Hualpai Mountains by a low débris-filled pass connecting the Big Sandy and the Sacramento valleys, and from the Buckskin Mountains by Williams Canyon.

Rock masses.—The rock at the northern end of the hills is granitic gneiss. In Williams Canyon occurs similar gneiss overlain by quartzite, argillite, and black metamorphic limestone. From a distance sheets of effusive rock were noted east of the hills, and dark-colored lava, probably basalt, was seen on their western flanks.

BLACK MOUNTAINS.

Location.—The Black Mountains, located in the extreme western part of Arizona, extend from the northern border of the Territory southward to Union Pass.

Topographic features.—The mountains are formed of three more or less distinct groups. The northernmost group, extending from Boulder Canyon southward to Eldorado Pass, a distance of about 15 miles, attains a maximum altitude of about 5,500 feet in Mount Wilson. From this peak the altitude diminishes northward to about

3,000 feet at Boulder Canyon, and southward to about 2,000 feet at Eldorado Pass.

Mount Perkins, 5,500 feet high, is the center of the second group, which consists of a north-south ridge about 30 miles long. The third or southernmost group, about 4,500 feet in maximum altitude, consists of many small irregular hills extending eastward for a considerable distance into the Detrital-Sacramento Valley. The three groups form a continuous range, the apparent separation being due to accumulation of detritus, which fills the old valleys and covers the low-lying passes.

Rock masses.—The core of the Black Mountains consists of granitic rock. In Boulder Canyon coarse-grained crystalline rock occurs, as described by Gilbert,[a] overlain on either side by gneiss. In Pyramid Canyon, farther to the south, and in the hills east of this canyon the rock is granitic gneiss.

The older crystalline rocks of the range are overlain by extensive masses of effusive rock representing several periods of eruption. The oldest of the effusives, the andesite of the Gold Roads region, was not observed in Black and Boulder canyons, but in many places rhyolites and light-colored andesite similar to those overlying the dark-colored andesite of Gold Roads (see p. 27), rest upon the granites and gneisses. These are especially prominent in Black Canyon, where they are many hundreds of feet thick. They were observed near the river at the head of the Cottonwood Valley (section *K*, fig. 6), at the head of Pyramid Canyon, and at many places in the Black Mountains up to an altitude of 3,000 feet or more.

The next younger effusive rocks of the Black Mountains are basalts. They occur in dikes cutting the older rocks and in sheets overlying the rhyolites and younger andesites. North of Union Pass they were outpoured in the Detrital-Sacramento Valley, which had previously been eroded through the rhyolites and younger andesites.

BLACK MESA.

Location.—Black Mesa, about 35 miles long and 5 miles or more in width, is situated between the Colorado and the Sacramento valleys, in the central western part of the area described.

Topographic features.—The mesa is a remnant of a once extensive plateau having a general altitude of about 4,000 feet and a maximum at Mount Nutt of about 5,000 feet. A large part of the plateau has been eroded away and the remaining part deeply dissected by erosion. The bordering cliffs, although deeply incised, form a comparatively regular escarpment at the eastern margin of the mesa, rising 1,000 feet or more above the floor of the Sacramento Valley. The western margin is much more irregular owing to the greater erosion caused by

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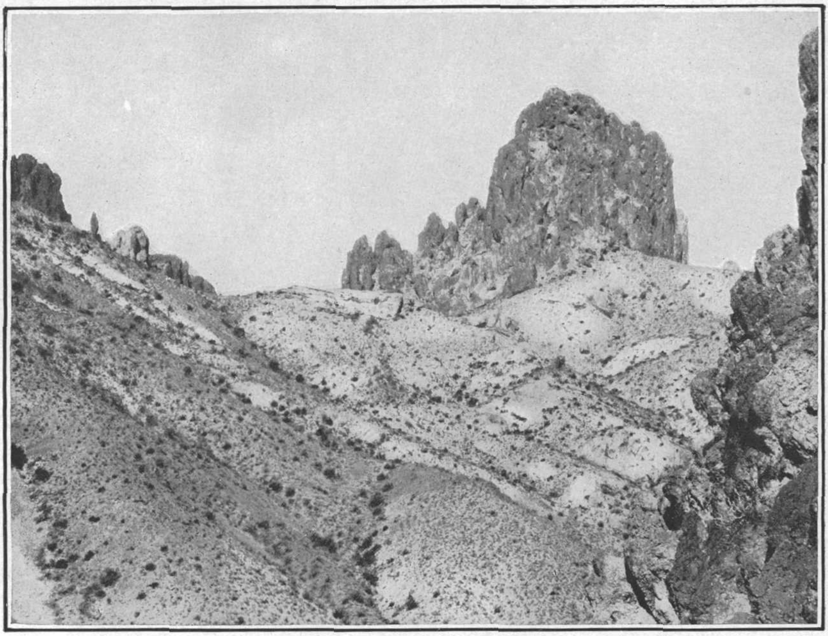
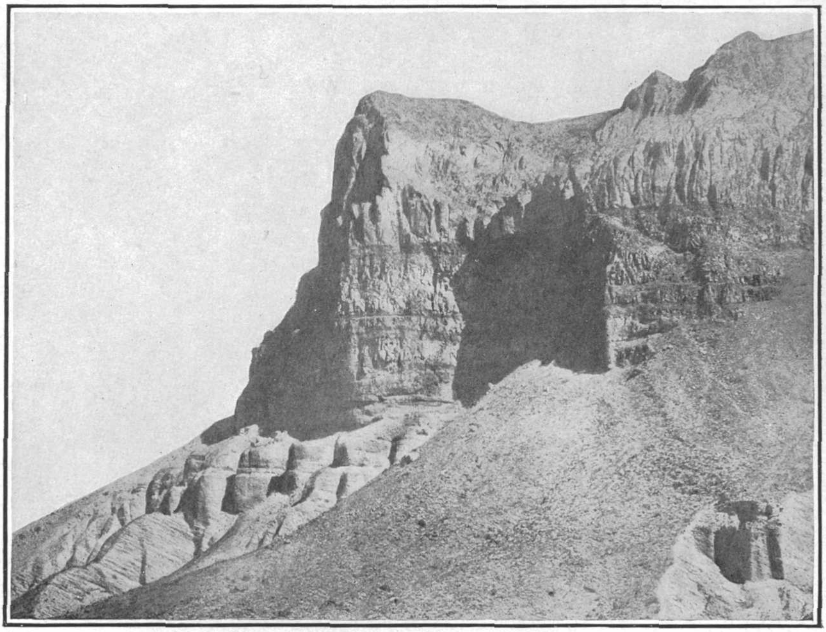
[a] Gilbert, G. K., Final Rept. U. S. Geol. Surv. W. 100th Mer., vol. 3, 1875, pt. 2, p. 35.



A. CASTLE-LIKE EROSIONAL FORMS IN BLACK MESA AT UNION PASS.



B. BASALT-CAPPED GRAVELS IN WILLIAMS CANYON.

the downcutting of Colorado River. On this side are many more or less isolated outlying remnants of erosion, well shown on The Needles special map of the United States Geological Survey, which includes a small part of the southern end of Black Mesa (there called Ute Mountains). The most conspicuous of these outlying masses is Boundary Cone, 3,429 feet high—a sharp pinnacle rising 2,500 feet above the graded detrital slope which stretches from its base westward to Colorado River.

The rock of Black Mesa varies greatly in hardness, and erosion has carved out a great variety of topographic forms. In places where the mesa is composed of moderately uniform layers it is bordered by prominent cliffs of regular outline 1,000 feet or more in height. Where the rock varies in hardness within short distances, as at Union Pass, it is eroded into a great variety of castellated forms. (See Pl. VI, *A*.)

Rock masses.—The granite forming the core of the Black Mountains extends southward underneath Black Mesa, but it is exposed in few places, the mesa to a depth of 2,000 to 3,000 feet being composed mainly of effusive rocks. Granite porphyry was found at the base of Boundary Cone at the western edge of the mesa, and dark-colored andesite at the base of the cliffs at the northeastern extremity; the latter is best exposed in the vicinity of Gold Roads mining camp. The andesite rests upon the granite and is apparently overlain by rhyolite. Wherever observed, however, Black Mesa is composed mainly of rhyolitic tuff, breccia, and flow. The rhyolite is in turn cut by dikes of olivine diabase and overlain to some extent by sheets of basalt.

The granite underlying the rhyolite is penetrated by the well at Yucca and exposed at the base of the hills extending eastward into the Detrital-Sacramento Valley at the northern end of Black Mesa. The thickness of the effusive rock as determined at these points is about 3,000 feet.

MOHAVE MOUNTAINS.

Location.—The Mohave Mountains are located south of Black Mesa, between the Colorado and the Sacramento valleys. They consist of a massive central group, with a spur, known as The Needles, extending westward to Colorado River, and low unnamed hills extending southward to Williams River.

Topographic features.—The central group is subcircular in outline and about 5,000 feet high. It is deeply scored by erosion, and is apparently the remnant of a once much more extensive mountain mass.

The Needles are irregular pinnacles resulting from the erosion of the mass of effusive rock which formerly extended across Colorado River and was later dissected by that river in cutting its present canyon. The unnamed hills north and south of the central mass are remnants of erosion, now separated from the main peak by débris-covered passes.

Rock masses.—With the exception of The Needles, the rocks of the Mohave Mountains, so far as observed, are granite, gneiss, and later intrusives. The crystallines have been greatly fractured and faulted and contain many dikes and veins. The extrusive rock of The Needles overlies the crystalline complex on the eroded flanks of the Mohave Mountains, and is exposed in the canyon down to the river level. The thickness of the effusive rock as measured from the river bed to the summits of The Needles is about 2,000 feet.

HARCUVAR AND HARQUAHALA MOUNTAINS.

Location.—The Harcuvar and Harquahala mountains are located in the southern part of the area described, and extend from the eastern border of this area about 50 miles in a general southwesterly direction. They resemble each other in many ways and may be described together.

Topographic features.—The axes of these mountains lie in a direction practically at right angles to those of the other ranges of the region. Next to the Hualpai Mountains they are the loftiest in central western Arizona.

Both ranges are narrow, with precipitous slopes rising abruptly to altitudes of several thousand feet above the graded plain which surrounds them. The main range of the Harcuvar Mountains is broken at Cunningham Pass, and at either end the ranges break up into isolated hills. At the west end of these mountains a group known as the Granite Wash Hills exhibits a tendency to return to the north-south trend characteristic of the other ranges of western Arizona.

Rock masses.—The rocks were observed only in Cunningham Pass in the Harcuvar Mountains and near Harrisburg in the Harquahala Mountains, where they consist of a crystalline complex underlying and to some extent including masses of quartzite, argillite, and metamorphic limestone. A few miles south of Harrisburg, where these sediments were examined most closely, the strata stand nearly vertical.

BUCKSKIN MOUNTAINS.

Location.—The Buckskin Mountains, lying immediately south of Williams River, are virtually the southward continuation of the Aubrey Hills, being separated from them only by the narrow gorge cut by Williams River.

Topographic features.—The Buckskin Mountains are lofty at their eastern extremity, with a precipitous slope facing southward. The group is greatly eroded, the peaks being separated by comparatively low passes. The western part is composed of irregular hills formed by the dissection of a plateau of igneous rock, the general surface of which has an altitude of about 2,400 feet. The topographic features of the basalt-covered plateau near the mouth of Williams River are especially conspicuous (Pl. VI, *B*). The basalt of the surface is very resistant, and the underlying sand and gravel (see p. 54) is easily eroded, resulting in the formation of precipitous cliffs nearly 2,000 feet high.

Rock masses.—The rocks of the Buckskin Mountains consist of biotite granite, granitic gneiss and schist, metamorphic sediments, and effusive rocks. The gneisses and schists are conspicuously exposed in Williams Canyon, where they are horizontally laminated and fissile, suggesting the name Banded Canyon, by which Williams Canyon is locally known.

The crystalline rocks are overlain by quartzites, slates, and black metamorphic limestones. These are faulted and intersected by intrusive rocks, and contain deposits of copper and iron ore. A bed of hematite about 150 feet thick was observed near Planet.

PALOMAS AND DOME ROCK RANGES.

Location.—The Palomas and Dome Rock Mountains, in the southwestern part of the region, were not visited by the writer. Their form and location are taken from the railway-location map made by the Santa Fe engineers in locating the Arizona and California Railroad, furnished for this bulletin by the chief engineer, W. A. Drake. Little is definitely known of their topographic features or rock masses.

GEOGRAPHIC AND GEOLOGIC DETAILS OF VALLEYS.

COLORADO VALLEY.

GENERAL STATEMENT.

Colorado River was traversed by boat from the mouth of Grand Canyon southward to Yuma, a distance of about 325 miles. Throughout this course the rocks in which the valley is eroded are well exposed and geologic features of great variety are well exhibited. For convenience of description the valley is divided into sections, the important features being taken up in order from the mouth of the Grand Canyon downstream. Several diagrammatic sections across the valley are included with the descriptions in order to illustrate relations not adequately shown in the more generalized sections on Pl. V.

In the published accounts of Major Powell's explorations of the Colorado little is said of the river west of the mouth of Grand Canyon.

The current is swift as far south as the mouth of Black Canyon, the fall being about 400 feet, or about 5 feet to the mile. There are several rapids of considerable size, formed by bowlders washed into the river from tributary canyons. The largest of these are: (a) Near Pierce Ferry in the Grand Wash Trough, caused by bowlders from the Greggs breccia entering from the south; (b) at the mouth of Grand Wash, caused by bowlders from this wash; (c) 3 miles east of the Nevada-Arizona boundary, caused by bowlders from a small wash entering from the north; (d) Red Granite Rapids, 3 miles west of the Nevada-Arizona boundary, at which point there is a long bowlder strainer[a] on the Arizona side which deflects the river sharply against the red granite on the Nevada side; (e) Hualpai Rapids, formed by the bowlders from Hualpai Wash; (f) Reverse Rapids, in Boulder Canyon; (g) Roaring Rapids, in Black Canyon.

MOUTH OF GRAND CANYON.

Colorado River emerges from the Plateau region about 7 miles east of the Nevada-Arizona boundary. The Grand Wash Cliffs, which form the western border of the plateau, rise to an altitude of about 4,500 feet, or 3,500 feet above the river. A few miles north of the rim of the canyon Shiwitz Plateau rises to an altitude of about 6,300 feet.

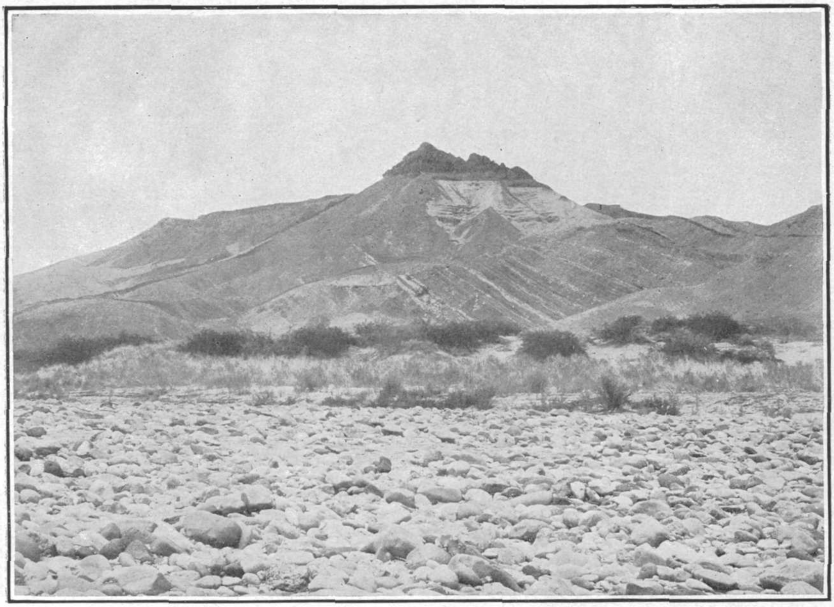
Grand Canyon is very narrow at its mouth (Pl. VII, *B*), and nearly perpendicular walls of Redwall limestone, sandstone and shale of the Tonto formation, and granite (see pp. 14–15) rise from the water's edge on either side. Springs emerge from these formations in many places and deposit carbonate of lime. The lower portion of the canyon walls is covered in many places with calcareous tufa and pendants of travertine. In some places the travertine projects irregularly, inclosing picturesque cavern-like chambers; in other places it forms basins built out into the river.

Massive beds of travertine were observed on both sides of the canyon at an elevation of 500 feet or more above the river. These may have been built out from the canyon sides by springs and later partly eroded away, but their horizontal bedding and location on opposite sides of the canyon at about the same altitude (see section *A*, fig. 3) indicate that they are probably remnants of a mass which formerly filled the canyon to a depth of several hundred feet. They are probably part of an extensive travertine formation having its greatest development near Hualpai Wash.

GRAND WASH TROUGH.

The Grand Wash Trough, lying between the Grand Wash Cliffs and Iceberg Canyon, is a depression formed by faulting and by the tilting

[a] "Strainer" is a term used locally to designate an accumulation of bowlders forming a porous dam in the river, through which the water finds its way as through a strainer.



A. NORTH WALL OF CANYON IN GRAND WASH TROUGH.

B. MOUTH OF GRAND CANYON.

of a large crust block. It derives its name from Grand Wash, which here enters the Colorado from the north. Its western limb consists of strata of the tilted block, and its eastern limb is the fault scarp of the Grand Wash Cliffs.

Not only are all the rock formations composing the Grand Wash Cliffs found in the tilted block in Iceberg Canyon, but strata younger than those in the cliffs are also present and pass beneath the river level with an eastward dip of 60° to 80°. Making no allowance for dip and considering only the altitude of corresponding strata in the walls of Grand Canyon and in Iceberg Canyon, the downthrow at the Grand Wash fault is about 5,000 feet. The strata of the block pass beneath the river level several miles west of the fault line. If the downthrow be computed from the dip of the strata and the distance from the fault line at which they pass beneath the river, the displacement at Grand Wash fault appears to be several times greater than the 5,000 feet in evidence at the surface.

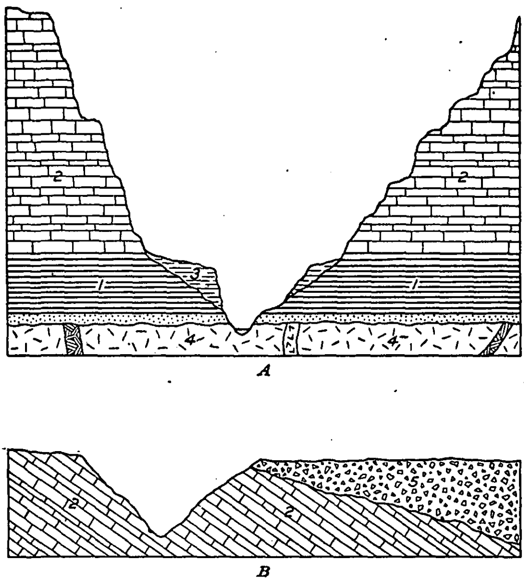


FIG. 3.—Diagrammatic sections across Colorado River. *A*, At mouth of Grand Canyon; *B*, in Iceberg Canyon. 1, Cambrian; 2, Redwall limestone; 3, travertine; 4, granite; 5, Greggs breccia.

The magnitude of the Grand Wash fault has long been recognized. Gilbert[a] states that the most profound dislocation of the plateau region has occurred at this fault, and Dutton,[b] in describing it, writes that "the plateau had its origin in a great fault along the crest of which the country east of it has been hoisted several thousand feet above the country on the west." Again he writes "It [the Grand Wash Cliffs] is a feature of the highest importance, since it is the boundary not only of the Grand Canyon district, but of the Plateau province itself. It drops the country on the west about 6,000 feet at a maximum." Huntington and Goldthwaite[c] have recently shown that the fault is traceable northward to

[a] Gilbert, G. K., Final Repts. U. S. Geog. Survey W. 100th Mer., 1873, pt. 1, p. 54.

[b] Dutton, C. E., Tertiary history of the Grand Canyon district: Mon. U. S. Geol. Survey, vol. 2, 1882, pp. 12, 19.

[c] Huntington, Ellsworth, and Goldthwaite, J. W., The Hurricane fault in the Toquerville district, Utah: Bull. Mus. Comp. Zoöl. Harvard Coll., vol. 42, 1904.

the vicinity of Toquerville, Utah, a distance of about 80 miles, where it joins the Hurricane fault. The present writer traced it southward into the Hualpai Valley, where it apparently forks, the western branch reappearing west of the Hualpai Mountains and the eastern one following the cliffs.

The Grand Wash Trough is filled with Greggs breccia to an altitude of about 2,500 feet, or 1,500 feet above the river. Where the breccia was examined most carefully, in the bluffs south of the river about 4 miles east of Greggs Ferry, it was found to be composed of unassorted and poorly stratified débris consisting of angular rock fragments, principally granite, the largest having a diameter of 10 feet or more. Toward the top the fragments were cemented by carbonate of lime into a very resistant mass, forming the cap rock of certain conspicuous cliffs east of Greggs Ferry. The upper 100 feet or more of this capping stratum is travertine and is nearly devoid of rock fragments. Farther south the surface consists of the truncated edges of the upturned limestone block. (See section *P-P′*, Pl. V.)

The breccia of the Grand Wash Trough has been much more eroded north of the river than south of it. The breccia was not examined far from the river, but, judging from the size and character of the bowlders brought down by the washes, it is probable that the material in the midst of the trough does not differ greatly from that described from the cliffs at its western edge near Greggs Ferry.

The Temple Bar conglomerate also occurs in the Grand Wash Trough, appearing in many places at altitudes several hundred feet higher than the river, in depressions previously eroded in the older rocks. It is composed of sand and waterworn pebbles of quartzite, limestone, marble, etc., not distinguishable at the present time from the gravels derived from Grand Canyon. These are in places cemented by carbonate of lime into very resistant masses, forming nearly perpendicular cliffs 500 feet high. The travertine deposits just described within the canyon were probably formed at the same time.

The Temple Bar conglomerate of the Grand Wash Trough contains a thick sheet of basalt. The lava appears in the face of a cliff in Iceberg Canyon in the midst of the conglomerate, and in the Grand Wash Trough as a columnar sheet overlying the conglomerate. The relation of the Temple Bar conglomerate to the underlying sedimentary formations of the tilted block and to the overlying sheet of basalt is shown in Pl. VII, *A*.

The Greggs breccia, where exposed near the river within the Grand Wash Trough, is roughly stratified, and the strata are tilted eastward, the maximum dip observed being about 30°. The Temple Bar conglomerate is also locally disturbed, dips of 10° eastward being observed in places. At the base of the Grand Wash Cliffs the detrital material ends abruptly against the sedimentaries at the fault line, and is locally disturbed by movements apparently of recent date.

The somewhat complicated relations in the Grand Wash Trough may perhaps be made clearer by a brief statement of the events in the order of their occurrence. The formation of the Grand Wash fault and the tilting of the crust block were followed by a long period of erosion and deposition, which filled the trough with débris and planed off the upturned edge of the block, bringing the surface to a graded condition. The Colorado Plateau to the east was apparently at the level of this graded plain. Then followed a second period of faulting, in which great displacements occurred at the Grand Wash fault and minor displacements at several smaller faults to the west, accompanied by further tilting of the crust block and the elevation of the Colorado Plateau. This uplift of the plateau resulted in the inauguration of Grand Canyon, the river cutting directly across the Grand Wash Trough. The erosion proceeded until the canyon was cut to a depth practically the same as that it has at the present time. This was followed by deposition of gravels and of the Temple Bar conglomerate, and by eruptions of basalt, after which occurred renewed faulting and tilting of the limestone block, the Greggs breccia, and the Temple Bar conglomerate. Erosion again became active, and a second time the canyon was eroded to a depth greater than that it now has.

Later events, which are important farther downstream, are not conspicuously recorded in the Grand Wash Trough.

HUALPAI WASH.

Hualpai Wash enters Colorado River from the south and occupies a structural depression between the western edge of the limestone block on the east and the crystalline rocks of the White Hills on the west. This trough extends northward across the river and is there filled with gravel deposits, but their relation to other formations was not determined.

In Hualpai Wash a limestone several hundred feet thick occurs. In some places it is a massive, pink, compact rock resembling the Redwall limestone of the canyon section. Unlike that limestone, however, its character varies within short distances from a compact rock to a comparatively soft earthy substance, weathering with rough cavernous surface. In Hualpai Wash it rests directly upon an irregular surface of granite. In other places it abuts rather abruptly against previously existing granite cliffs, and contains fragments of the granite embedded within it. In still other places it apparently rests upon beds of sand and clay, although this observation was not satisfactory.

The material is similar in character to the travertine capping Greggs breccia (section *C*, fig. 4), and to that occurring in beds 500 feet or more in thickness in the mouth of Grand Canyon (section *A*, fig. 3). It is apparently a travertine deposit belonging either to the Greggs deposits, let down to its present position by faulting (section *D*, fig. 4) or to the Temple Bar deposits, both of which are known to contain large beds of travertine. Its relation to the sedimentary rocks and to the underlying granite of the tilted block to the east is shown in the sketch sections in fig. 4.

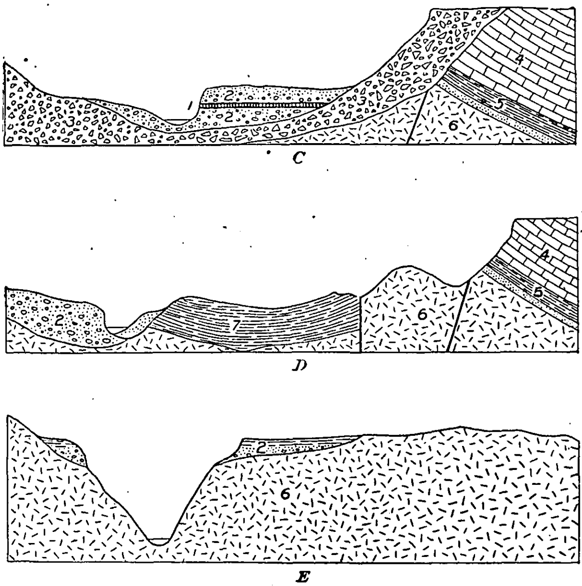


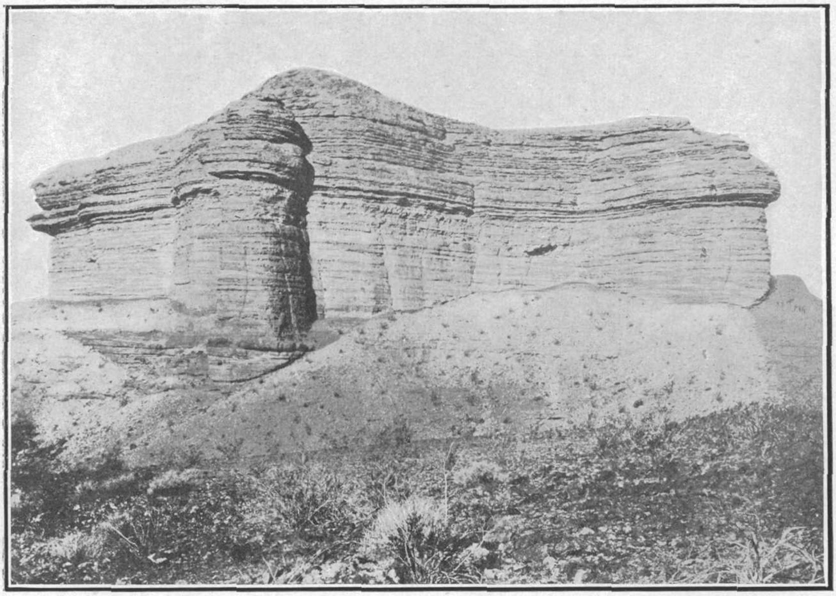
FIG. 4.—Diagrammatic sections across Colorado River. *C*, 4 miles east of Greggs Ferry; *D*, near Hualpai Wash; *E*, in Virgin Canyon. 1, Basalt; 2, Temple Bar conglomerate; 3, Greggs breccia; 4, Redwall limestone; 5, Cambrian; 6, granite; 7, travertine.

Within the canyon, resting unconformably upon Temple Bar conglomerate and the older formations at various points on either side up to an altitude of 150 to 200 feet above the water level, occur unconsolidated gravels. They are not conspicuous east of Iceberg Canyon, although some gravel beds in the Grand Wash Trough above high-water level may have been formed at the same time. Farther downstream they are conspicuously developed and are there known as the Chemehuevis gravel.

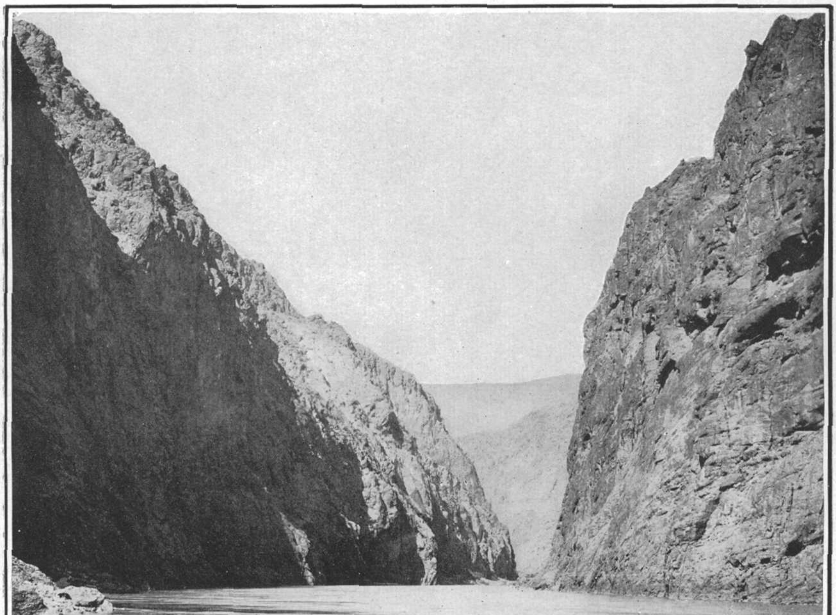
VIRGIN CANYON.

At the mouth of Hualpai Wash Colorado River enters a narrow rock gorge cut in the crystalline rocks of the Virgin Range. The canyon is about 5 miles long and from 1,000 to 1,500 feet deep, with walls rising steeply from the water's edge on either side.

High in the sides of the canyon walls occur remnants of light-colored, horizontally bedded material. (See section *E*, fig. 4.) These were not examined closely, but from a distance they have the same general appearance as the Temple Bar conglomerate characteristically developed at the same altitude a few miles farther west.



A. TEMPLE BAR CONGLOMERATE RESTING UPON OLDER BRECCIA, NEAR TEMPLE BAR.



B. ENTRANCE TO BLACK CANYON.

TEMPLE BAR.

Virgin Canyon widens westward as the river emerges from the crystalline rocks and enters the detrital beds. At Temple Bar the sand and gravel filling the Detrital Valley is exposed in vertical cliffs several hundred feet high. At the base of the cliffs is a coarse breccia exposed through a thickness of about 300 feet and composed principally of fragments of a rhyolite flow breccia cemented into a resistant mass. The cementing material is mainly carbonate of lime, but in some places it is silica and in other places oxide of iron. Springs issuing from this breccia are strongly charged with common salt and alkali, which gather as white incrustations about the springs.

Resting unconformably upon this breccia and abutting against it, as illustrated in section *F*, fig. 5, occurs the characteristic Temple Bar conglomerate. The conglomerate consists of well-stratified sand and gravel (see Pl. VIII, *A*), and, although poorly consolidated, forms perpendicular cliffs hundreds of feet in height. Pl. II shows this conglomerate in one of its most characteristic exposures, where the cliffs rise abruptly from the water's edge to a height of 815 feet. A large number of equally conspicuous sand and gravel cliffs and monuments occur in the vicinity of Temple Bar, extending from the river level to altitudes of 2,000 to 2,500 feet.

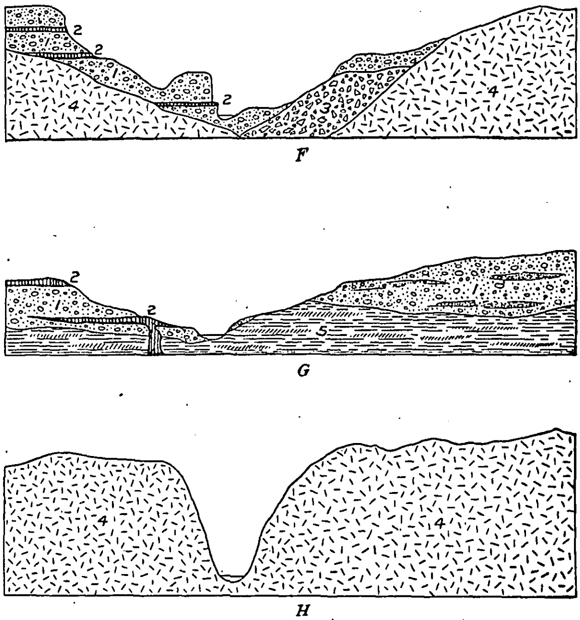


FIG. 5.—Diagrammatic sections across Colorado River. *F*, At Temple Bar; *G*, at Virgin River; *H*, in Boulder Canyon. 1, Temple Bar conglomerate; 2, basalt; 3, Greggs breccia; 4, granite; 5, salt and gypsum beds.

Sheets of basalt occur at several horizons of the conglomerate. A shelf about 200 feet from the base (see Pl. II) is formed by one of these sheets of basalt, and other sheets occur at higher horizons (section *F*, fig. 5). South of the river a basalt sheet resting on top of the gravel beds may be younger than those included in them, or may be one of the included sheets exposed by erosion.

The composition, stratigraphic relations, and general appearance of the older or cemented breccia suggest that it is probably a time equivalent of the Greggs breccia. The gravels above it form the Temple Bar conglomerate, which derives its name from this locality. The younger or Chemehuevis gravel is also present at Temple Bar, but is not conspicuous.

VIRGIN VALLEY.

Between Temple Bar and Boulder Canyon, a distance of about 12 miles, Colorado River crosses the old débris-filled valley which to the south of the Colorado is known as the Detrital-Sacramento Valley and to the north as the valley of the Virgin.

The filling of this old valley is apparently composed of two distinct formations, but their relation was not satisfactorily determined. The older one consists of alternating layers of sand and clay, and contains extensive beds of gypsum. Rock salt occurs in the Virgin Valley a few miles north of the Colorado, in beds similar to those containing the gypsum. These salt beds apparently lie beneath the gypsum, as shown by the salt well near the mouth of Virgin River, described by Gilbert.[a] The salt well is a crater-like depression about 300 feet across and 65 feet deep, situated in the midst of a level gravel plain. It is not connected with any surface drainage, and is evidently formed by a local caving of the surface probably due to the removal by solution of underlying beds of salt. It is filled with salt water to a depth of 15 to 20 feet.

The gypsum and gypsiferous clays are conspicuously exposed along the river, where they are deeply dissected over a large area locally known as the badlands of the Virgin. The presence of gypsum and salt indicates that this formation is not a part of the Temple Bar conglomerate, which overlies it with apparent unconformity (section *G*, fig. 5) and which does not contain gypsum or salt in its typical exposures so far as observed. The relation of the gypsiferous shales to the underlying rocks and to the overlying conglomerates was not satisfactorily determined. The stratigraphic position, however, suggests that this formation may be a time equivalent of the Greggs breccia.

BOULDER CANYON.

Boulder Canyon is a sharp gorge cut by Colorado River through the Black Mountain Range. It is about 5 miles long and 2,000 feet or more in depth, the walls rising steeply from the water's edge. The rocks exposed in the canyon are syenite, gneiss, rhyolite, and basalt. The basalts and their associated gravel deposits near the entrance to the canyon are faulted and tilted to some extent, and faults and open fissures occur in the canyon walls.

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[a] Gilbert, G. K., Final Rept. U. S. Geol. Survey W. 100th Mer., vol. 3, 1875, pt. 1, pp. 109-110.

Boulder Canyon is apparently younger than Virgin Canyon. The walls are but slightly eroded by lateral washes, although the open fissures and shattered condition of the rock in many places are favorable to the development of such; none were observed containing beds of the Temple Bar conglomerate, as is the case in Virgin Canyon.

LAS VEGAS WASH.

West of Boulder Canyon, and extending southward to the head of Black Canyon, the river flows through a débris-filled basin in which Colville and Las Vegas washes join the river from the north and west. Detrital beds resembling the Temple Bar conglomerate and containing sheets of lava are capped by a thick lava sheet in Fortification Hill at an altitude of 3,500 feet, or nearly 2,500 feet above the river (section *I*, fig. 6). The gravels are well stratified and are faulted and tilted in places.

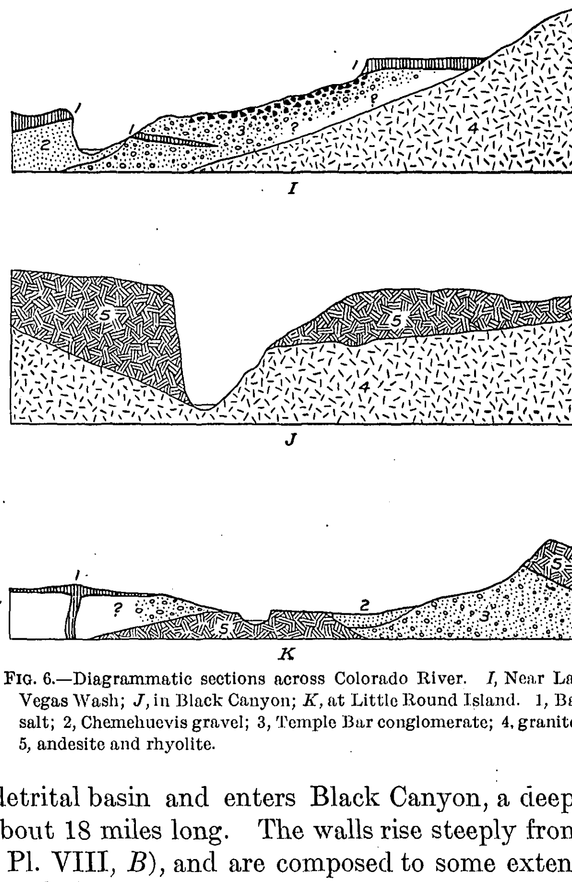


FIG. 6.—Diagrammatic sections across Colorado River. *I*, Near Las Vegas Wash; *J*, in Black Canyon; *K*, at Little Round Island. 1, Basalt; 2, Chemehuevis gravel; 3, Temple Bar conglomerate; 4, granite; 5, andesite and rhyolite.

BLACK CANYON.

A few miles south of Fortification Hill the river leaves the detrital basin and enters Black Canyon, a deep, narrow rock gorge about 18 miles long. The walls rise steeply from the water's edge (see Pl. VIII, *B*), and are composed to some extent of coarse crystalline rock, but mainly of massive rhyolite (section *J*, fig. 6). Black Canyon is very similar to Boulder Canyon in its general youthful appearance and in the absence of notable tributary washes and remnants of gravel beds.

COTTONWOOD VALLEY.

A few miles north of Eldorado Ferry the river emerges abruptly from Black Canyon into a broad open basin, the central part of which is known as the Cottonwood Valley. The basin is about 30 miles long and extends laterally from the Dead Mountains on the west to the Black Mountain Range on the east. At the northern

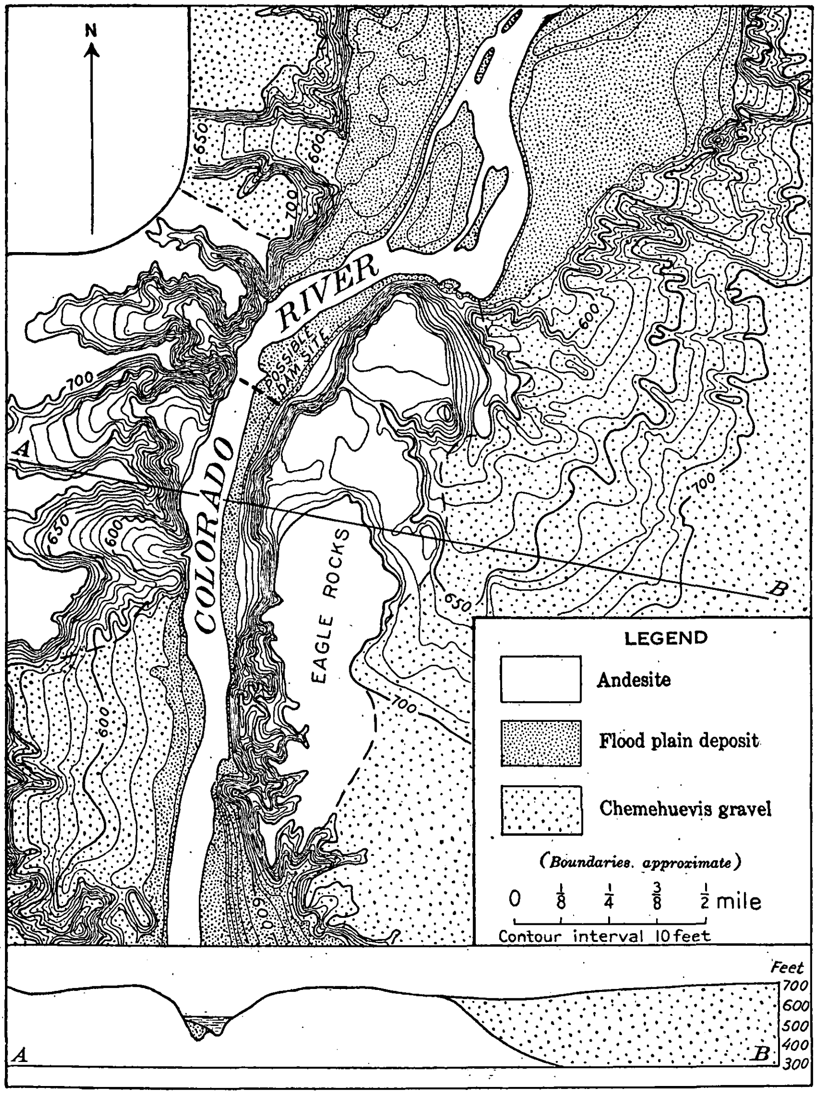
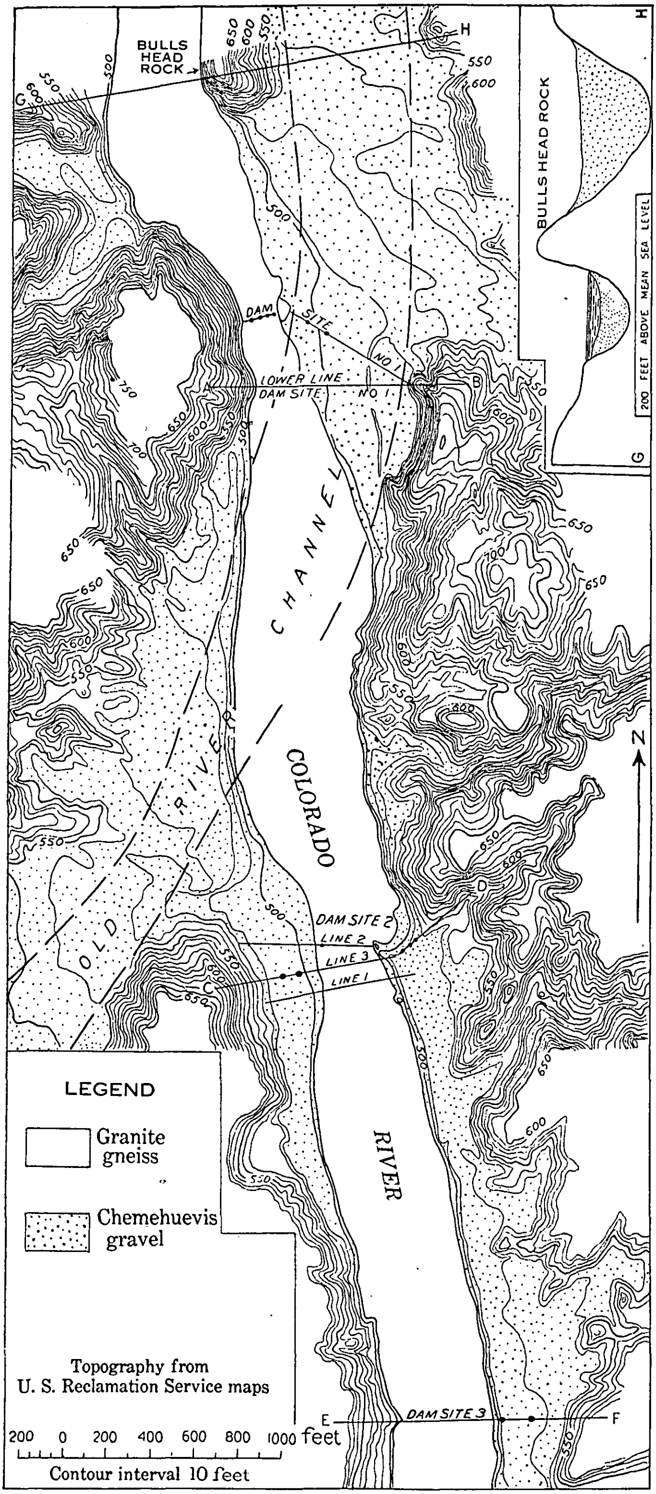


FIG. 7.—Map of a part of the Colorado Valley at the northern end of the Cottonwood Valley, showing an old gravel-filled channel at the right and the rock channel of the river at the left.

end of the basin gypsum-bearing beds similar to those near the mouth of the Virgin occur with an observed thickness of several hundred feet.



MAP AND SECTION AT SOUTH END OF PYRAMID CANYON, COLORADO RIVER.

Near Round Island partly consolidated gravel beds similar in general appearance to the Temple Bar conglomerate and intersected by basalt dikes (see section *K*, fig. 6) occur above andesitic lavas. The gravels are well stratified, tilted steeply to the east, and extensively eroded. Horizontally bedded Chemehuevis gravel lies in depressions eroded in older upturned beds which in turn are younger than the andesites. For these reasons the older gravels are provisionally correlated with the Temple Bar conglomerate.

The Cottonwood Valley is the northernmost of a series of large basins which extend thence southward to the Gulf of California. The flood plain in the center of the valley is terminated laterally by bluffs of the Chemehuevis gravel. Between these bluffs and the mountains on either side are long corrugated slopes covered with angular rock débris or wash from the highlands. The slopes in the Mohave Valley were examined with more care than elsewhere, and are described in a following section. (See pp. 41–42.)

At Eagle Rock, near the southern end of Round Island, the river leaves the flood plain and flows through a narrow rock gorge about a mile long and 150 feet deep. The rock is andesite, and its relation to the gravel formations is shown in fig. 7. The gravel-filled channel to the east connects the Round Island Valley with the Cottonwood Valley proper. In other words, Colorado River, during one of its periods of canyon cutting, described under "Geologic history" (pp. 62–67), failed to reexcavate its old gravel-filled channel at Eagle Rock and cut a new channel in the rock west of the old one.

PYRAMID CANYON.

South of the Cottonwood Valley the granite and gneiss of the bordering mountains extend across the valley of the Colorado, and through these rocks the river has cut a canyon about 300 feet deep and 8 miles long. This is known as Pyramid Canyon, the name being derived from a pyramid-shaped rock near the northern end. East of the canyon, and separated from it by a narrow rock ridge (see Pl. IX), is an old channel filled with sand and gravel—Chemehuevis gravel—remnants of which occur 400 feet or more above the river, overlying and abutting against the granite and gneiss, as shown in Pl. III, *B*.

One of the proposed dam sites of the Reclamation Service is located at the southern end of Pyramid Canyon, near Bulls Head rock, the southern extremity of the rock ridge. On account of the investigations of the Reclamation Service in this vicinity much exact information is available. On this account the Bulls Head region is perhaps the best locality for the description and illustration of the late physiographic history of Colorado River. Unfortunately the detailed maps do not extend far enough northward to show to advantage the relation of the new rock channel to the old gravel-filled valley, but its southern end is shown in Pl. IX, and its relations are indicated in fig. 8. In Pl. X, *A*, a view of Bulls Head rock is presented, showing the river channel to the left and the gravel-filled valley to the right, as seen from the south. At intervals for several miles north of Bulls Head rock the ridge between the old and new channel is cut through by tributary washes, exposing such sections of the Chemehuevis gravel as that shown in Pl. III, *B*.

The old course was not so satisfactorily traced to the south. As shown on the map, it apparently crossed the present course of the river at a point where the gravels fill a depression similar to that at

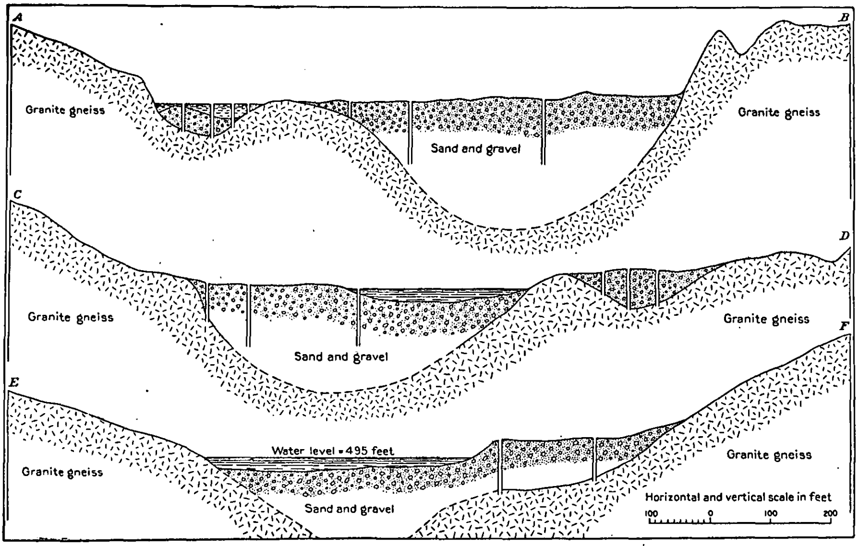
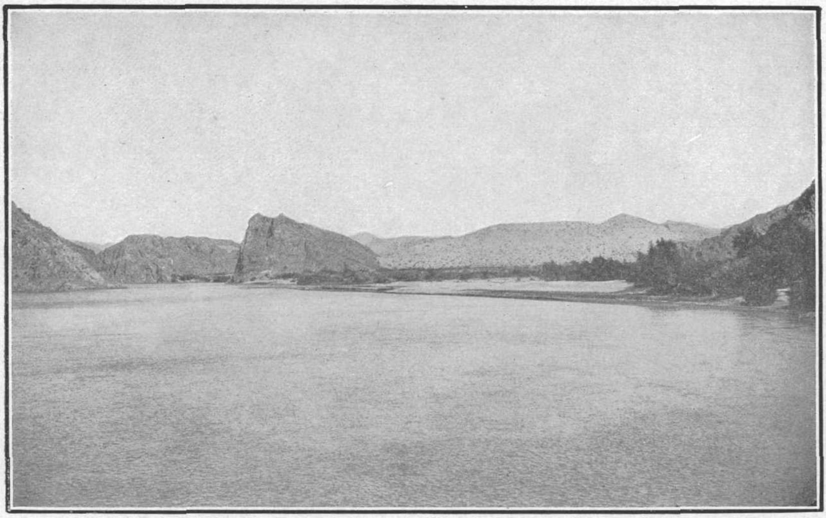


FIG. 8.—Profiles across Colorado River at the southern end of Pyramid Canyon, constructed from boring records. (For location see Pl. IX.)

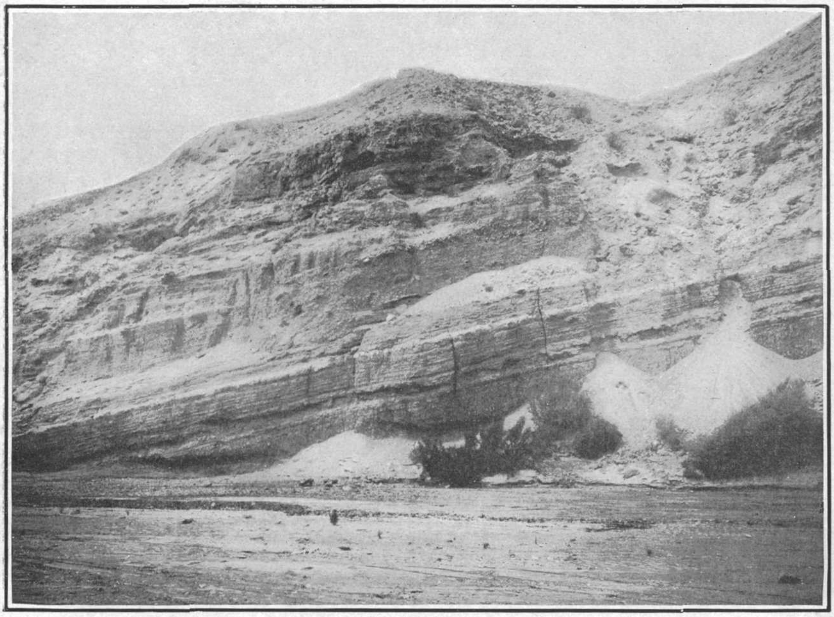
the north, and connected with the extensive gravel deposits of the Mohave Valley to the south.

Although the river occupies a narrow rock channel in Pyramid Canyon, it does not flow upon a rock bed, as might be expected. Borings were made for the Reclamation Service in three localities across the river (see Pl. IX), and the gravel filling was found to be more than 100 feet deep. The probable profiles, as constructed from the boring records, are shown in fig. 8.

No distinction can be drawn with certainty between the old and new channels at the places where the borings were made. At the northernmost locality (section *A-B*, fig. 8) the channel at the left now occupied by the river, in which the gravels are about 50 feet deep, is apparently the new one, and that at the right, more than 100 feet



A. COLORADO RIVER AND GRAVEL-FILLED VALLEY AT BULLS HEAD ROCK.



B. TILTED GRAVELS IN SACRAMENTO WASH.

deep, the old one; but in the absence of soundings within the canyon north of Bulls Head, the depth of the new channel remains in doubt. Borings 100 feet deep in the older channel do not penetrate through the gravels.

A brief statement of the physiographic history of the river, as here recorded, may give a clearer understanding of the phenomena described. The river at some former time occupied the old course to the east (Pl. IX) and eroded its channel to a depth considerably below the present river level. Later the Colorado deposited the Chemehuevis gravel, filling its valley with sand and gravel to a level several hundred feet above the present bed. When the river again began to erode, it reexcavated the old valley throughout the greater part of its course, but in Pyramid Canyon, at Eagle Rock (described in the previous section), and at other places farther south to be described in following sections, it left its old course and cut rock gorges at one side.

MOHAVE VALLEY.

The Mohave Valley is a large basin extending from Bulls Head southward to The Needles, a distance of about 35 miles. The center of the basin is occupied by a broad flood plain having an area of about 50,000 acres. This is bordered on either side by terraced gravel bluffs, from which long, graded, alluvial slopes extend to the bordering mountains, joining the slopes at altitudes of 2,500 to 3,000 feet.

The rock masses in the Mohave Valley were examined principally east of the river. The rocks of Black Mesa to the east are mainly andesite and rhyolite, resting upon granitic gneiss. Overlying these older rocks occurs a formation of partly consolidated sand and gravel, which in composition and general appearance resembles the Temple Bar conglomerate. It is exposed in steep cliffs in the washes of the alluvial slope, and the strata are generally nearly horizontal. In some places, however, the layers are faulted and tilted (see Pl. X, *B*). These stratified sands and gravels are covered with coarse rock débris, due partly to wash from the hills and partly to surface concentration of the coarser material of the conglomerate.

Resting upon this formation and occupying spaces eroded in it is the Chemehuevis gravel, forming conspicuous terraces, three of which are prominent and traceable continuously for considerable distances; in some places five are distinguishable. The lowest is about 50 feet above the river, and is represented by the broad shelf upon which old Fort Mohave stands; the second is about 100 feet higher, and the others occur at intervals of 50 to 100 feet.

The Chemehuevis gravel varies considerably in character from place to place from beds of large, well-rounded pebbles to those of fine sand and clay. At the northern end of the Mohave Valley, near Bulls Head, there are two distinct divisions of the gravel. (See Pl. III, *B*.) The lower division consists mainly of well-stratified and firmly packed sand and silt; the upper of stratified but very loose sand and gravel. The two divisions appear to be perfectly conformable, and the difference in character is probably due to some change in the river, such as an increase in its carrying power, enabling it to bear the finer material away and deposit only the coarser material; or to a change in course, bringing the gravel-bearing current over what had formerly been a flood plain.

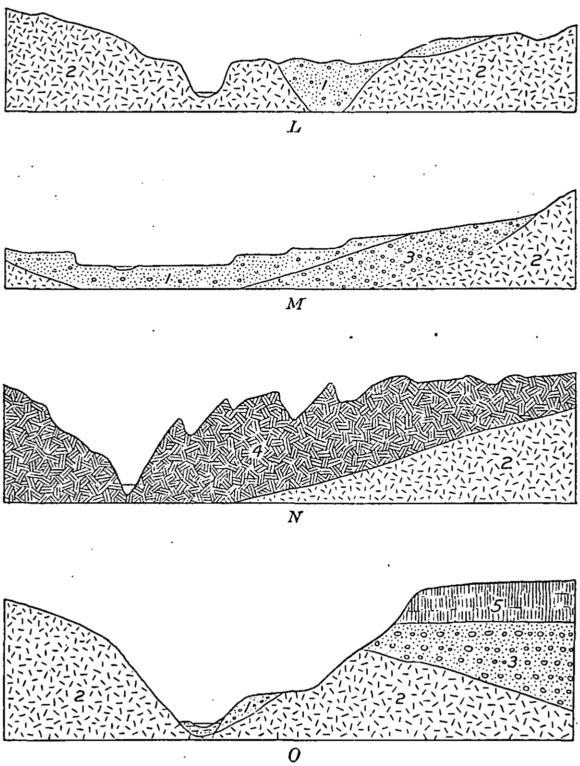


FIG. 9.—Diagrammatic sections across Colorado River. *L*, Pyramid Canyon; *M*, in the Mohave Valley; *N*, in the Needles Mountains; *O*, at the mouth of Williams River. 1, Chemehuevis gravel; 2, granite; 3, Temple Bar conglomerate; 4, eruptive; 5, basalt.

The gravels in the old channel east of Pyramid Canyon were examined with considerable care and found to consist of limestone, marble, sandstone, and metamorphic and igneous rocks of great variety. Many of the limestone pebbles have beautifully etched surfaces, which Gilbert[a] describes as "carved with a network of vermicular grooves into a most beautiful arabesque design." These etched pebbles were observed in the Chemehuevis gravel throughout the region described.

THE NEEDLES.

South of the Mohave Valley occurs a mass of eruptive rock resting on the flanks of the Mohave Mountains (section *N*, fig. 9), and characterized by sharp pinnacles of erosion, from which the group has been called The Needles. Mohave Canyon, about 8 miles long, has been cut in this eruptive mass to a depth of about 2,000 feet. In gen-

[a] Gilbert, G. K., U. S. Geog. Surv. W. 100th Mer., vol. 3, 1875, pt. 1, pl. 9 and p. 83.

eral the rock walls rise abruptly from the water's edge, but in some of the more open spaces sand and gravel of the Chemehuevis formation occur to a considerable height above the river.

At Big Bend, 4 miles south of Mellen, the river leaves a comparatively open portion of the canyon and turns abruptly to the west into a narrow rock gorge having an old gravel-filled channel, which continues southward in the normal direction of the river (fig. 10).

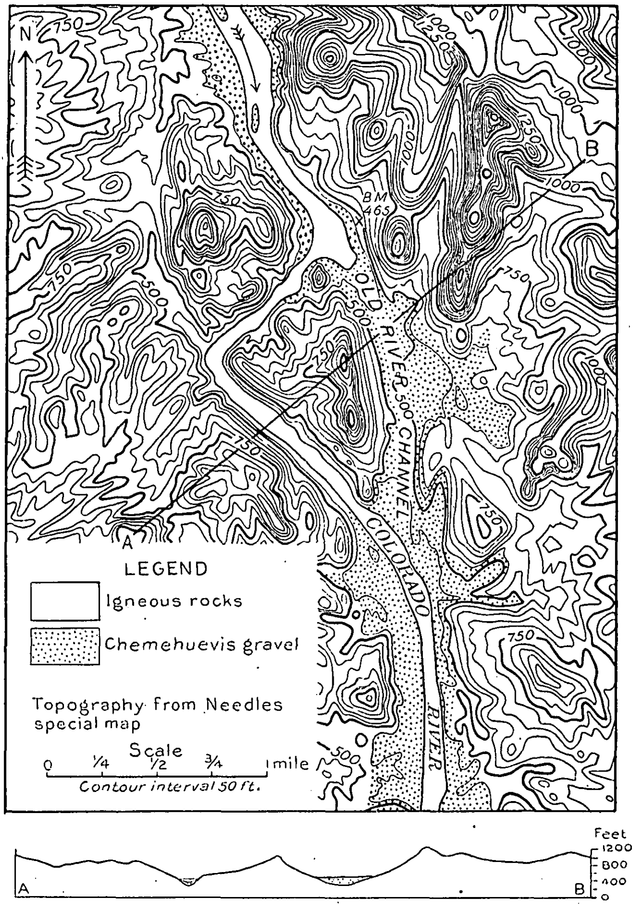


FIG. 10.—Map of Great Bend in Mohave Canyon, showing relation of an old débris-filled channel to the present course of Colorado River.

The phenomena here are similar to those just described from Pyramid Canyon, except that the new course is shorter and the gravel filling of the old one has been more nearly eroded away than in Pyramid Canyon.

CHEMEHUEVIS VALLEY.

The Chemehuevis Valley extends from The Needles to the mouth of Williams River, a distance of about 25 miles, and is narrower than the other basins along the course of the river. The Chemehuevis gravel, which derives its name from this valley, occurs here in characteristic development, lying unconformably upon older and partly consolidated gravels. The older gravels are horizontally bedded in some places but in others are faulted and highly inclined.

The relation of the Chemehuevis gravel to the older conglomerate was noted at several points along the river. In some places the older gravels are undisturbed beneath the Chemehuevis, the two being separated by an unconformity of erosion (section *A*, fig. 11). In other places the older gravels are upturned, eroded, and overlain by horizontally stratified Chemehuevis gravel (section *B*, fig. 11). In still

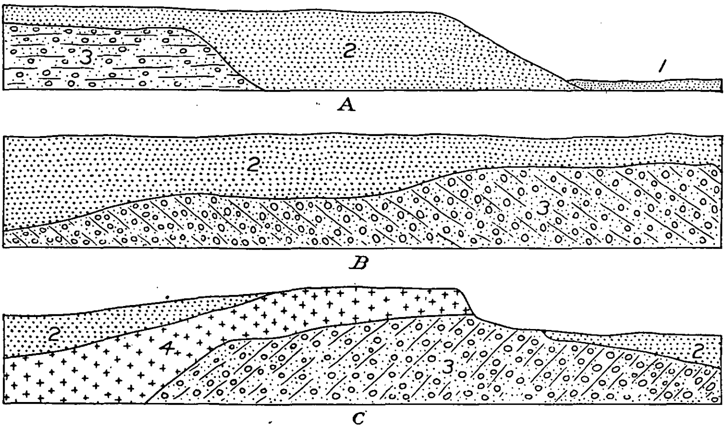


FIG. 11.—Relations of gravel formations to each other and to igneous rock in the Chemehuevis Valley. *A*, The three gravel formations horizontally bedded but separated by unconformities of erosion; *B*, the older conglomerate tilted, eroded, and overlain by horizontally bedded younger gravels; *C*, the older gravels tilted, intersected and overlain by lava, eroded, and again overlain by horizontally bedded younger gravels. 1, Flood-plain deposits; 2, Chemehuevis gravel; 3, Temple Bar (?) conglomerate; 4, igneous rocks.

other places the older gravels are tilted, intersected by lava, eroded, and overlain by the Chemehuevis gravel (section *C*, fig. 11).

The older gravels apparently overlie rhyolite and andesite, and at one point a stratum of rhyolitic ash occurs within them. They vary greatly in character from place to place from sandy clay to a breccia with granite bowlders 4 feet in diameter. In general appearance they resemble the Temple Bar conglomerate, and are provisionally correlated with it. This conglomerate is apparently the one which Newberry[a] in the Ives report referred to the Tertiary.

AUBREY CANYON.

Near the southern end of the Chemehuevis Valley the granite of the bordering mountains approaches the river, and at the mouth of Williams River the Colorado enters a narrow canyon, the walls of

[a] Newberry, J. S., Report upon the Colorado River of the West by Lieut. J. C. Ives, pt. 3, 1861, p. 29.

which are composed of granite overlain by eruptive rock (section *O*, fig. 9). The eruptives west of the canyon were not examined closely, but resemble in general appearance the rhyolite and andesite to the north and the great masses of similar rock composing the Chocolate Mountains to the south. The eruptive rock east of the river is the basalt which caps the Temple Bar conglomerate, as described and illustrated from Williams Canyon (fig. 16).

East of Aubrey Canyon, and exposed in the bluffs of Williams Canyon (see p. 54), is an old valley filled to a depth of about 1,000 feet with the Temple Bar conglomerate and covered with 800 feet of basalt. Aubrey Canyon is younger than this gravel-filled valley, having been cut through the basalt sheet covering the Temple Bar conglomerate.

The rock channel in Aubrey Canyon has been cut to a considerable depth beneath the present river level, and filled with sand and gravel. Borings made for the Reclamation Service near the head of the canyon failed to reach bed rock at a depth of 75 feet. In the open basins the river is building flood plains, and the sediment accumulated within the canyon evidently corresponds with that in the open basins, but the maximum depth of this most recent deposit is nowhere indicated.

Here, as elsewhere along Colorado River, there is abundant evidence of a complex physiographic history. A broad valley, described elsewhere as the Detrital-Sacramento Valley (see p. 52), was formed east of Aubrey Canyon and filled to a depth of 1,000 feet or more with sand and gravel—the Temple Bar conglomerate. This was covered with 800 feet or more of basalt, and a new canyon was later eroded west of the old one (section *O*, fig. 9). Still later this canyon was filled with several hundred feet of sand and gravel—Chemehuevis gravel—which were partly carried away by renewed erosion that cut the canyon to a depth lower than the present river level. This channel was in turn filled to its present condition.

GREAT COLORADO VALLEY.

The Great Colorado Valley was examined only in the immediate vicinity of the river during a somewhat hurried excursion by boat, but the data obtained are supplemented to some extent by the investigations of the Reclamation Service. The valley is the largest of the basins through which Colorado River flows, extending, with varying width, from Aubrey Canyon southward to the Chocolate Mountains, a distance of about 75 miles. The Riverside and Halfway mountains form a partial boundary on the west, and the Dome Rock and other mountains on the east; but between the mountain groups occur broad grades, such as the Cactus Plain.

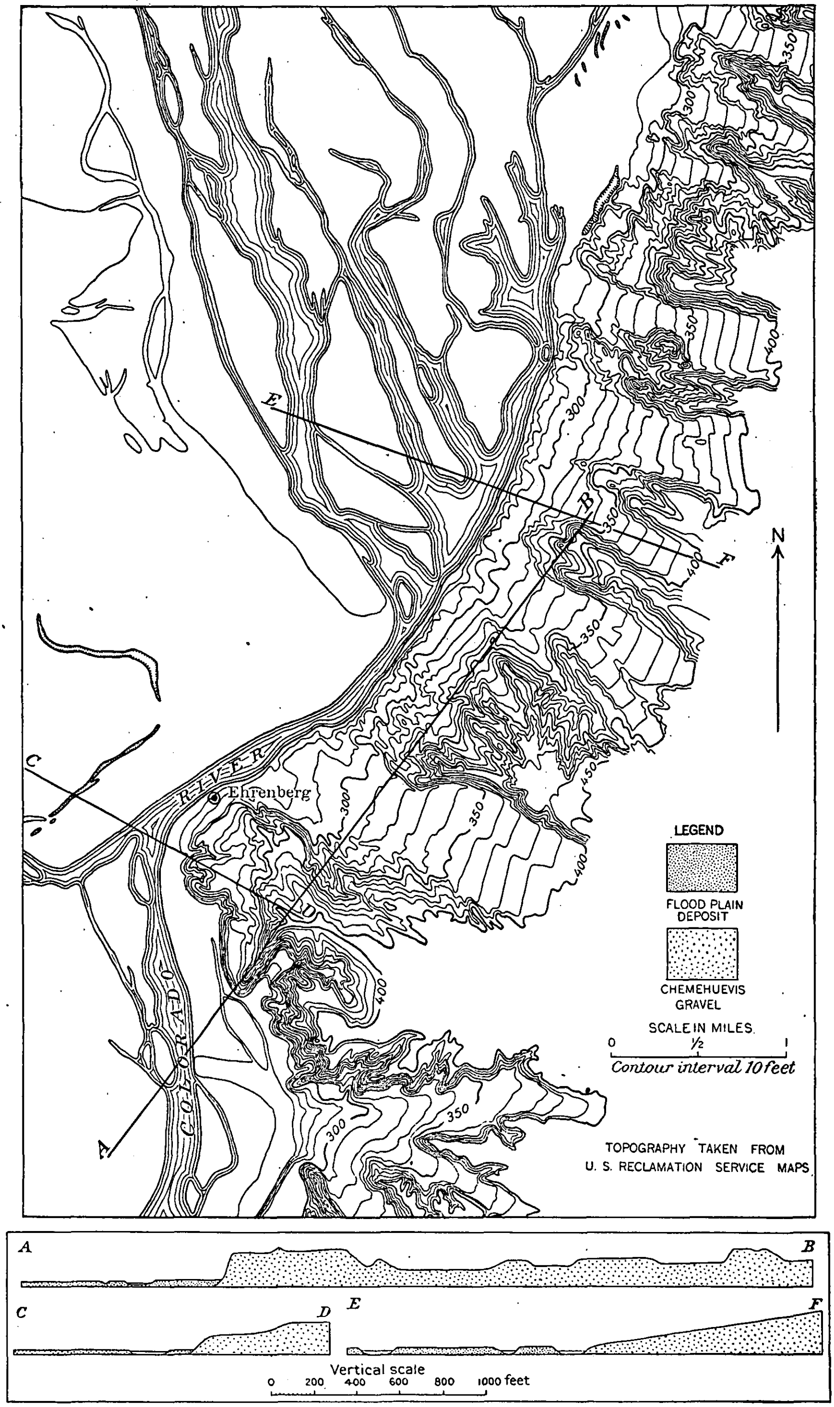


FIG. 12.—Map and sections of a part of the Great Colorado Valley, illustrating the lateral migrations of the river, the relation of the flood plain to the bluffs of the Chemehuevis gravel, and the corrugated slopes at the margins of the valley.

Like the other basins described, the Great Colorado Valley contains gravels representing three distinct epochs of accumulation. The oldest, interpreted as belonging to the Temple Bar conglomerate, was observed near the northern end of the valley, where it is overlain by lava, as at Headgate Rock. Farther to the south, in the middle of the valley, it was not identified.

The younger or Chemehuevis gravel occurs throughout the Great Colorado Valley in conspicuous terraced bluffs. The beds vary much in composition, from a sandy silt to coarse gravel, the finer material greatly predominating. The sand is regularly stratified, cross-bedded, and not distinguishable in physical character or composition from the beds forming at the present time over the flood plain. The Chemehuevis gravel extends for an undetermined distance back from the terraced bluffs, and form corrugated slopes illustrated in fig. 12. The washes entering at the sides of the valley have steeply graded floors, often extending back many miles toward the hills, and are terminated laterally by nearly perpendicular walls. These floors often join laterally, forming wide graded slopes.

From the foot of the gravel bluffs (fig. 12) and extending throughout the valley with a maximum width of 12 miles and a length of 75 miles are flood plains building up by the deposition of sand and silt. Over this great area Colorado River is continually shifting its channel, sometimes gradually by slow cutting and filling and sometimes suddenly by turning through one of the numerous abandoned channels.

The annual floods carry immense quantities of silt, which they spread over the flood plain, building it up with great rapidity. Where the caving banks of the river expose vertical sections it was noted that the roots of living arrow weeds had been buried to a depth of 6 feet or more. In other words, there have been accumulations of silt 6 feet or more in depth during the life of this shrub. The material is well stratified, sometimes with horizontal lamination, but often showing a conspicuous oblique lamination similar to that found in the Chemehuevis gravel. Much of the silt is very fine and is held in suspension for a long time. When deposited in thick beds it dries and cracks in columnar form, some of the columns being 2 to 3 feet in diameter and separated by cracks several inches wide and 2 feet or more deep.

CHOCOLATE MOUNTAINS.

South of the Great Colorado Valley, for a distance of about 30 miles, Colorado River flows in a canyon or narrow valley through the Chocolate Mountains—a name applied generally to a complex group consisting of the Spire Range, the Picacho group, the Castle Dome Mountains, and the Purple Hills.

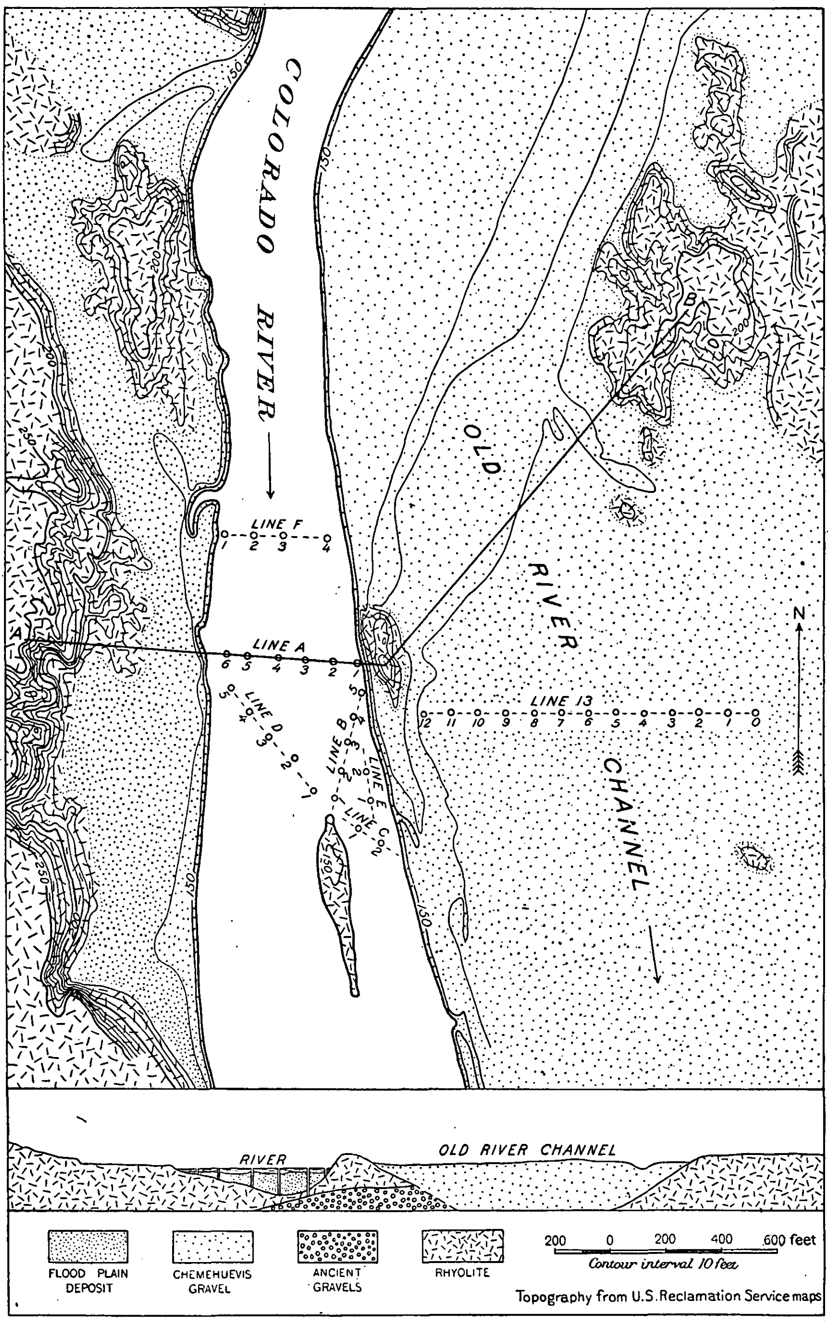


FIG. 13.—Map and section of a part of Chocolate Canyon, showing an old débris-filled channel to the east of the present channel. (Section constructed from boring records.)

The rock exposed along the river is principally effusive, although granite and metamorphosed sediments occur in some places. The effusive rock, consisting of pink and white rhyolite in the form of ash, breccia, and flow, extends from the river level apparently to altitudes of several thousand feet, and is characterized by conspicuous cliffs, erratic forms of erosion, and rock slopes barren of vegetation.

Physiographic changes similar to those at Bulls Head and elsewhere were noted in Chocolate Canyon. At Lighthouse Rock the river has apparently left its old channel and cut laterally into the rhyolite, leaving Lighthouse Rock standing in the water. A boring in the channel at this point failed to reach bed rock at a depth of 80 feet. Farther down the river, near Picacho, several borings in the river bed failed to reach solid rock at a depth of 100 feet.

Probably the best illustration of changes in the course of the river in this vicinity is to be found at the so-called Cácopah dam site of the Reclamation Service, near the southern end of Chocolate Canyon. At this point the Colorado flows close to the rhyolite hills on the west, with one rock island standing in the river and another on the eastern bank. (See fig. 13.) Between these islands and the hills to the east is a broad sand flat.

Borings made at the various places indicated in fig. 13 show that the channel now occupied by the river has been eroded to a depth of about 100 feet, and later filled with sediment, while the old channel to the east is deeper, no solid rock being found at a depth of 138 feet.

A significant observation was made at this point by Homer Hamlin,[a] who noted that in one of the borings the drill penetrated through the rhyolite and entered a gravel bed. (See fig. 13.) The rhyolite is presumably of Tertiary origin, as are also the rhyolites farther north, more fully described elsewhere (p. 83). It is possible that the underlying gravels may be equivalent in age to some of the tilted and consolidated gravels farther north, which were referred by Newberry to the Tertiary, but which the present writer has provisionally correlated with the Temple Bar conglomerate and referred to the Quaternary.

HUALPAI VALLEY.

Location and character.—The Hualpai Valley, about 60 miles long and 25 miles wide, is located in the northeastern part of the region described. Except for a few miles at the northern end, it is an undrained basin, in the lowest part of which flood waters gather and remain until they either evaporate or sink into the valley filling. "Red Lake," thus formed, contains water for periods varying from a few days to several months. At other times it is a broad, barren mud flat.

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[a] Personal communication.

The floor of the Hualpai Valley is nearly level at an altitude of about 3,000 feet and is met on either side by mountain slopes at high angles. The plateau to the east drains away from Hualpai Valley into Colorado River, and the drainage from the White Hills and the Cerbat Mountains to the west and from the Hualpai and Peacock mountains to the south is so small as to be negligible. The only stream worthy of note that enters this great valley is Truxton Creek, the bed of which is usually dry, but which occasionally contains floods of great volume.

Structure.—The Hualpai Valley is a structural trough formed by faulting and block tilting. The Grand Wash fault, with a displacement of 10,000 feet or more at the mouth of Grand Canyon, continues southward into the valley, together with several smaller faults to the west. The general trend of this fault zone in the vicinity of Colorado River, where it is best known, suggests that it may extend through the Hualpai Valley beneath the detrital accumulations and reappear in the fault west of the Hualpai Mountains. On the other hand, extensive displacements by faulting have taken place along the Cottonwood and Aquarius cliffs (see pp. 19–20), and it is possible that these cliffs mark the southward extension of the Grand Wash fault.

At the northern end of the valley the sedimentary formations are tilted steeply to the east; along the eastern flank of the White Hills and Cerbat Mountains the sheets of basalt dip eastward beneath the valley floor. The trough formed by this downthrow to the east has been filled with rock débris to some unknown depth; a well bored 700 feet deep near the head of Hualpai Wash did not pass through it. The material on the alluvial slopes is coarse, but in the center of the valley it is fine and is continually shifted by the winds.

BIG SANDY VALLEY.

Location and character.—The Big Sandy Valley is located between the Aquarius Cliffs on the east and the Hualpai Mountains and Aubrey Hills on the west, and extends from Hackberry southward to Williams River. The lowest part of the valley, known as Big Sandy Wash, lies at the foot of the cliffs as far south as Signal, but at this point the Big Sandy leaves the main valley and passes through Signal Canyon. Several streams of considerable size emerge from the plateau to the east through deep, narrow canyons and discharge into the Big Sandy. The largest of these are White Cliff, Trout, and Sycamore creeks.

That portion of the valley between the Hualpai Mountains and Big Sandy Wash consists of a long, graded detrital slope (see fig. 2, p. 24), more or less deeply cut by parallel washes, such as Deluge Wash. This highly inclined detrital slope, the western fault scarp of the Hualpai Mountains, and the fault scarp to the east (Aquarius Cliffs) all terminate at the south in practically the same latitude. The southern end of the valley, between the Artillery Mountains and the Aubrey Hills, has a slight inclination to the east, but is in general an undissected and undrained detrital plain.

Rock formations.—The oldest rocks in the Big Sandy Valley are the granites exposed in the bordering mountains and cliffs, which, because of their resemblance to the granite beneath the Cambrian sediments in the Grand Wash Cliffs, are thought to be of pre-Cambrian age. They are overlain in places by Tertiary andesites.

The trough formed by these older rocks is partly filled with rock débris which has been later exposed by erosion. The oldest detrital beds have been upturned and eroded to depths of 800 feet or more. They are composed of clay, sand, and gravel, and in places contain

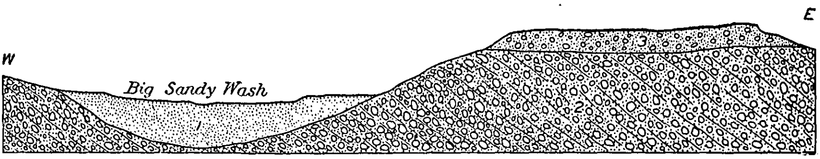


FIG. 14.—Sketch section across Big Sandy Wash near mouth of Deluge Wash, showing the older gravels tilted eastward, eroded, and overlain by younger gravels, and again eroded and partly covered by recent flood-plain deposits. 1, Flood-plain deposits; 2, Temple Bar (?) conglomerate; 3, gravel.

granite bowlders 5 to 8 feet in diameter. In other places, as at Deluge Wash (Pl. IV, *B*), they are composed of clay and fine, well-stratified sand and volcanic ash.

Within the valley eroded in the oldest tilted detrital beds, and resting with horizontal bedding upon their eroded edges, is a second series of gravel deposits. These are perhaps best exposed near the mouth of Deluge Wash, where they are about 50 feet thick. This second gravel accumulation was in turn eroded and a third deposit laid down. (See fig. 14.)

In general character and stratigraphic position the oldest detritus corresponds with the Temple Bar conglomerate, the middle with the

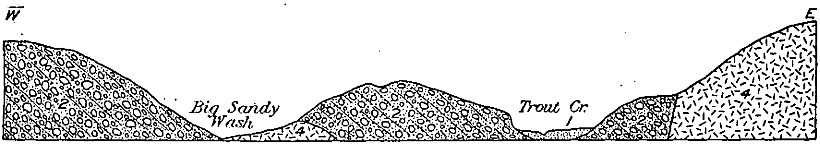


FIG. 15.—Sketch section across Big Sandy Wash at the mouth of Trout Creek, showing the older gravels overlying granite, tilted eastward, and terminating against the granite of Cottonwood Creek. 1, Flood-plain deposits; 2, Temple Bar (?) conglomerate; 4, granite.

Chemehuevis gravel, and the youngest with the flood-plain deposits of the Colorado Valley, but no definite correlation can be made at the present time.

Structure.—The Big Sandy Valley is a trough formed by faulting. The fault zone along the Grand Wash and Cottonwood cliffs continues southward to the Aquarius Mountains. Recent movement along this zone is indicated by the displacement of portions of the andesite sheet at the northern end of the valley and by the faulted and tilted gravel beds near the mouth of Trout Creek (fig. 15), where the strata incline

32° to the east and end abrubtly against the granite at the fault line. This evidence of faulting, considered in connection with the faulting and block tilting in the Hualpai Mountains, indicates that the Big Sandy Valley was formed by a downthrow of the eastern edge of the Hualpai block. (See fig. 2 and section *S–S′*, Pl. V, p. 24.)

SIGNAL CANYON.

At the town of Signal the Big Sandy leaves the débris-filled trough and passes through a rock gorge known as Signal Canyon. The rocks exposed are coarse-grained granites in the northern part of the canyon and andesites in the southern part. These rocks had been deeply dissected previous to the accumulation of the older detrital beds (just described) which later filled the old valleys and were in turn buried beneath effusive rock. Later, during the erosion of Signal Canyon, these old valleys were reexcavated in part, leaving on the mountain sides conspicuous shelves of lava-covered detritus. (See Pl. III, *A*.)

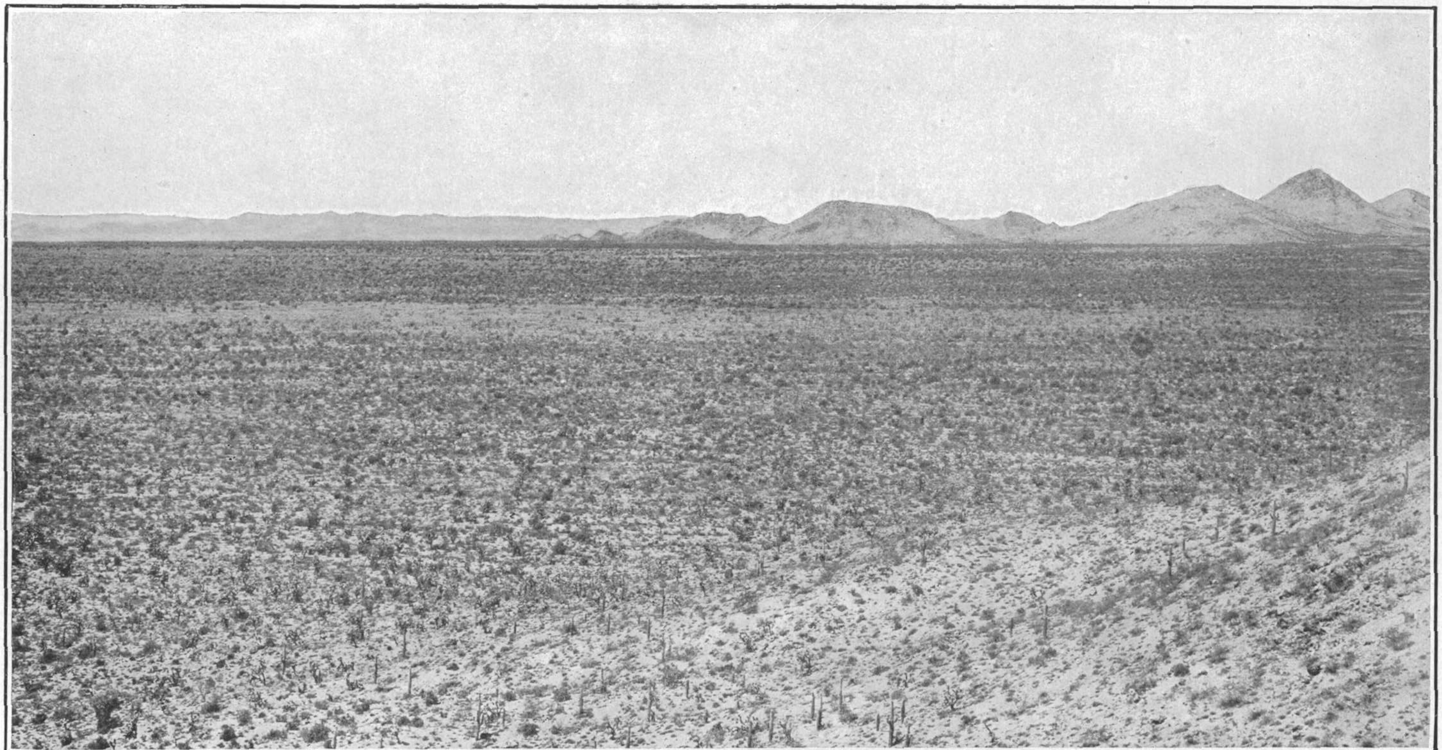
The broad, débris-filled trough here called the Big Sandy Valley continues southward west of the Artillery Mountains to Williams Canyon, where the detritus is seen to extend lower than the bed of Williams River.

DETRITAL-SACRAMENTO VALLEY.

Location and character.—The Detrital-Sacramento Valley extends from Colorado River on the north to Williams River on the south, between the Cerbat and Hualpai mountains to the east and the Black Mountain Range to the west. Thus defined it is about 130 miles long and 5 to 15 miles wide. The northern part of the valley, drained by Detrital Wash, is locally known as the Detrital Valley, and the central part as the Sacramento Valley. (See Pl. XI.) The southern part bears no name, but since it is the southern continuation of the Sacramento Valley, the whole is here called the Detrital-Sacramento Valley.

The valley was apparently formed mainly by erosion, although its form has been modified by crustal movements; such is notably the case west of Chloride, where sheets of basalt, outpoured within the valley, have been tilted eastward. The andesites and rhyolites on either side, from the southern end of Black Mesa northward to Colorado River, are similar in character and occur at about the same level. They are probably remnants of a single effusive mass through which the Detrital-Sacramento Valley was eroded.

The depth to which this valley was cut is not definitely known. At the northern end it was deeper than the present Colorado Valley (altitude 800 feet), and in Williams Canyon (altitude 505 feet) it extends beneath the bed of the river. The maximum depth between



SACRAMENTO VALLEY AT SOUTH END OF HUALPAI MOUNTAINS.

these extremities is not known. At Yucca (altitude 1,804 feet) the bottom of the gravels was reached in a well at a depth of 905 feet, or at an altitude of about 900 feet above sea level. The general altitude of Black Mesa, a few miles west of Yucca, and of the mesa east of the valley near Kingman, is about 3,500 feet. Assuming that the mesas are remnants of the surface which formerly extended across the Detrital-Sacramento Valley, the known depth of erosion at Yucca is about 2,500 feet. Since the valley is known to be deeper than this at both the northern and southern ends, it is probable that the well at Yucca does not penetrate the filling at the deepest point and that the depth of the old valley is greater than 2,500 feet.

Detrital filling.—The Temple Bar conglomerate filling this ancient valley is exposed at the north in the banks of Colorado River (Pl. II) and at the south in Williams Canyon (Pl. VI, *B*). It is composed of horizontally bedded sand, gravel, and wash, and contains sheets of basalt at several horizons. The composition of the filling at the extremities of the valley is described under "Temple Bar" (p. 35), and under "Williams Valley" (p. 54), and need not be repeated here. Where exposed in the washes throughout the valley and penetrated by wells the material does not differ greatly in character. Horizontally bedded sand and gravel containing sheets of basalt and having the same general appearance as the beds at Temple Bar and in Williams Canyon were observed within the valley up to altitudes of 2,500 feet or more, and sheets of basalt within the detrital beds were penetrated in the well at Drake. For these reasons the detrital filling is correlated with the Temple Bar conglomerate.

Considerable erosion has taken place within the Detrital-Sacramento Valley since the filling was completed. Sacramento Wash is 1,000 feet or more lower than the valley floor farther north. This difference in elevation is probably due in part to surface warping, but is regarded as due mainly to erosion.

In general the sands and gravels of the Detrital-Sacramento Valley are covered with angular rock débris, consisting in part of fragments of basalt, andesite, rhyolite, and granite, working their way over the surface as wash from the hills, and in part of the coarser material originally deposited with the sand and gravel and accumulated by surface concentration during the later degradation as the finer material was washed away by the rains or blown away by the winds.

WILLIAMS VALLEY.

Location and character.—Williams River, formerly known as Bill Williams Fork, is formed by the junction of two streams (Big Sandy Wash and Rio Santa Maria) and extends from this junction westward to Colorado River. The south fork, or Rio Santa Maria, emerges through a narrow canyon from the plateau to the east upon a broad detrital plain, into which it has cut a canyon several hundred feet deep. At the point where the river crosses the direct southward continuation of the Big Sandy Valley the canyon has been broadened to a basin several miles wide. About 12 miles east of Planet this basin narrows to a gorge about 8 miles long, known as Williams Canyon. The southern wall continues westward to Colorado River, but the northern wall is broken down west of Planet.

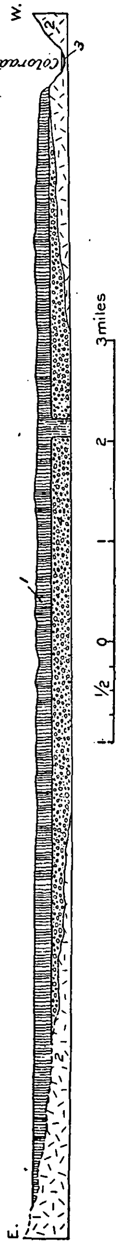


FIG. 16.—Section exposed in the south wall of Williams Canyon, showing the relation of the Colorado Valley to the Detrital-Sacramento Valley. 1, Basalt; 2, crystalline rocks; 3, flood-plain deposits; 4, Temple Bar conglomerate. Horizontal and vertical scale the same.

Although Williams River crosses the Temple Bar conglomerate, filling the Detrital-Sacramento Valley, it has not excavated a broad basin in it, as it has in the gravels filling the Big Sandy Valley, the difference being due to the protection afforded the conglomerate by the sheets of basalt.

Rock formations.—The oldest rock masses exposed in Williams Canyon are gneisses and metamorphosed sediments consisting of quartzites, slates, and limestones associated with beds of iron ore and veins of copper. Within valleys eroded in these rocks occur beds of the Temple Bar conglomerate. In the Detrital-Sacramento Valley, which crosses the Williams Valley, a thickness of nearly 1,000 feet is exposed under a sheet of basalt 800 feet thick. (See fig. 16.) The lowest part of the detritus extends beneath the bed of Williams River, but the underlying gneiss and granite are exposed at the sides of the old valley. The horizontally bedded sand and gravel have been disturbed locally, probably by the eruption of the basalt which burst upward through them.

Geologic section in Williams Canyon, 2 miles east of Colorado River.

	Feet.
Massive flow of basalt	800
Alternating layers of sand and basalt	40
Sand and gravel intersected by basalt dikes	900
Granite gneiss	50

Between the gravels and the massive flow of basalt at the top is a transition zone 40 feet in thickness, containing at the point where the section was made (Pl. VI, *B*) five thin sheets of basalt separated by beds of sand. Each sheet of basalt was outpoured upon what was then the surface, and each in turn was covered by sand. The sand is metamorphosed for a few inches beneath each sheet and contains fragments of scoriaceous basalt immediately above each sheet. The basalt extends completely across the old débris-filled valley to the rock walls on either side.

That the basalt burst upward through the sands and gravels in the midst of the old filled valley is proved by the occurrence of a large dike or neck, about 400 feet wide and several thousand feet long, exposed in the Williams Valley near the point where the section was made. The stratified deposits through which this dike broke are disturbed and burned to a brick red for about 300 feet from the dike. Several smaller dikes occur in the vicinity, and some of the eruptive masses to the north, seen only from a distance, appear to be volcanic necks standing as sharp pinnacles several hundred feet above the level of the surrounding plain.

OTHER VALLEYS.

Location and character.—There are several intermontane plains south of Williams River, known as the Cactus, Posas, and Ranegras plains, McMullan Valley, and an extensive unnamed plain south of the Harquahala Mountains. These are parts of the great desert plains of southwestern Arizona. They are, in part at least, old débris-filled valleys similar to those just described, but their original depth and the character of the filling can be judged only by surface indications. These plains have a general altitude of about 2,000 feet in the eastern half of the area described, and decline gradually westward to Colorado River (altitude 345 feet).

Detrital filling.—Near Williams River the Cactus Plains have been somewhat dissected by erosion; detrital bluffs 500 feet or more in height occur, while the total depth of erosion into the detritus (the difference between the general surface altitude of 2,000 feet and the river elevation of 600 feet) is about 1,400 feet. The bluffs thus exposed are composed of clay, sand, gravel, and angular rock fragments, consisting of granites, andesites, etc., with sheets of embedded basalt. Near the mouth of Date Creek a sheet of basalt about 30 feet thick caps the bluffs, but passes into the detrital beds a short distance back from the face of the cliffs. West of Date Creek two basalt sheets occur in the detrital beds. The lava was outpoured upon an old surface and metamorphosed the material beneath it to some extent. At the surface of each of the lava sheets the cavities contain zeolites, and the overlying sands contain fragments of the basalt, indicating that the gravels and the lavas are contemporaneous.

The detrital material exposed in the bluffs is comparable in thickness and has the same general appearance as the oldest detritus in the Big Sandy Valley and the Temple Bar conglomerate of the Detrital-Sacramento Valley. The basalt sheets embedded in it have the same petrographic character as those contained in the Temple Bar conglomerate (see p. 17) and were supposedly erupted at about the same time. For these reasons the detrital filling is correlated tentatively with the Temple Bar conglomerate.

GEOLOGIC HISTORY.

INTRODUCTORY STATEMENTS.

It is desirable to consider at this point the geologic history of the region—to review the facts that have been presented and to emphasize their significance. Certain considerations which depend upon the interrelations of features at various localities are also presented without reference to former descriptions. The reader should be reminded again that the observations were made during rapid reconnaissance trips and that large intervening areas were not examined. With the exception of the Paleozoic formations of the Plateau region, none of the sediments of northwestern Arizona are fossiliferous so far as observed, and the younger formations can not be traced continuously from place to place. The history of the region is largely one of destructive processes, and the ordinary means of correlation are wanting. For these reasons, although the sequence of the events is apparently clear, their places in the geologic time scale can not now be definitely fixed. The observed facts show that the late geologic history of the region is separable into epochs comparable with those established in neighboring regions, but in the absence of adequate correlation data the intention is to emphasize the sequence of events, the provisional correlations being offered only as a working basis.

PRE-CAMBRIAN CONDITIONS.

Crystalline rocks.—Throughout northwestern Arizona the oldest rocks are coarsely crystalline granites and gneisses. In the plateau to the east the granites underlie the Cambrian sandstone and are intersected by less coarsely crystalline intrusives.

Sedimentation.—The pre-Cambrian sediments so extensively developed in the Grand Canyon region apparently once extended over western Arizona, and remnants of them remain at the northern end of the region near Virgin Canyon and from Williams River southward in the southern part of the area examined.

Base-leveling.—Previous to the deposition of the Cambrian sediments there was a long period of erosion during which such sediments as may have been deposited in the eastern part of the region were removed by erosion and the underlying granites were base-leveled. The line representing this base-level may be followed in the cliffs from Grand Canyon to the southern end of the Juniper Mountains.

PALEOZOIC AND MESOZOIC CONDITIONS.

But little can be said of the history of this region during Paleozoic and Mesozoic time. Cambrian sediments, consisting of sandstone and shale (Tonto formation), underlie the plateau, and were probably deposited over a large part of western Arizona. No Ordovician or Silurian formations have been discovered, and the Devonian of Grand Canyon, described by Walcott,[a] was not identified in the area examined. The Carboniferous is represented by the Redwall limestone, which extends from the Mississippian into the Pennsylvanian, as previously shown in the description of rock formations (pp. 15–16). There is a limited exposure of Carboniferous strata younger than the Redwall in Iceberg Canyon, and Mesozoic formations occur east of the rim of the plateau in a manner which suggests the probability that they originally extended westward over the region described. So far as known, however, no remnants of any of these formations remain west of the cliffs.

Little is known regarding the original extent of the older sedimentary formations in western Arizona or of the circumstances attending their removal. Probably some of the erosion occurred during the Cretaceous period, as suggested by Gilbert,[b] but nothing was found to indicate what proportion of it was accomplished in pre-Tertiary and what in early Tertiary time.

TERTIARY EVENTS.

Explanatory statement.—No great amount of sediment was deposited within the area described during Tertiary time. The period was apparently one of uplift, volcanic activity, and extensive erosion, but it is not known whether the uplift began with the Tertiary or before, nor can the Tertiary be confidently separated from the Quaternary. The sequence of events, based upon physiographic evidence, can be stated with some confidence, but the various epochs can not be confidently referred to established subdivisions of time.

Denudation.—The erosion which removed the older sedimentary formations from western Arizona during early Tertiary and pre-Tertiary time was evidently on an extensive scale. Whatever Paleozoic and Mesozoic sediments had been deposited were stripped off and the underlying granites deeply dissected previous to the eruption of the oldest effusives. The Eocene sediments extensively developed farther north in parts of the plateau region are apparently absent from western Arizona, and the extensive denudation may have been accomplished in large part during Eocene time.

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[a] Walcott, C. D., Am. Jour. Sci., 3d ser., vol. 20, 1880, pp. 221-225.
[b] Gilbert, G. K., U. S. Geog. Surv. W. 100th Mer., vol. 3, 1875, pt. 1, p. 134.

Eruption of andesite.—The oldest effusive rock thus far found in western Arizona is the andesite in the vicinity of Gold Roads, a mining camp on Black Mesa, west of Kingman. The andesite rests upon granite and underlies an extensive series of rhyolites and younger andesites, but no further evidence of its age was obtained. It may be a time equivalent of the great masses of andesite comprising the Pine Valley Mountains and resting upon the Eocene sediments in the southwestern part of Utah. These masses, according to Huntington and Goldthwaite,[a] were probably extruded at the close of the Eocene. The provisional reference of the Arizona andesite to the close of the Eocene is based on the fact that, in the general sequence of events here described, its extrusion occurred between the period of early Tertiary erosion and the long period of base-leveling, during which part of the Mohave peneplain was formed. (See p. 59.)

Crustal movements and erosion.—Either during or shortly after the extrusion of the older andesites further uplift apparently occurred in western Arizona, followed by renewed erosion, which carried away much of the andesite and again exposed the granite. The Paleozoic sediments that formerly extended much farther to the west were eroded away at about the same time and the region reduced to a peneplain, parts of which are still preserved in the Truxton Plateau and in the plateau lying south of Iceberg Canyon, in which soft and hard layers alike are truncated. This may prove to be a part of the Mohave peneplain in southwestern Utah, which in the opinion of Huntington and Goldthwaite[b] was formed after the period of folding of the early Miocene.[c]

Certain phenomena described by Spurr,[d] from Meadow Valley Canyon, a tributary of Virgin River in southern Nevada, strengthen this supposition. He describes a succession of rocks very similar to those found in northwestern Arizona. Extensive beds of rhyolite rest on an eroded surface of older rocks and are overlain by extensive deposits of conglomerate and soft sandstone which he refers with a query to the Pliocene, and these in turn are overlain by basalt and Pleistocene gravel. His description of the Pliocene (?) conglomerate and its position in the sections given indicate that it is probably equivalent to the Temple Bar conglomerate, which is here regarded as Pleistocene. Fig. 16 of Spurr's paper shows faulted Paleozoic sediments peneplaned and overlain by the conglomerate. This faulting may prove to be part of the early faulting of the Plateau region, and the peneplain beneath the conglomerate to be part of the Mohave peneplain, in which case the relations in Meadow Valley Wash would

[a] Huntington, Ellsworth, and Goldthwaite, J. W., The Hurricane fault in the Toquerville district, Utah: Bull. Mus. Comp. Zoöl. Harvard Coll., vol. 42, 1904, p. 217.

[b] Idem, p. 226.

[c] Idem, p. 222.

[d] Spurr, J. E., Descriptive geology of Nevada south of the fortieth parallel and adjacent portions of California: Bull. U. S. Geol. Survey No. 208, 1903, pp. 139-148.

correspond with those found in the Plateau region and would form another link in the chain of evidence that the pre-Quaternary course of Colorado River was through southern Nevada, to the north of the present canyon.

Eruption of rhyolite and younger andesite.—After the formation of the peneplain, extensive masses of rhyolite and andesite, in the form of tuff, breccia, and flow, were spread over its surface, filling the depressions and covering all but the higher parts of the land surface. Although largely removed by later erosion, these lavas still cover wide areas, such as Black Mesa, a large part of the Truxton Plateau, and the mesa in the vicinity of Kingman. These lavas occur also to the east beyond the area described, and far to the south, where they form Castle Dome and the Chocolate Mountains in southwestern Arizona.

In places where the rhyolites and younger andesites occur in more or less regular horizontal beds, as near Kingman and in Black Mesa, they have a maximum thickness of about 3,000 feet. In more mountainous regions, as at the southern end of the Aquarius Mountains, they are apparently thicker. In other places, notably in the Truxton Plateau, they thin and disappear. The thickness of the rhyolites and younger andesites, and their areal distribution, indicate that they originally covered a large part of northwestern Arizona.

The time at which these great masses of igneous rock were extruded is not definitely known. It was after the Mohave peneplain had been formed, at least in large part, for the lavas rest upon the eroded surface. Furthermore, the amount of erosion which followed the extrusion of these lavas places this event far back in the Tertiary. For these reasons, and because of the evidence that the close of the Miocene was a time of mountain forming and of great volcanic disturbance in the Great Basin and the mountains west of it, the extrusions of rhyolites and younger andesites may be provisionally referred to the close of the Miocene.

Formation of the Grand Wash Trough.—Sometime during the middle Tertiary, and apparently before the completion of the Mohave peneplain, the Grand Wash fault was formed, with a displacement of several thousand feet, giving rise to the Grand Wash Trough. This faulting probably corresponds to the early displacements of the Hurricane and other faults described by Huntington and Goldthwaite,[a] and should not be confused with the faulting which accompanied the later uplift of the plateau.

Deposition of the Greggs breccia.—At the north end of the region described local deposition followed the extrusion of the rhyolites and younger andesites. These sediments in the vicinity of Temple Bar lie unconformably beneath the Temple Bar conglomerate and consist

[a] Huntington, Ellsworth, and Goldthwaite, J. W., op. cit., p. 226.

mainly of angular fragments of rhyolite, but otherwise are similar in character and stratigraphic position to the Greggs breccia, which, as already stated, consists mainly of granitic débris. Both breccias antedate the present course of Colorado River, which has eroded into them. This correlation would tend to place the Greggs breccia in the Pliocene. On the other hand, the physiographic evidence does not seem to favor this correlation. The rhyolites, supposed to have been erupted at the close of the Miocene, rest upon the peneplain, a fact which tends to place the breccia in the Miocene. It is evident, therefore, that the determination of the age of the Greggs breccia must await further investigation.

Erosion of the Detrital-Sacramento Valley.—A long period of erosion apparently followed the rhyolitic eruptions and succeeding accumulation of breccia, during which the Detrital-Sacramento Valley was excavated. Measured from the original surface now represented by the mesas on either side, this valley is 5 to 15 miles wide and 3,000 feet deep, including the gravel filling. It extends from southern Nevada southward to Williams River, where it is apparently interrupted by a lava-covered plateau, but its real continuity is shown by the gravel-filling beneath the lava (fig. 16, p. 54). From the plateau southward it is occupied by Colorado River for a distance of 75 miles, in the basin known as the Great Colorado Valley. Owing to circumstances beyond the writer's control, the old valley was not traced south of this basin. It may be pointed out, however, that at the southern end of the basin the river turns abruptly to the east and passes in a narrow rock canyon through the Chocolate Mountains. The general trend of the old valley suggests that it may continue through the hills west of Chocolate Canyon, or perhaps beneath the lavas, and connect with the Gulf of Calfornia (including at that time the Salton Sink), which lies southwest of the Chocolate Mountains.

The origin of the Detrital-Sacramento Valley, although a matter of great interest, can not be fully described until more information is available. It is in a region of profound faulting and surface warping, and may have originated as a succession of depressed areas. But whatever its origin it is believed to have been occupied and greatly modified, if not wholly formed, by a stream of considerable size. The reasons for this belief are as follows:

The beds of volcanic tuff, breccia, and flow in the mesas on either side are composed of the same kinds of rock and are so disposed as to indicate that they may originally have been connected across the intervening space. The width of the valley, 5 to 30 miles, as compared with its length, about 375 miles (including the Great Colorado Valley), together with its somewhat sinuous course, accords more nearly with the conception of a moderately mature river valley than with a succession of downthrown areas. But perhaps the strongest argument in favor of its formation mainly by river erosion is the presence, throughout its length, of sands and gravels similar to those known to have been deposited by aggrading streams.

Relation of Colorado River to the Detrital-Sacramento Valley.—The influence of Colorado River has not been considered thus far for the reason that no clear evidence has been obtained of its presence within the area described. The erosion previously accomplished may have been the work of the Colorado, or may have been accomplished by streams now extinct. But with the erosion of the Detrital-Sacramento Valley the recorded history of the Colorado in western Arizona apparently begins. The river changed its course within the area described during Quaternary time, and there are indications that still greater changes occurred in late Tertiary time; but in order to determine the nature and extent of the changes, it would be necessary to examine a large part of the Plateau region, where, on account of recent faulting, uplift, and subsequent erosion, the investigation would be difficult. There was apparently no great difference in elevation between the Basin region and the southern part of the Plateau region during mid-Tertiary time, the Mohave peneplain extending continuously over both. The evidence of peneplanation in the Meadow Valley and in the Toquerville region, and the general trend of the broad valley of the Virgin heading into this region, suggest that the Colorado may have flowed across what is now the Plateau region to the north of its present course and through the valley now occupied by the lower part of the Virgin into western Arizona, where it excavated the Detrital-Sacramento Valley. A large part of Tertiary time must have been consumed in eroding this great valley. If the formation of the peneplain be correctly assigned to the Miocene, and the extrusion of the rhyolites and younger andesites to the close of this epoch, the erosion of the Detrital-Sacramento Valley must have been accomplished in the Pliocene.

Uplift of the plateau.—The Plateau region seems to have been not notably higher than the area west of it until the end of the epoch during which the Detrital-Sacramento Valley was excavated. But at this time it was greatly elevated and faulted. Extensive displacements occurred along its western border, forming the Grand Wash, Cottonwood, and Aquarius cliffs. Probably the tilting of the great crust blocks like that of the Hualpai Mountains occurred about the same time. The block at Iceberg Canyon, previously upturned, was again tilted, together with the overlying Greggs breccia. The Cerbat Mountains were probably uplifted to some extent, but the principal movement there seems to have been downward, forming Hualpai Valley. About the same time flows of basalt occurred in the Detrital-Sacramento Valley west of Chloride, in the Cerbat Mountains, and elsewhere, which may antedate the crustal movements or may have occurred as accompaniments of the initial movements and later have been tilted to their present position.

Effect of uplift on Colorado River.—The lines of faulting and the axes of uplift were developed across Colorado River and no doubt materially changed its course. Whatever this may have been previously, the uplift of the plateau finally established its direction by causing it to erode the Grand Canyon. In the low-lying region west of the plateau the river flowed across the Grand Wash Trough, previously filled with the Greggs breccia, across the truncated edges of the upturned sediments now exposed in Iceberg Canyon, across a second débris-filled trough near Hualpai Wash, through the crystalline rocks of the Virgin Mountains, and into the previously formed Detrital-Sacramento Valley, which it apparently followed thence to the sea.

The reasons previously given in the detailed descriptions for believing this to be the river's former course may be briefly summarized as follows: Boulder and Black canyons west of the Detrital-Sacramento Valley are apparently younger than Virgin and Iceberg canyons. Remnants of the Temple Bar conglomerate, which occurs typically as the filling of the Detrital-Sacramento Valley, are found in Virgin and Iceberg canyons in positions that indicate deposition after these canyons were eroded; no such occurrence was observed in the canyons west of the Detrital-Sacramento Valley. There are gravel formations similar to the Temple Bar conglomerate west of the Black Mountain range, but they were apparently deposited previous to the erosion of Boulder and Black canyons.

QUATERNARY (?) EVENTS.

First canyon cutting.—During the first epoch of erosion that followed the uplift of the plateau Colorado River eroded Grand Canyon to a depth of 5,000 feet or more beneath the Mohave peneplain. West of the plateau it cut to a depth of somewhat more than 1,400 feet beneath this plain in Iceberg and Virgin canyons. The erosion in the Detrital-Sacramento Valley was probably correspondingly great, but little is known of this on account of the detrital filling of the valley which has not been removed.

The reasons for departing from the usage of former writers who assign the erosion of Grand Canyon to late Tertiary time are twofold: First, the Temple Bar conglomerate, deposited immediately after the first epoch of canyon cutting, is regarded as a Quaternary deposit for reasons stated in the section next following; second, the crustal disturbances resulting in the elevation of the plateau and the erosion of the Grand Canyon were of such magnitude and far-reaching influence in effecting radical changes in the geography and geology of the region that, considering this region alone, without reference to established subdivisions, they appropriately constitute the separation between two great periods of time. Since, therefore, the canyon cutting followed the uplift, it falls into the later or Quaternary period.

Deposition of the Temple Bar conglomerate.—After the canyon had been eroded to something like its present depth some change occurred which caused the river to deposit sand and gravel from Grand Canyon to the Gulf of California. Between the mouth of the canyon and the Detrital-Sacramento Valley no great volume of the gravels accumulated, owing to the limited dimensions of that part of the valley; but in the broad Detrital-Sacramento Valley extensive deposits were laid down to a depth of something like 2,000 feet.

Similar deposits were formed in other valleys of the Southwest, and the low-lying interstream areas were built up with angular rock débris derived from the near-by mountains. As previously described, the detrital formations of various parts of the Territory can not be definitely correlated, but beds apparently equivalent to the Temple Bar conglomerate are found throughout the Southwest.

During this epoch of deposition numerous volcanic eruptions occurred. Sheets of basalt underlie the gravels in some places and in others are included within them at several horizons. Toward the close of the epoch eruptions occurred near the mouth of Williams River, the molten basalt bursting upward through the filling of the Detrital-Sacramento Valley and spreading over its surface to a depth of 800 feet or more, apparently forming a volcanic dam. This sheet has since been greatly eroded and its original extent has not been determined. Lava hills north of Williams River having the appearance of volcanic necks suggest that the center of eruption and the real obstruction across the valley may have been between the Mohave Mountains and the Aubrey Hills, the sheet of compact lava south of Williams River being an outflow from this center.

A dam 800 feet high thrown across Colorado River at this place would have created slack-water conditions not only throughout the entire length of the Detrital-Sacramento Valley, but far into Grand Canyon, and must have facilitated the deposition of sand and gravel, which had previously accumulated in the valley to a depth of about 1,000 feet. The altitude of the basalt sheet does not differ greatly from that of the aggraded floor of the Detrital-Sacramento Valley to the north, and of the sand and gravel remnants found far above the river in the walls of Virgin Canyon. Deposition of sand and gravel apparently continued long after the extrusion of these lavas, filling the Detrital-Sacramento Valley to a level corresponding to the surface of the lava sheet, an additional depth of about 800 feet.

It is probable that the volcanic dam did not at once divert the river from its former course through the Detrital-Sacramento Valley, for the upper part of the valley filling, so far as observed, does not differ in physical character from the lower 1,000 feet, which is presumably a river deposit. The coarseness of the sediment and the absence of terraces along the margin are unfavorable to the supposition that the valley was transformed into a lake separated from the river. It is more probable that the water of the river continued to flow through the temporary lake, filling it rapidly with sediment or even building above the level of the dam before being finally deflected from its former course. A general view of the aggraded valley floor and its relation to the neighboring hills is shown in Pl. XI.

While accumulation was going on in the Detrital-Sacramento Valley other valleys and basins were filling with sediment. The Big Sandy, probably flowing at that time west of the Artillery Mountains and through the Cactus Plains to the Colorado, was evidently building up its course, and the Hualpai Valley, probably at first a lake basin, was filling with sediment. Briefly stated, it is probable that the Temple Bar conglomerate is a part of the widespread accumulation which occupies the low places of the Southwest from central New Mexico to California and northward over the entire basin region. The probability that sedimentation over a wide area was due to a single far-reaching cause or group of causes constitutes one of the principal reasons for correlating the Temple Bar conglomerate with the Lake Bonneville beds and less confidently with the Gila conglomerate. It is not the author's intention to argue that these beds are exact equivalents. They apparently belong, however, to a single division of time, like the Pleistocene epoch of the Quaternary.

It may not be out of place, furthermore, to reiterate the statement that the reconnaissance surveys were inadequate for the final solution of the broad problems which, on account of their local bearing, must of necessity be discussed. The age of the Temple Bar conglomerate and its relation to other similar deposits, the changes in the course and activities of Colorado River, and the causes of these changes, are all problems to be finally solved only after much more extended investigation.

River diversion.—The extensive aggradation caused some of the streams to abandon their old courses, and the sand and gravel filling the valleys were in some cases covered with angular wash. A notable occurrence of the diversion of a river and the burial of its gravels, in the Salt River Valley, has been described by the writer,[a] who shows that Salt River, which now flows north of the Salt River Mountains, formerly joined the Gila east of these mountains, about 40 miles farther upstream.

Colorado River left the Detrital-Sacramento Valley and established a new course west of the Black Mountain Range, from Boulder Canyon

[a] Lee, W. T., Underground waters of Salt River Valley, Arizona: Water-Supply Paper U. S. Geol. Survey No. 136, 1905, pp. 125–127.

to the mouth of Williams River, a distance of about 125 miles. This diversion may have been due in part to the volcanic dam which had been thrown across the Detrital-Sacramento Valley near Williams River; or it may have been caused wholly by the normal deflection of the river over the aggrading surface—an action well illustrated in the frequent changes of course over the flood plains and delta of the Colorado at the present time. It is noteworthy in this connection that the volcanic dam near Williams Canyon, the highest remnants of the detrital beds, and the mountain ridges through which the river cut at Boulder and Black canyons, do not differ greatly in altitude.

Second canyon cutting.—A second epoch of canyon cutting was brought about by some change which caused the streams throughout the Southwest to erode their channels. The streams which had not been deflected from their former courses reexcavated their old valleys; those that had been deflected cut new canyons. Colorado River reexcavated its old valley from Grand Canyon westward to the Detrital-Sacramento Valley, where it left its former course, passing westward across the Black Mountain Range and thence southward to the mouth of Williams River, where it returned to the old valley which it now occupies.

Viewed from the standpoint of existing topography, a more difficult course could scarcely have been selected. Instead of reexcavating the Detrital-Sacramento Valley, where the only hard rock to be eroded was the volcanic dam, it eroded four rock canyons (Boulder, Black, Mohave, and Aubrey) and crossed four débris-filled basins (Las Vegas, Cottonwood, Mohave, and Chemehuevis) before returning to its former course. The excavation of the detritus in the basins was naturally more rapid than the work in the hard rock of the ridges separating them, and the result is the conspicuous alternation of short, sharp canyons and basin-like valleys characteristic of lower Colorado River.

During this epoch the downcutting was apparently very rapid, the rock canyons being narrow, their walls rising abruptly from the water's edge, as in Black Canyon (Pl. VIII, *B*) and in Boulder Canyon. The rapidity of the downcutting is perhaps most strikingly shown where the river has cut through the Temple Bar conglomerate, as at Temple Bar, leaving the poorly consolidated gravels standing in perpendicular cliffs hundreds of feet high. (See Pls. II and VIII, *A*.) The occurrence of these high cliffs of unconsolidated gravel and the absence of extensive weathering are not wholly in accord with the suggestion that the change from the aggrading to the degrading condition of the river was due entirely to a change of climate.

Deposition of Chemehuevis gravel.—Some influence not certainly known brought the second epoch of erosion to a close and caused Colorado River and other streams of the Southwest again to fill their valleys with sand and gravel. The open basins which had been excavated along the Colorado while the canyons were being cut in the harder rock were filled to a depth of several hundred feet with material which has been called the Chemehuevis gravel, and which extends from the mouth of Grand Canyon to the Gulf of California. In the midst of this epoch some change occurred which caused the accumulation of coarser material in the vicinity of Bull Head. This change, however, may have been local, as the division into lower and upper gravels is not conspicuous in other places, so far as observed.

During the accumulation of the Chemehuevis gravel Colorado River evidently shifted its course within narrow limits over the aggrading valley floor, as it had done over a much wider area during the accumulation of the Temple Bar conglomerate.

Third canyon cutting.—When the river again began to erode its channel it reexcavated for the most part the old valley, but in a number of places abandoned its former course and cut rock gorges, leaving the gravel-filled channel at one side, as in Cottonwood Valley (p. 37), Pyramid Canyon (p. 38), Mohave Canyon (p. 42), and Chocolate Canyon (p. 48).

For a third time the river eroded to some unknown depth below its present bed. Borings to a maximum depth of about 200 feet at the dam sites of the Reclamation Service failed to penetrate through the gravels.

Formation of flood plains.—In very recent geologic time Colorado River changed again from a degrading to an aggrading stream, and is once more building up its course. In the broad parts of the valley the accumulation is evidenced by the wide bottom lands over which the river frequently changes its course, sometimes gradually by lateral cutting and filling, and sometimes suddenly by cutting a new channel during a flood, forming numerous sloughs, lagoons, and oxbow lakes.

The great depth of the débris-filled channels within the newest canyons, as shown by the soundings for bed rock, raises the question, What proportion of the depth should be attributed to the normal cutting of the river and what proportion to permanent filling?

Cooley[a] shows that Missouri River at Nebraska City probably erodes its bed to a depth of 70 to 90 feet. Near Omaha the depth of scour and fill during the year 1883 amounted to about 40 feet. On this subject Chamberlin[b] remarks: "In the drift-filled bottoms of the great branches of the Mississippi system it is wholly within bounds to regard at least the upper 40 or 50 feet of the deposit over which the

[a] Report Chief Eng. U. S. A. for 1879-80, pt. 2, pp. 1060-1071. See also Chamberlin and Salisbury, Text Book of Geology, vol. 1, p. 185.

[b] Chamberlin, T. C., Jour. Geol., vol. 11, 1903, p. 72.

river meanders as subject to scour and fill, and to entertain the suggestion that the deeper portions down to 100 feet or more may be similarly affected."

Some instructive data were secured during the construction of bridges across Mississippi and Missouri rivers. N. M. Fenneman[a] has made a special study of this subject and states that the depth of scour, as shown by the occurrence of buried wreckage and also by direct soundings, is 100 feet or more, and that the occurrence of gravels resting on freshly polished rock at a maximum depth of about 335 feet is interpreted as showing that the river transports gravels of considerable size and actively erodes its bed to this great depth. It seems possible, however, that some part of this material may be due to permanent filling in a glacial or preglacial valley, such as are known to exist in the Mississippi Valley.

It is probable that the depth to bed rock shown by the soundings at the various dam sites is largely due to the normal action of the river, cutting deep in times of flood and filling the channel at times of low water. It is equally probable, however, that the channel is to some extent permanently filled.

RÉSUMÉ OF HISTORY.

For convenience of reference, the succession of epochs and their possible time relations are tabulated below.

Table of events in geologic history in western Arizona.

Period.	Epoch.	Deposition epoch.	Erosion epoch.
Quaternary.	Recent	11. Formation of flood plains; accumulation still in progress.	
		10	Rejuvenation of streams; Colorado reexcavates old valley in part and cuts several short rock gorges.
		9. Deposition of the Chemehuevis gravel.	
		8	Rejuvenation of streams; Colorado River, flowing west of the Black Mountains, lowers its bed 2,000 feet or more and cuts Aubrey, Mohave, Black, and Boulder canyons.
	Pleistocene	7. Widespread aggradation and volcanic eruption. About 2,000 feet of the Temple Bar conglomerate deposited.	
		6	Uplift of the Colorado Plateau; erosion of Grand Canyon; flow of Colorado River in the Detrital-Sacramento Valley.
?	?	?	?
Tertiary.	Pliocene	5	Erosion of the Detrital-Sacramento and other valleys.
	Miocene	4. Local deposition; eruption of rhyolite and andesite.	
		3	Peneplanation and recession of the Yampai Cliffs.
	Eocene	2. Eruption of andesite.	
		1	General degradation.

[a] Personal communication.

CORRELATIONS.

Explanatory statements.—Although no definite correlations can be made between the products of deposition and erosion of this and other regions, there are certain presumptions worthy of consideration. The succession of Quaternary events in western Arizona is similar to that of the Lake Bonneville and other inland regions, and the long epochs of erosion and thick deposits of sediment represent comparable lengths of time for each region. Western Arizona is a part of the great area of western America which underwent extensive changes of elevation during Tertiary and Quaternary time, the various epochs of which were recorded in marine deposition and erosion along the Pacific coast. Since western Arizona is a part of the Pacific drainage area, although far inland, it is presumably true that the great epochs of the coast correspond in some measure with the great epochs of the interior, inasmuch as the thick marine deposits must represent long periods of erosion of the land areas.

Comparison with Lake Bonneville history.—In his summary of the history of the Lake Bonneville oscillations Gilbert [a] enumerates the following events, given in order from oldest to youngest:

1. Erosion. Gilbert says: "This we may call the pre-Bonneville low-water epoch. It was of great duration compared with those enumerated below."
2. Deposition. First Bonneville epoch of high water; deposits of Yellow Clay. This epoch is estimated (p. 316) as being five times as long as the second epoch of deposition (4).
3. Erosion. Represented by unconformity and by alluvial deposits. The duration is estimated (p. 316) as greater than that of the final retreat of the water (5).
4. Deposition. Second Bonneville epoch of high water; deposit of White Marl.
5. Final retreat of water, intermittently, to present stage.

The thickness of the Lake Bonneville beds was not known at the time of Gilbert's writings, nor is their maximum thickness yet determined. Boutwell [b] has shown that a 2,000-foot well at the eastern margin of Salt Lake, near Farmington (altitude 4,231 feet), does not penetrate through the fragmental beds. A similar thickness of sediments has recently been found in a deep boring at Neels, Utah (altitude 4,621 feet), a station on the San Pedro, Los Angeles and Salt Lake Railroad east of Sevier Lake. The well, which was completed in 1906, is 1,998 feet deep and penetrates 1,944 feet of sedimentary matter before reaching bed rock, which is granite.

[a] Gilbert, G. K., Lake Bonneville: Mon. U. S. Geol. Survey, vol. 1, 1890, p. 259.

[b] Boutwell, J. M., Oil and asphalt prospects in Salt Lake basin: Bull. U. S. Geol. Survey No. 260, 1904, p. 471.

A driller's record, which was apparently kept with exceptional care, exhibits no change in character to indicate that the lower part of the beds are pre-Bonneville in age. It is worthy of note that Neels is located in the narrow neck of Lake Bonneville that connected Escalante Bay with the larger body of water to the north, as shown in Gilbert's map (Pl. III of the Lake Bonneville monograph). It is probable that the broader parts of the lake were much deeper than this narrow strait, and that the sediments filling them were correspondingly thicker.

Because of the importance of this well in showing the character and depth of the Lake Bonneville sediments, the driller's record is here given:

Record of San Pedro, Los Angeles and Salt Lake Railroad well at Neels, Utah.

	Thickness (feet).	Depth (feet).
Surface soil	4	4
Sedimentary (alkali)	5	9
Fire clay	40	49
Water-bearing quicksand	9	58
Shale and soapstone	21	79
Rock (sedimentary)	6	85
Water-bearing quicksand	3	88
Soapstone	11	99
Soapstone with fossil bowlders	39	138
Water-bearing quicksand	4	142
Fire clay	12	154
Blue waxy clay	34	188
Gray shale and clay mixed	7	195
Gray waxy clay	36	231
Lava rock	12	243
Blue waxy clay	12	255
Sedimentary sandstone	6	261
Blue waxy clay	25	286
Water-bearing quicksand	6	292
Blue waxy clay	28	320
Water-bearing quicksand	7	327
Sedimentary sandstone	10	337
Yellow clay	16	353
Water-bearing quicksand	5	358
Yellow clay	27	385
Blue waxy clay	110	495
Yellow clay	15	510
Sedimentary sandstone	24	534
Blue waxy clay	17	551
Soapstone	50	601
Blue waxy clay	11	612
Silt	8	620
Water-bearing quicksand	3	623
Yellow clay	53	676
Sedimentary sandstone	12	688

	Thickness (feet).	Depth (feet).
Yellow clay	34	722
Blue waxy clay	117	839
Yellow clay	9	848
Blue waxy clay	210	1,058
Blue shale (sand mixed)	18	1,076
Blue waxy clay	13	1,089
Blue shale	45	1,134
Blue shale (sand mixed), yielded hot water	71	1,205
Red shale	12	1,217
Blue shale	70	1,287
Red shale	24	1,311
Blue shale	28	1,339
Red "keel" stone	6	1,345
Water, sand, gravel, and bowlders	70	1,415
Sedimentary sandstone (brown)	35	1,450
Red sandstone	95	1,545
Red shale (burned)	35	1,580
Trap rock (dark brown)	36	1,616
Red shale (burned)	56	1,672
Lava rock with calcite crystals	14	1,686
Red sandstone	68	1,754
Red clay (sticky)	48	1,802
Volcanic deposit, ash, and bowlders	105	1,907
(Gas under pressure sufficient to raise 6,200 pounds of tools 400 feet.)		
Bowlders (cemented)	6	1,913
Cavity	9	1,922
Bowlders	22	1,944
Cavity	6	1,950
Granite with cavities and gas	48	1,998
	1,998	

At the risk of carrying comparisons too far, attention is called to the possible correspondence between the Quaternary epochs of western Arizona and those of the Lake Bonneville basin. The high stages of Lake Bonneville have been explained as being due to the changes of climate toward increasing precipitation, and the low-water stages toward increasing aridity. Periods of great precipitation (and high water in an undrained lake) are those of active stream erosion, and, other things being equal, the periods of sedimentation in Lake Bonneville should be the periods of stream erosion in neighboring regions. On this assumption Gilbert's first Bonneville epoch of high water, during which 2,000 feet or more of sediment consisting largely of fine material was deposited, seems to correspond in duration and position in the time scale to the erosion of Grand Canyon (epoch 6 of the Arizona scale); his first epoch of low water, to the deposition of the Temple Bar conglomerate; his second Bonneville epoch of high water, to the erosion of Black and Boulder canyons (epoch 8 of Arizona); and his final epoch of desiccation, which was accomplished intermittently, to the deposition of the Chemehuevis gravel and the following minor epochs represented along lower Colorado River. Whether so close a parallelism of events is warrantable or not, it is evident that the general sequence of events as recorded in the Bonneville basin is similar to that of the Colorado Valley.

Comparison with southern California.—Hershey[a] has arrived at a conclusion regarding the length of Quaternary time and the complexity of its history which is similar in a general way to that shown by the epochs of the Bonneville basin and of western Arizona. Probably the most significant feature of his subdivisions in relation to the phenomena of western Arizona is a long epoch of erosion at the beginning of the Quaternary, which in his opinion is much longer than all the subsequent epochs combined. This epoch may, on further study, prove to be equivalent in point of time to the erosion of Grand Canyon.

Comparison with the Pacific coast.—In studies of the marine beds of the Pacific coast, Arnold[b] shows that, while the epochs of the Tertiary and Quaternary are very fully represented, the subdivisions do not conform in all cases to those of the standard time scale. The division of Tertiary time as given in his publications, which in personal interviews he asserts will hold good for the Pacific coast generally, is shown in the following table:

Correlation table of the marine Tertiary and Pleistocene formations of the Pacific coast.

Period.	Epoch.	Formation.[c]
Quaternary	Pleistocene	San Pedro, 1,000 ± feet.
Tertiary	Pliocene	Merced, 5,000 ± feet.
		Purisima, 800 ± feet.
	Transitional	San Pablo, 1,500 to 2,000 feet.
	Miocene	Monterey, 2,500 ± feet.
		Vaqueros, 3,000 ± feet.
	Oligocene	San Lorenzo, 2,300 ± feet.
	Eocene	Tejon, 4,000 ± feet.
		Martinez, 1,000 to 2,000 feet.

a Hershey, O. H., The Quaternary of southern California: Bull. Univ. California Dept. Geol., vol. 3, 1902, pp. 1-30.

b Arnold, Ralph, The Tertiary and Quaternary pectens of California: Prof. Paper U. S. Geol. Survey No. 47, 1906, p. 9.

c In this column full lines represent unconformity; broken lines, conformity.

According to Arnold, the great time breaks occurred: (a) At the close of the Eocene, the break in this case being indicated by a distinct change of fauna; (b) before the close of the Miocene; and (c) sometime during the Quaternary; the latter two being erosion breaks. It seems probable that the long periods of sedimentation along the Pacific coast may be equivalent in a general way to the periods of quiet erosion described in western Arizona, and that the great and widely recognizable unconformities of the coast may correspond to the periods of crustal disturbances and volcanic activity of the interior. Thus the long period of erosion resulting in the formation of the Mohave peneplain may correspond to the deposition of the Vaqueros and Monterey formations, and the eruptions of rhyolite in Arizona to the unconformity between the San Pablo and the Monterey, which is associated with the volcanic eruptions of the coast region.

The similarity in succession of Quaternary events in the two regions is not striking. Pleistocene time is represented on the coast by thick sediments and Recent time by some of the raised sea beeches. The thickness of the Pleistocene sediments renders it probable that the time required for their deposition is comparable with the long period of erosion during early Quaternary in the Arizona region, and the relative position of these epochs in the time scale apparently warrants provisional correlation. The terraces of the coast may correspond in time with the various epochs of erosion and deposition of the Arizona region.

Comparison with the Plateau region.—In the Plateau region the subdivision of Tertiary and Quaternary time is based mainly on physiographic evidence. Davis [a] has shown that there were two main cycles of erosion, designated the plateau cycle and the canyon cycle. During the first or plateau cycle a large area in northern Arizona and southern Utah was reduced to a peneplain. The original surface of this peneplain is preserved in places by lava flows, as on the Shiwitz Plateau in northern Arizona and near Toquerville, Utah, [b] but has generally been dissected by later erosion. The peneplain will perhaps be best recognized—if due allowance be made for subsequent erosion—as the surface of the plateau in which Grand Canyon is eroded in northern Arizona. During the second or canyon cycle Grand Canyon was carved by the Colorado, and the peneplain, now elevated, was dissected to a less extent by the smaller streams.

Following Davis, Huntington and Goldthwaite in their description of the Toquerville region of southwestern Utah emphasize the importance of these cycles and add many details which aid in studying

[a] Davis, W. M., An excursion to the Grand Canyon of the Colorado: Bull. Mus. Comp. Zoöl. Harvard Coll., vol. 38, 1901, pp. 107-201.

[b] Huntington, Ellsworth, and Goldthwaite, J. W., The Hurricane fault in the Toquerville district, Utah: Bull. Mus. Comp. Zoöl. Harvard Coll., vol. 42, 1904, p. 231.

the geologic history of the Grand Canyon region. The succession of Tertiary and Quaternary events described by them may be summarized, in order from oldest to youngest, as follows:

1. Eocene. A period of deposition during which the Plateau region was low.
2. A period of elevation accompanied by folding, flexing, and extrusion of andesite.
3. A second period of erosion—the pre-fault cycle.
4. Earlier faulting, during which the great faults of the Plateau region, such as Hurricane and Grand Wash faults, were originally formed.
5. Interfault cycle of erosion, during which the Mohave peneplain was formed.
6. Later faulting and final uplift of the High Plateau.
7. Erosion of Grand Canyon.

The history thus developed corresponds in many ways with that of western Arizona, but differs notably in some respects. The early Tertiary erosion in western Arizona seems to correspond in time with the Eocene sedimentation of the plateaus, and eruptions of andesite marked the close of the period of both provinces. There is, furthermore, no disagreement regarding the time of uplift and faulting immediately preceding the erosion of Grand Canyon, but further investigation is necessary before the subdivision of middle and later Tertiary time in the two provinces can be harmonized. Apparently, the great masses of rhyolite, 3,000 feet thick in western Arizona and presumably extruded at the close of the Miocene, were not found in southwestern Utah, and the long period of erosion which followed their extrusion, presumably during Pliocene time, seems to be included by Huntington and Goldthwaite in the time during which the Mohave peneplain was being formed, since according to them this cycle of erosion ended with the uplift of the plateau and the origin of Grand Canyon.

Since the Mohave peneplain is here used as a correlation horizon, it may be in place to inquire into its probable extent. As already stated, this peneplain, which in the Plateau region of southern Utah and northern Arizona is represented by the platform at the top of Grand Canyon, is here regarded as extending generally over northwestern Arizona. A similar peneplain has been described by Lindgren[a] in the Sierra region of eastern California, where he finds evidence of an extensive peneplain, formed presumably during the Miocene and covered in part by the younger auriferous gravels, and these in turn by rhyolites and andesites—a sequence which corresponds with that in northwestern Arizona. Other localities might

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[a] Lindgren, Waldemar, Age of the auriferous gravels of the Sierra Nevada: Jour. Geology, vol. 55, 1896, pp. 881-906.

be referred to in which mid-Tertiary erosion may correspond in time with the formation of the Mohave peneplain. In view, however, of the great distances between the various localities described and the difficulties of correlating periods of erosion, the most that can be said is that the available evidence points to the probability that the Mohave peneplain was one of great extent and may prove to be a valuable means of correlation.

WATER SUPPLIES.

SURFACE WATERS.

PRECIPITATION.

Little is definitely known of the rainfall in western Arizona. According to E. C. Murphy,[a] of the U. S. Geological Survey, the average annual precipitation for the region is approximately 5 inches. At Needles, Cal., records kept by the Weather Bureau since 1892 show an annual mean of 2.47 inches.

EVAPORATION.

Evaporation in western Arizona greatly exceeds rainfall. No records are available for the area described, but it probably does not differ very much from that at Yuma, Ariz., where the annual evaporation, as given by Murphy, is 82.32 inches.

STREAMS.

COLORADO RIVER.

Flow.—A gaging station has recently been established at Hardyville, near old Fort Mohave, for measuring the flow of Colorado River. Records, however, are already available for the last four years at Yuma, Ariz., which probably give most satisfactorily the volume carried by the lower Colorado.

Discharge of Colorado River at Yuma, Ariz.

	Total in acre-feet.	Mean in second-feet.
1902	7,960,189	10,970
1903	11,329,032	15,595
1904	10,109,004	13,922
1905	19,710,000	27,300
Average	12,277,056	16,947

Irrigable lands.—Although a large amount of water is available in Colorado River, the irrigable land is limited in amount and confined

[a] Personal communication.

to the flood plains. According to Homer Hamlin,[a] of the Reclamation Service, the acreage is distributed as follows:

Irrigable land along Colorado River.

	Acres.
Cottonwood Valley	5,000
Mohave Valley	50,000
Chemehuevis Valley	20,000
Great Colorado Valley	200,000
Yuma Valley	100,000
	375,000

The ways and means of irrigating these lands have been investigated by the Reclamation Service, but except for the Yuma project, now under construction, no development has yet been undertaken.

Outside of the flood plains no lands within the area described are sufficiently low to be irrigated from the river. The broad valleys and detrital plains occupying so large a part of the region, although admirably adapted to agriculture in other respects, are too high to be economically supplied with water from Colorado River by any means known at the present time. In order to water the Hualpai or Detrital valleys it would be necessary to raise the water of the river about 2,000 feet, and the case is nearly as hopeless for the valleys farther south.

Dam sites.—Several dam sites have been selected along Colorado River by the engineers of the Reclamation Service, and much has been done in the way of investigation as far north as the Cottonwood Valley. Possible dam sites occur in Chocolate Canyon (fig. 13), Aubrey Canyon, at Bulls Head in Pyramid Canyon (Pl. IX), and at Eagle Rock in the Cottonwood Valley (fig. 7). In none of these localities, however, has bed rock been found sufficiently near the surface to warrant the construction of masonry dams. In Chocolate Canyon borings reached the depth of 138 feet; in Aubrey Canyon, 75 feet; in Pyramid Canyon, 100 feet. But in no case was the maximum depth of the old gravel-filled channel reached.

The canyons north of the Cottonwood Valley offer excellent opportunities for the construction of dams, but little has been done further than the selection of certain favorable localities. Several have been selected by the Reclamation Service, and others by private companies who contemplate using the water power in developing the mineral resources of the region. The questions involved are mainly of an engineering nature, but it may be in place here to describe certain geologic conditions that are likely to affect development.

In Recent time—the last epoch described under "Geologic history"—the river has been filling its channel, at least in its lower

[a] Personal communication.

reaches. It is evident, therefore, that even in the newest channels, such as that at Bulls Head, bed rock is not to be expected as near the surface as it would be if the river were in an eroding stage. In other words, it is probable that the rock channel is deeper than the maximum depth of scour.

The flood-plain deposits, so conspicuous in the lower reaches of the river, become less conspicuous upstream, until in Black Canyon rapids of notable proportions occur. In the absence of soundings in the channel for bed rock farther north than Bulls Head, it is impossible to say that the channel is not filled in the northern portion of the region as it is farther south where soundings have been made. The swift current washes the fine material away and leaves large bowlders clogging the channel even where the grade of the river is steep enough to form dangerous rapids. It is the writer's impression that the river is flowing essentially on rock bottom through Black, Boulder, Virgin, and Iceberg canyons, with only such obstructions of bowlders as are incidental to variations in the river's power of transportation; in other words, that there is no permanent filling in the bottom of those canyons.

The deflection of the river previously described has resulted in the cutting of young channels in many places for short distances, as at Eagle Rock, Bulls Head, Great Bend, etc. It is in these young channels that bed rock is to be expected at the least depth. The relation, however, to the old débris-filled channel at the side may be such as to influence this depth. For example, at Bulls Head the depth to bed rock in the channel now occupied by the river might be greater near the edge of the old channel, owing to the fact that the new channel might coincide with some lateral wash of the old, while north of Bulls Head Rock, midway of the young channel, bed rock might be much nearer the surface. The depth to which a large river works is known to be great, although there is little information at present to indicate the maximum depth to which Colorado River works. The records of Missouri River, previously cited (p. 66), indicate the possibility that a depth of 73 to 100 feet, or even more in narrow channels, such as that at Bulls Head, is to be expected as a result of river abrasion alone.

Considering further the depth of scour, it is evident that the river will cut to a less depth in wide passages than in narrow passages where the current is swift. The narrow places are usually selected as dam sites on account of the presence of favorable abutments comparatively close together. It is possible that in certain cases the depth to bed rock in the wide part of a gorge, where the abrasive force is weak owing to a diminution of velocity, might be enough less than in the narrow parts, where the current is swift, to more than compensate for the greater length of a dam.

BIG SANDY WASH AND WILLIAMS RIVER.

Big Sandy Wash has a small permanent flow, and Williams River furnishes water for the irrigation of a few ranches, but the floods of Williams River are evidently large. Water marks on the rocks and drift material lodged in the face of the canyon walls are seen at the height of 20 feet or more above the bed of the stream. The quantity of water discharged by Williams River is apparently sufficient to warrant the construction of a reservoir in the basin east of Williams Canyon. This basin is about 7 miles long and 5 miles wide, and the gorge forming a possible dam site is about 60 feet wide at the water line.

A reservoir at this place would be of comparatively little use in irrigation, as there is practically no irrigable land available. It might, however, be of great benefit in producing power for the development of the mineral resources. Rich deposits of gold, copper, and iron are known to occur in this region, but development is hindered or wholly prevented by the want of transportation facilities. The production of power, such as seems possible in this locality, might be the means of developing a rich mining district.

UNDERGROUND WATERS.

SURFACE INDICATIONS.

In many places throughout the Southwest the unconsolidated deposits filling the old valleys and intermontane basins are saturated with water, and the hope was entertained that this might be the case in the area here described. The geography of the region, however, is not favorable for the accumulation of large quantities of underground water, nor for the retention of such as might accumulate. The rainfall is slight and no large quantities can be derived from streams. Colorado Canyon on the north and west forms an effectual outlet for waters which might otherwise accumulate in the gravels.

From surface indications the Hualpai Valley would seem to have an underground water supply. It is an undrained basin into which Truxton Creek empties, and contains standing water for considerable periods. Only one well has been bored in the valley, at its northern extremity in Hualpai Wash. The absence of water in this well is not considered proof that water may not exist near the surface in the center of the valley.

In the other valleys and plains of the region the prospect is not encouraging. There is little opportunity for the accumulation of water in the gravels of the Cactus Plains, because of drainage into Colorado River to the west and Williams Canyon to the north. Conditions in the McMullen Valley are slightly more favorable, but water is found only at depths of 100 feet or more. No wells are reported from the plains south of Harrisburg.

WELLS.

Nelson.—The well at Nelson, Ariz., is 1,043 feet deep. At 516 feet a little water was found, and in the sandstone near the bottom a larger supply was encountered; but the available quantity has not been ascertained. The formations passed through are as follows:

Log of railroad well at Nelson, Ariz.

	Feet.
Cemented detritus	0– 44
Limestone (Redwall)	44– 396
Sandstone and shale (Tonto)	396–1,043

Peach Springs.—A well at Peach Springs, Ariz., is 920 feet deep. A small amount of water was encountered somewhere in the lower half, but the horizon is not known. Water stands at a depth of 413 feet, and a preliminary pumping test yielded 25 gallons per minute, or 14,000 gallons per day of twenty-four hours. This is insufficient for railway use, and the well is to be sunk deeper. The formations passed through are as follows:

Log of railroad well at Peach Springs, Ariz.

	Feet.
Cemented gravel	0–200
Limestone (Redwall)	200–560
Shale (Tonto)	560–920

Hackberry.—There are several dug wells at Hackberry, Ariz., in or near the bed of Truxton Creek. They penetrate through the detritus and encounter granite at a depth of about 70 feet, where a limited flow of water is obtained. The well at the railway station is taxed to its extreme limit in supplying 80,000 gallons in twenty-four hours, or 55 gallons per minute.

Kingman.—There are about 60 wells in the town of Kingman. A few of these are dug, but most of them are drilled. They are from 120 to 200 feet in depth, according to the difference in surface elevation. The water occurs in a bed of volcanic tuff about 30 feet thick, which rests upon the granite. An abundance of water is obtained from these wells to supply the needs of the railroad and the town.

Gold Basin.—Two wells 500 and 700 feet deep were drilled several years ago in Gold Basin at the northern end of the Hualpai Valley, about 50 miles north of Kingman. Nothing but detrital material was penetrated, and no water was encountered.

Drake.—The well at Drake, in the Sacramento Valley, is 687 feet deep and penetrates to bed rock. Water was encountered at a depth of 430 feet in "gray granite" and rose 30 feet. (This material is undoubtedly granitic wash, cemented by carbonate of lime. Cemented material of this kind is common in the Quaternary deposits throughout the arid regions. The yield of the well has not been determined.

Log of railroad well at Drake, Ariz.

	Feet.
Sand and bowlders	0- 45
Brown sand	45- 90
Bowlders	90-160
Brown sand	160-178
Sand and gravel	178-223
Black lava	223-308
Yellow sand	308-368
Black lava	368-408
Flint	408-414
Black lava	414-419
Gray granite	419-475
Black lava	475-483
"Gray granite," water bearing	483-537
Clay	537-578
Disintegrated granite	578-603
Solid granite	603-687

Yucca.—There are two deep wells at Yucca, situated near Sacramento Wash. The first was drilled in 1889 and has been in operation since that time. The amount of water obtainable was not sufficient for the needs at that point, and a second well has been put down to a depth of 1,004 feet. Water is said to have been encountered at a depth of 310 feet, but when measured by the writer in the new well it was standing at a depth of 346 feet. No special water-bearing stratum was encountered below the first, and the additional supply is obtained by slow seepage through the sand and gravel. The material encountered is as follows:

Log of railroad well at Yucca, Ariz.

	Feet.
Cemented sand and gravel	0- 370
Clay	370- 455
Gravel	455- 555
White sand	555- 905
Granite	905-1,004

Haviland.—The well at Haviland is 505 feet deep and is in volcanic material most of the way. Water was encountered at a depth of 248 feet and rose 48 feet. The well yields 60,000 gallons of water per day, or about 42 gallons per minute. The material penetrated is as follows:

Log of railroad well at Haviland, Ariz.

	Feet.
Bowlders	0- 12
Lava	12-260
White volcanic tuff	260-505

Big Sandy Valley.—Several wells dug in Big Sandy Wash encountered water 15 to 75 feet below the surface, according to locality. It is reported that a few years ago water was sufficiently near the surface to seep into the lower places along the bottom of the valley, where it was used for irrigation; but during the last few years this seepage has disappeared.

Harrisburg.—Near Harrisburg, at the point where the wash draining the McMullen Valley passes through the constriction between the mountains, a centrifugal pump has been established, and water is obtained in sufficient quantities to irrigate a small ranch. This supply is local and limited in amount.

Other wells.—At a number of places in McMullen Valley, in the Cactus Plain, and in the plains of the southern extremity of the region, wells were reported; but nowhere was ground water encountered in sufficient quantities or near enough to the surface to warrant any attempt at development for irrigation.

Records of railway wells in northeastern Arizona.

Location.	Depth.	Diameter.	Year completed.	Depth to water.	Water raised by—	Amount raised in 24 hours.	Remarks.
	Feet.	*Inches.*		*Feet.*		*Gallons.*	
Haviland	505	12	1901	200	Air lift	60,000	
Yucca No. 1	534	10	1889	346	....do	[a]90,000	36,000 gallons per day is all that can now be pumped.
Yucca No. 2	1,004	13	1903	346	....do	Not tested.	
Kingman	120–200	Dug.	(?)	(?)	Steam pump		
Drake	684	12	1901	400	Air lift	Not tested.	
Hackberry	70	Dug.	(?)	66	Steam pump	80,000	
Peach Springs	920	13	1903	413	....do	14,000	Not satisfactory; will be sunk deeper.
Nelson	1,043	13	1902	490		Not tested.	Water struck at 516 feet.

[a] When tested.

DEEP-WELL TEMPERATURES.

Temperature readings taken at two of the deep wells are given in the following table. The results obtained at Yucca are probably more satisfactory than those at Nelson, as conditions were more favorable for satisfactory observation. At Nelson the thermometer was not in the water at the upper horizon tested, while at Yucca it was under water at both horizons. The increase of temperature downward in the Yucca well was 1° F. for 55+ feet. That in the Nelson well was 1° F. for 68+ feet.

Temperatures of water in wells at Yucca and Nelson, Ariz.

Location.	Surface elevation.	Total depth.	Depth to water.	Date of observation.	Surface temperature at time of observation.	Depth at which temperature was taken.	Temperature.
	Feet.	*Feet.*	*Feet.*		*° F.*	*Feet.*	*° F.*
Yucca, Ariz.[a]	1,804	1,004	346	Sept., 1903	98	1,004	90.5
Do	1,804	1,004	346	....do	98	455	80.6
Nelson, Ariz.[b]	5,200	1,043	490	....do	75	1,040	73.4
Do	5,200	1,043	490	....do		200	61.2

[a] General region volcanic. Drilling suspended three months previous to observation.
[b] In limestone region at edge of plateau. No work done on well for several months previous to time of observation.

NOTES ON THE IGNEOUS ROCKS OF WESTERN ARIZONA.[a]

By Albert Johannsen.

PRE-CAMBRIAN CRYSTALLINES.

The oldest of the volcanic rocks in northwestern Arizona are granites (A–6, A–44).[b] According to Lee, they occur below the effusives throughout the entire area, and in the cliffs to the east are overlain by the same series of Cambrian rocks which in the Grand Canyon section is called the Tonto formation. Over the whole area the fact that the granite is an older and not a younger intrusive is clearly indicated by the occurrence of dikes and veins within it which do not extend through the overlying rocks. The upper surface was planed nearly to a base-level and the effusives generally overlie it in horizontal sheets.

Much granite occurs in the area. The rock is red to gray in color, is usually coarsely crystalline, and is much cut by dikes and veins. Here and there in faulted regions, the rock is highly gneissoid, while in other places the mass passes, by easy transitions, from the normal rock to the schistose. The specimens are very similar in mineralogic character, though no thin section of the normal type was examined. Megascopically A–6 is fine and schistose, and consists of black and white bands of feldspar and biotite. A–44 is dark red in color and is very compact. Under the microscope the former is schistose, hypautomorphic-granular, while the latter is similar but without showing schistosity. In both, the minerals are feldspar, less quartz, and still less biotite. Zircon and apatite are accessory. The feldspar is chiefly orthoclase, which is now and then intergrown with plagioclase in the form of microperthite; a little microcline and a little oligoclase or andesine occur. The biotite occurs in shreds and patches (subparallel in A–6) and is in many specimens considerably altered to iron oxide, so that it is black and opaque. Normally the pleochroism of the biotite is $\mathfrak{a}$ = light green and $\mathfrak{b}$ = dark green. Zircon occurs as short, stout, rounded grains, and apatite occurs

[a] The specimens here described were collected by Mr. Lee and the geologic relations are given from his observations. The report on the examination of the thin sections was made in 1906.
[b] References are to original specimen numbers; see list, p. —.

both in small and thin and in large and stout prisms, the latter being sometimes irregular in form. The accessories occur within both the quartz and the feldspar.

Farther to the south, in Williams Canyon, the banding of the underlying rocks becomes much more marked, giving long-drawn-out black and white bands (A–49), for which reason the name of "Banded Canyon" is applied to the gorge through which Williams River flows. Lee describes the rock as apparently continuous with the granitic rocks to the north, although the transition was not followed. Megascopically the rock is aphanitic, black and white banded, the black bands occasionally showing white phenocrysts and rounded inclusions. Under the microscope the texture is markedly schistose. The constituents are irregular rounded grains, very variable in size, of hornblende, orthoclase, some plagioclase, and a little quartz. There is much chlorite, and a little epidote and titanite.

EFFUSIVE ROCKS.

OLDER ANDESITE.

Some time during the Tertiary period, after the Paleozoic and Mesozoic sediments had been removed from the area and the underlying granite deeply eroded, began a period of volcanic activity. The earliest erupted rocks of which traces now remain were andesites, a remnant of which occurs at Black Mesa, north of Boundary Cone (A–11). It here appears to underlie and is cut by dikes of rhyolite (A–12). This is the only area where any eruptive rock is definitely known between the rhyolite and the granite. In several places the andesite (A–40, A–41) rests directly upon the granite, but no rhyolite occurs above it, and consequently the later flow and the intervening rocks may have been eroded. The andesite from Black Mesa is, then, as described above, beneath the rhyolite and is cut by it; and since within the rhyolite flow breccia from various parts of the region andesite fragments occur, it is very probable that this rock is in place and is older than the rhyolite.

Megascopically this andesite (A–11) is dark reddish gray in color and shows numerous white phenocrysts in a fine aphanitic groundmass. Under the microscope the texture is porphyritic and sempatic. The phenocrysts are fairly regular laths, some of which are partially and some completely altered. The partially altered phenocrysts are plagioclase, which still show indistinctly the original twinning, but the extinction angle can not now be determined. They have an index of refraction higher than Canada balsam, and are much altered to calcite, sericite, and kaolin. Besides these, there are fewer chlorite pseudomorphs and still less magnetite. The chlorite pseudomorphs are lath-shaped and are very similar in form and size to the plagioclase laths. None of the original mineral remains, and there is occasionally a center of calcite. Possibly they are pseudomorphs after hornblende. The magnetite occurs in irregular and corroded grains and is usually surrounded by a rusty rim. By incident light the surface appears black and metallic, but with rusty patches, the smaller grains sometimes having the entire surface rusty. The groundmass is anisotropic and full of alteration products, and consists of xenomorphic laths and patches of feldspar, much altered to kaolin, sericite, and chlorite, and of magnetite grains and dust. It has the appearance of having originally contained small lath-shaped feldspars. Whether there was also originally orthoclase is indeterminable. Kaolin occurs as a secondary product in semiopaque patches in the groundmass and in the feldspar phenocrysts.

RHYOLITE SERIES.

Resting upon the andesite at Black Mesa, and in other places directly upon the granite, is a thick series of rhyolites, rhyolite flow breccias, and tuffs, which reach a thickness of 3,000 feet or more. They are all clearly older than some of the andesites (107, A–18) and older than all of the basalts. In the field the general appearance of the rhyolite is white to pink, making a sharp contrast with the underlying granite and the overlying andesites and basalts. Usually the flows are massive, often brecciated, and often very coarse agglomeratic, with angular blocks having a maximum diameter of several feet. In places these included fragments are rounded and the bedding of the tuffs is horizontal. No attempt was made to separate the rhyolite into distinct flows, as might be possible with more detailed study. The areas at which the specimens studied were collected being in many cases far removed from the others, it is impossible to correlate the relative geologic positions.

The rhyolites may be divided into four groups—flow breccia, ash, normal rhyolite, and spherulitic rhyolite.

In general the megascopic appearance of the rhyolite flow breccia is white to pink, with included irregular dark-brown fragments, usually small. Under the microscope the appearance of all (101, A–13, A–19, A–35) is very similar. The rock consists of a glass full of bubbles, often in flow lines and sometimes devitrified. It is full of irregular and broken fragments of orthoclase, quartz, sometimes a little biotite, microcline, apatite, plagioclase, and hornblende, several or all, and usually some iron ore. Some of the specimens are altered and contain, besides iron oxide, much calcite. Besides the mineral fragments contained in the glass, there are irregular dark and altered inclusions of andesite, which clearly indicate that there was a previous eruption of a basic rock. No correlation is possible, however, between these fragments and the single specimen obtained from the flow below the rhyolite at Black Mesa. There may have been, and probably were, volcanic eruptions previous to that of the rhyolite, of which now no trace remains, and the fragments in the rhyolite flow breccia indicate that the andesite was much more extensive than at the present time.

West of Boulder Canyon in Colorado River is a volcanic tuff (A–39). It is gray to pink in color, ashlike, gritty, very friable, and fine grained, and occurs in horizontal beds. Under the microscope it is tuffaceous and is composed chiefly of small angular glass fragments, needle-like and in flakes, and contains a few very small and irregular quartz grains.

Compact normal rhyolite (117, A–7, A–12, A–43) occurs within the rhyolite series, but no attempt was made to find the relationship which may exist between these flows and the sheets of breccia, flow breccia, and so on, in which it occurs. Megascopically these rocks are white or pink and sometimes banded. Under the microscope a glassy flow texture is plainly seen in one of the rocks (A–43), while in others (117, A–7), although now devitrified, the flow texture can be clearly made out. In 117 the original flow lines of the groundmass show in polarized light by the fact that there are larger and more numerous quartz particles along certain lines, while areas between these lines are much finer grained, and very often the centers of these areas are almost entirely isotropic. In the specimen from Black Mesa (A–12), from the region where the andesite (A–11) underlying the rhyolite was obtained, no flow texture can now be made out. It is completely devitrified and is now an aggregate of quartz and feldspar. According to Lee, this rhyolite occurs in dike-like intrusions and in sheets overlying the andesite, a fact which clearly proves the older age of the andesite, provided that the intruded and overlying rocks are both like the specimen (A–12). All of the sections are perpatic. In some, fragments of orthoclase, a little plagioclase, and some quartz occur, and in others the original phenocrysts are much altered. Magnetite and zircon are accessory, and calcite and zeolites secondary minerals. Chlorite, from an original femic mineral, occurs in 117.

Two of the rhyolite specimens are spherulitic (A–1, A–8). Megascopically these specimens are pink, spherulitic, and full of large irregular cavities, occasionally filled with quartz crystals. Under the microscope the rock shows very few phenocrysts of orthoclase, plagioclase, and biotite, and rather rare magnetite crystals in a spherulitic groundmass. In one specimen (A–8) the entire rock is filled with trichites, generally in hairlike bunches. Sometimes margarites occur—that is, hairlike strings of globules; and in places microlites appear in schools. In the specimen from Wickenburg (A–1) there is, in the groundmass, besides the spherulites, a quartz-orthoclase aggregate in finger-like interlocking particles. The rock is rather dark with feritic material, and there is considerable kaolin and other alteration products. In the rays of the spherulites there is often a deposit of red hematite or limonite, and cubes of what may have been magnetite show a slight red edge in transmitted light, as though altered to limonite.

YOUNGER ANDESITES.

Definitely in place in a number of localities above the rhyolite is an andesite (107, A–18). This is much more limited in extent than the earlier flow. A number of other andesites which occur in the area either rest directly upon the granite (A–40, A–41) or are in masses isolated from the other effusives, so that no relationship is seen (112, A–2, A–42); they may belong either to the upper flow, the underlying rhyolite having been eroded, or to the earlier flow. In the field all of the andesites are of a dark-red to brown color, are often vesicular, and are often very hard to distinguish from the overlying olivine basalts.

The two specimens (107, A–18) from above the rhyolite are dark reddish black in color and are vesicular, with more phenocrysts in A–18 than in 107. Under the microscope the two rocks are very similar in appearance. Both of them are porphyritic-intersertal in texture and contain more phenocrysts than groundmass. The phenocrysts occur in two generations and consist of plagioclase (andesine to labradorite), augite, and magnetite. The larger plagioclase crystals occur as irregular fragments, often zonal, while the smaller occur in perfect laths. There is much less augite than plagioclase. This also occurs in two generations, and in each case is less in amount than the corresponding generation of plagioclase. Two generations of magnetite, less in amount than the augite, occur in quadratic and irregular crystals and grains. Of these the larger crystals are less in amount and the grains are smaller than the second generation of augite, and the small crystals are very small and are scattered through the groundmass in isometric crystals. They occasionally occur in the augite, but very rarely in the feldspar. The groundmass in both specimens is isotropic and consists of brown glass full of magnetite—so much in A–18 that it is nearly opaque.

Specimens A–40 and A–41, from sheets in the walls of Black Canyon, are augite andesite; possibly the latter at one time contained olivine; if so, it was an olivine basalt. Megascopically they are medium dark red-brown in color, with more or less black and white phenocrysts in an aphanitic groundmass. Under the microscope they are porphyritic and sempatic. The phenocrysts of 40 consist of broad, irregular laths, and the groundmass is apparently a devitrified glass, full of dust and grains of magnetite and hematite. Specimen 41 has phenocrysts of plagioclase, somewhat greater in amount than augite and much greater than some red-brown pseudomorphs which may be altered biotite or olivine. The groundmass in this specimen is in laths and irregular patches, much of which is definitely plagioclase. Besides the feldspar, much black and red iron oxide and shreds of augite and dark altered biotite (?) occur.

A–42 is a biotite-augite andesite from a sheet forming Eagle Rock, near Little Round Island, and is similar in character to the two preceding. The phenocrysts, less in amount than the groundmass, are, in the order of their importance, plagioclase, biotite, diopside, and magnetite. The plagioclase is andesine to labradorite. The biotite has a peculiar deep red-brown color, is pleochroic with 𝔟=brownish red and 𝔞=greenish yellow, and has much the appearance of basaltic hornblende. It has, however, parallel extinction, gives a uniaxial interference figure, shows parallel cleavage in laths, has the "bird's-eye maple" surface, and is optically negative. It always has a dark rim of magnetite. The pyroxene is pale green in color, is nonpleochroic, has an extinction of about 40°, and has good cleavage—parallel in laths and at right angles in basal sections. It is diopside. Both the plagioclase and the pyroxene are much altered to calcite. The ground mass is yellowish to red, cloudy, and apparently partially devitrified glass full of red ore dust. Most of the anisotropic part of the groundmass is spherulitic or contains innumerable microlites.

South of Seligman there is a hypersthene andesite (113). This is from the lower of two flows, the upper of which is darker and may be basalt, though no specimen was examined. Megascopically 113 is a dark-gray rock with white patches and occasional calcite fillings in cavities. Microscopically the texture is porphyritic and dopatic. The phenocrysts are either thin or broad laths, and the groundmass is hypautomorphic. The phenocrysts, in the order of their abundance, are plagioclase, augite, and hypersthene. The feldspar occurs in both large and small laths. The stout crystals are not twinned and are always zonal; the narrow crystals are usually twinned and give an extinction between 20° and 25°, or that of andesine. In the zonal feldspars the index of refraction at the center is higher than at the rims; the interference figures are positive, and show a comparatively small value for 2E. This excludes all the feldspars but andesine and labradorite. Since the rims have a lower index but are still positive in character, it shows that the feldspar is either labradorite or andesine or both, and that the interior is more basic than the exterior. The femic minerals consist of very irregular grains of a greenish pyroxene with a high extinction angle—augite; and another pyroxene occurring in elongated prisms with longitudinal cleavage, having parallel extinction, showing high interference colors, optically negative, and slightly pleochroic in pink and green tones—hypersthene. Magnetite occurs in grains which, in size, grade into the groundmass. There is no definite line, and it is in such irregular grains that it may be included with either the phenocrysts or the groundmass. Exclusive of the femic minerals, the groundmass is made up of xenomorphic areas and laths of feldspar which are probably of the same kind as the large phenocrysts. The xenomorphic feldspar has an index of refraction greater than Canada balsam and is consequently plagioclase, but the areas are so small that the kind is indeterminable. Besides the feldspar there is an isotropic substance which occurs in very small anhedrons and which may be glass or a zeolite. The groundmass is full of magnetite dust and there is an alteration product in the cleavage cracks of some of the feldspars which is anisotropic and has an index of refraction less than Canada balsam. It is a zeolite.

Twenty-five miles west of Congress Junction there occurs a coarse breccia formed of large angular blocks cemented with red material. Megascopically the specimen (A–2) has a red compact groundmass, and there are phenocrysts of hornblende forming about one-eighth of the mass. Microscopically the texture is porphyritic and perpatic. The phenocrysts are hornblende, much less plagioclase, and still less biotite. The hornblende is very peculiar in several ways. It has a very low extinction angle, generally appearing as parallel, the largest found being only $3\frac{3}{4}°$—that is, c: $\mathfrak{c}$ is circa 4°. The pleochroism is also peculiar. For $\mathfrak{a}$ it is a greenish yellow, while for $\mathfrak{c}$ it is a deep red-brown. Absorption $\mathfrak{c} > \mathfrak{a}$. The elongation is parallel to $\mathfrak{c}$, and therefore it is positive, while the optical character of the mineral is negative. Surrounding the mineral there is always a dark rim of iron oxide. This is usually black, but occasionally it shows a red tone. The cleavage is good, parallel to ć in lath-shaped sections, and in basal sections the usual amphibole cleavage. The mineral is basaltic hornblende. The feldspar is generally zonal and is positive in character. It is between andesine and labradorite. Actually the amount of plagioclase that occurs is much less than the amount of hornblende, but the phenocrysts of feldspar have either weathered out or been ground out in preparing the thin section. Apparently they were originally much more numerous and both longer and broader than the hornblende. Biotite occurs in a very few long, thin flakes. It has dark rims, and magnetite is included along the cleavage lines. Pleochroism is brownish to greenish. Magnetite occurs in irregular grains. The groundmass consists chiefly of laths of plagioclase, which have an extinction angle of 30° and are consequently labradorite. Between the feldspar laths there is a much iron-stained substance which is probably glass. Iron oxide occurs in the form of very fine dust and in patches, producing the red color of the rock.

OLIVINE BASALTS.

Resting upon the andesite, upon the rhyolite, or even upon the granite, and also upon and within Quaternary gravels, depending upon the amount of erosion that has taken place, is a series of olivine basalts—the youngest lava in the region. There are at least three flows of this, but it is impossible, from the amount of field work done, to correlate the different sheets in different parts of the area. Five or six varieties can be distinguished under the microscope, but they may be but different phases of the same rock, a greater or less development of olivine or a coarser or finer groundmass forming the various types. This difference in appearance may be seen even in two sections (as 110, 111) which have been collected near together from undoubtedly the same flow and which show different characters. Five types may be distinguished, according to the fineness of the groundmass: (A) 110, 111, 3, 45; (B) 15, 16, 24, 25, 27; (C) 37, 46; (D) 22, 23; (E) 30, 34.

Occasionally the field relation can be seen; thus, 24 is from a sheet overlying 25; 15 is from a sheet intruded into the rhyolite and lifting it; and 16 is from a sheet above the rhyolite.

In the field the general appearance of the basalt is black or very dark red. In general it is darker in color than the underlying andesite and is often vesicular and ropy. Where it rests upon the rhyolite it forms sharp cliffs. In many places it forms flows in erosion valleys, and though actually lower in position, is higher geologically.

Megascopically the hand specimens are compact and vary in color from black through dark gray to dark brownish red. Occasionally there is a somewhat banded arrangement—that is, alternating bands of a lighter color. Under the microscope the texture of all the specimens is porphyritic, with a groundmass generally trachytic and with the small plagioclase laths in subparallel position. In general the phenocrysts of the rock are olivine, or, when other minerals occur, they are greatly in the minority. In four specimens, however (22, 23, 45, 46), the phenocrysts are chiefly plagioclase.

In specimens 22 and A–23 the plagioclase phenocrysts are greatly in excess of the olivine, and the latter are much in excess of the augite. The groundmass is much coarser than A–45 and consists of plagioclase laths and areas, less augite grains, and still less magnetite. The feldspar is labradorite. Olivine is very much altered to a red-brown mineral which may be iddingsite or an iron-stained serpentine. Some of the olivine is fresh and shows simply an altered rim or altered center.

A–45 is perpatic, has a much finer groundmass than either A–22 or A–23, and does not contain prominent augite grains in the groundmass. The constituents, in the order of their abundance, are plagioclase, augite, olivine, and magnetite. The feldspar is labradorite or andesine. The olivine occurs in doubly terminated crystals, only slightly altered.

A–46 is very similar to A–23, except that the difference between the size of the grains in the groundmass and the phenocrysts is not so great.

Specimens 110, 111, and A–3 are similar to A–45, in having a very fine groundmass. The phenocrysts of 110 and 111 are augite and biotite in about equal amounts, and less of a completely altered red-brown mineral which may have been olivine. The biotite and augite are usually altered in part also, and are surrounded by black rims. The groundmass consists of lime-soda feldspar laths in subparallel position in swirling eddies—a trachytic texture. There are also a few small irregular patches in the groundmass which have an index of refraction less than Canada balsam and are faintly anisotropic. They may be analcite, but are too small to determine. Calcite occurs as a secondary product, and magnetite occurs in a few large crystals as well as in small grains in the groundmass.

In A–3 there are more augite phenocrysts than olivine. The latter is altered, completely or in cracks, to a red-brown mineral, which has an index of refraction much less than that of the olivine and is fibrous. It appears to be iron-stained serpentine. Magnetite occurs within the olivine in rather large grains and crystals. The groundmass consists of laths of labradorite in broad flow lines swirling around the olivine phenocrysts. Almost invariably they are twinned according to the albite law, and show an extinction angle in the neighborhood of 30°. Between the feldspar laths is much augite, pale green in color, and occurring in irregular grains, never in well-formed crystals or laths. Somewhat less in amount is magnetite, which occurs in cubical and irregular sections. Less in amount than the magnetite and, like it and the augite, occurring in irregular grains between the feldspar laths, is a reddish-brown mineral which has an index of refraction apparently greater than the augite. The grains are small and irregular, so that the determination is impossible. It appears to be partially altered olivine.

Somewhat coarser in texture under the microscope than the above are A–15, A–16, A–24, A–25, A–27, A–37. Of these, A–15 and A–16 have phenocrysts of olivine, augite, and plagioclase, with hornblende and biotite also in A–16. The olivine phenocrysts are generally entirely altered to a brownish-red serpentine and are usually ground out in the centers in preparing the section. The groundmass of A–15 is a dark glass full of small laths of plagioclase, laths of augite, and grains of red iron oxide, while A–16 has a groundmass of dark glass full of innumerable small feldspar laths and microlites and magnetite dust.

A-24, A-25, A-27, and A-37 are very similar in appearance. The texture of all of them is porphyritic, with phenocrysts of olivine and a groundmass made up of laths of feldspar and grains of augite and magnetite and glass full of magnetite dust. The amount of glass is small and fills spaces between the plagioclases, but these spaces are very few and hardly show in the thickness of the section. The olivine phenocrysts are rather fresh, being generally altered only around the rims. Secondary calcite is common.

A-37 has more plagioclase than A-24 and the olivine is entirely altered to a dirty brownish-black substance.

A-30 and A-34 are porphyritic, with irregular rounded to angular crystals of olivine which are perfectly fresh. Some magnetite may be classed with the phenocrysts. The groundmass consists of long, narrow laths of labradorite with extinction angles of from 32° to 35°, and a less amount of a purplish, very slightly pleochroic augite, which fills the interspaces. The augite is not in typical ophitic form, but in irregular laths which fill the interstices. Generally it is very fresh, although there are patches of serpentine in the groundmass, some of which is definitely derived from olivine. Within the augite there is a great deal of magnetite in strings and in skeleton crystals, in beautiful branching forms.

DIKE ROCKS.

OLIVINE DIABASE.

Cutting the rhyolite at the eastern edge of Black Mesa, in Gold Roads Pass at Mud Spring, is a large dike, some 25 feet in thickness, of olivine diabase (A-14), apparently connected with a dark sheet which overlies the rhyolite. Megascopically the rock is dark in color and is rather coarsely granular. Under the microscope it has a typical ophitic texture and there is more feldspar than augite. The feldspar occurs in twinned laths with a maximum extinction angle of 31°, and is labradorite. It is very fresh, although occasionally it contains serpentine in cleavage cracks. Fresh augite in less amount than the plagioclase fills the interspaces between the feldspar laths. It is pale purple in color, and is nonpleochroic or very slightly pleochroic. It contains a small amount of iron oxide in extremely fine particles. Olivine, less in amount than the augite, occurs in irregular rounded grains, mostly small, though some are large. Some of the olivine is altered to serpentine, chlorite, and red iron oxide around the edges and in cracks. Magnetite occurs in still less amount and in irregular grains.

RHYOLITE PORPHYRY.

At the base of Boundary Cone is a plug, or dike from a plug, of rhyolite porphyry (A-10). Megascopically it is a pink, fine-grained rock, with quartz and feldspar phenocrysts. Under the microscope the texture is porphyritic and dopatic. The phenocrysts are large, occasionally somewhat corroded, and the groundmass is xenomorphic-holocrystalline. The phenocrysts are orthoclase, greater in amount than quartz, and much greater than acid plagioclase. The plagioclase occurs in but few crystals; it has, in part at least, an index of refraction less than Canada balsam, and is probably all albite. The groundmass is a quartz-feldspar aggregate with much hematite. Secondary kaolin and sericite are derived from the feldspar, and the red iron oxide perhaps from magnetite.

ROCK SAMPLES FROM NORTHWESTERN ARIZONA.

Following is a list of rock samples collected in northwestern Arizona with the original specimen numbers:

A–6. Granitic gneiss from south end of Hualpai Mountains.
A–10. Granite porphyry from base of Boundary Cone west of Black Mesa.
A–44. Biotite granite from mouth of Williams River.
A–49. Granite gneiss from Williams Canyon.
101. Rhyolite flow breccia from Lost Basin, about 5 miles south of Colorado River, in a depression of older crystalline rock.
A–35. Rhyolite breccia from Temple Bar.
A–7. Rhyolite from southern end of Black Mesa, at base of cliffs.
A–39. Rhyolitic tuff from Colorado River west of Boulder Canyon.
A–12. Rhyolite from Black Mesa, at Gold Roads.
A–13. Rhyolitic tuff from Black Mesa, in pass east of Gold Roads.
A–19. Rhyolitic tuff from Black Mesa, at summit of Union Pass.
A–43. Rhyolitic tuff from bluffs of Colorado River in Chemehuevis Valley.
A–2. Hornblende andesite from southern end of Aquarius Mountains, a few miles north of Date Creek.
A–11. Andesite from Black Mesa, north of Boundary Cone.
A–40. Andesite from north end of Black Canyon.
A–41. Andesite from south end of Black Canyon.
A–42. Andesite from Eagle Rock, near Little Round Island.
107. Andesite from coyote holes northwest of Kingman, at western edge of mesa.
A–18. Andesite from a sheet above the rhyolite 2 miles northwest of Kingman.
110, 111. Basalt from a flow sheet 300 feet thick resting on top of 400 feet of varicolored ash and breccia at mouth of White Cliff Creek.
112. Andesite resting on granite at top of Cottonwood Cliffs near mouth of Cottonwood Creek, 1,200 feet above Nos. 110 and 111.
A–3. Olivine basalt from a sheet in the detrital beds of Santa Maria Canyon, near mouth of Big Sandy Wash.
A–15. Basalt intruded into the rhyolite 1 mile west of Kingman.
A–16. Basalt from a flow sheet above the rhyolite 1 mile west of Kingman.
A–27. Olivine basalt from a sheet above the andesite near Kingman.
A–30. Olivine basalt from a columnar sheet resting on the Temple Bar conglomerate north of Colorado River in Grand Wash.
A–34. Olivine basalt from a flow sheet within the Temple Bar conglomerate near Greggs Ferry.

A-14. Olivine diabase from the eastern edge of Black Mesa, at meadow spring in Gold Roads Pass; dike cutting the rhyolite.

A-22. Olivine basalt from Mud Spring at eastern edge of Black Mesa.

A-23. Olivine basalt from north end of Cerbat Mountains.

A-24. Olivine basalt from a sheet resting upon granite east of Cerbat Mountains.

A-25. Olivine basalt from a sheet resting above A-24.

A-45. Basalt from a sheet 800 feet thick covering the Temple Bar conglomerate in Williams Canyon.

A-46. Olivine basalt near Planet, in Williams Canyon.

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