Geology and Promising Areas for Ground-Water Development in the Hualapai Indian Reservation, Arizona

By F. R. TWENTER

WATER SUPPLY OF INDIAN RESERVATIONS

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ABSTRACT

The geology and ground-water resources of the Hualapai Indian Reservation were studied to determine the possibility of developing additional water for stock purposes. The reservation is a large U-shaped area in the northwestern part of Arizona and includes the Hualapai Plateau and the western part of the Coconino Plateau. The major streams in the area are ephemeral tributaries of the Colorado River.

Precambrian granite, gneiss, and schist are the oldest rock units in the report area. The sedimentary rocks, in ascending order, are the Tapeats sandstone, Bright Angel shale, and Muav limestone of the Tonto group of Cambrian age; limestone of Devonian age; the Redwall limestone of Mississippian age; limestone of Pennsylvanian age; the Supai formation, Hermit shale, Coconino sandstone, Toroweap formation, and Kaibab limestone of the Aubrey group of Pennsylvanian and Permian age; the Moenkopi formation of Triassic age; gravel and fluvial beds of the Hindu Canyon area, both of Tertiary age; lake beds in Truxton Valley of Tertiary and Quaternary age; and alluvium of Quaternary age. Volcanic rocks are of Tertiary and Quaternary age.

The major geologic structures in the area are the Hurricane and Toroweap faults and the Meriwitica and Peach Springs monoclines. The Grand Wash fault is along the western boundary of the area. The regional dip of the sedimentary beds is toward the northeast.

The occurrence and movement of ground water in the area are related to the lithologic, structural, and erosional features of the rocks. Most of the ground water occurs in the sedimentary rocks. Ground water in the area moves northeastward along the regional dip of the beds. Aquicludes retard the downward movement of ground water, which collects in the overlying beds, or aquifers.

The principal aquifer in the area of this report is the Muav limestone. Several large springs issue from this formation in the deep side canyons of the Colorado River, and small springs issue from it along the Grand Wash Cliffs. Several successful wells have been drilled in the Muav limestone, Tertiary gravel beds, and lake beds of Truxton Valley. Locally, small springs issue from the Precambrian rocks and Bright Angel shale. Seeps occur at the base of the Tapeats sandstone.

Moderate quantities of water of good quality probably can be developed from the Muav limestone. Three promising areas for developing water from the limestone have been selected in the Hualapai Plateau west of Peach Springs Canyon. In these areas, the wells would have to be about 700 to 800 feet deep before maximum production could be obtained. Water probably can be obtained from the Muav limestone in other parts of the reservation, but at greater depths. In the western part of the Coconino Plateau the depth to water-bearing beds in the Muav is 2,500 to 3,500 feet.

Small to moderate quantities of water of good quality probably can be obtained from the lake beds of Truxton Valley in the reservation. A site was selected for a test well west of Peach Springs; the well would have to be about 400 to 500 feet deep.

The Tertiary gravel beds in the western part of the Coconino Plateau are water bearing, and future investigations of these beds may show that additional water can be obtained from them.

INTRODUCTION

Cattle raising is the major occupation of the Hualapai Indians. The small quantities of water presently available from springs and wells on the Hualapai Indian Reservation (fig. 1) are insufficient to supply the cattle adequately.

The streams in the reservation are intermittent and contain water only after thunderstorms. On the Hualapai Plateau (fig. 1) many stock tanks have been constructed to catch the surface flow, but they do not contain water during periods of hot, dry weather. The large springs in the reservation are at the bottoms of the deep canyons and are inaccessible to cattle. Thus, the available supplies of ground water and surface water are not adequate to promote efficient use of the rangelands, and it is necessary to haul water to the cattle during the summer.

At the request of the Bureau of Indian Affairs, an investigation of the ground-water resources of the Hualapai Indian Reservation was undertaken by the U.S. Geological Survey in November 1957. In addition to an overall appraisal of the water resources of the area, the study included the delineation of areas that appeared to be most favorable for the development of moderate supplies of ground water.

Previous investigations have shown that rocks near the surface in the Hualapai Plateau yield little water. In the western part of Coconino Plateau (fig. 1), however, surficial deposits yield moderate quantities of water at several localities.

LOCATION AND EXTENT OF THE AREA

The Hualapai Indian Reservation is an area of about 993,000 acres in northwestern Arizona. The reservation is mostly in Coconino and

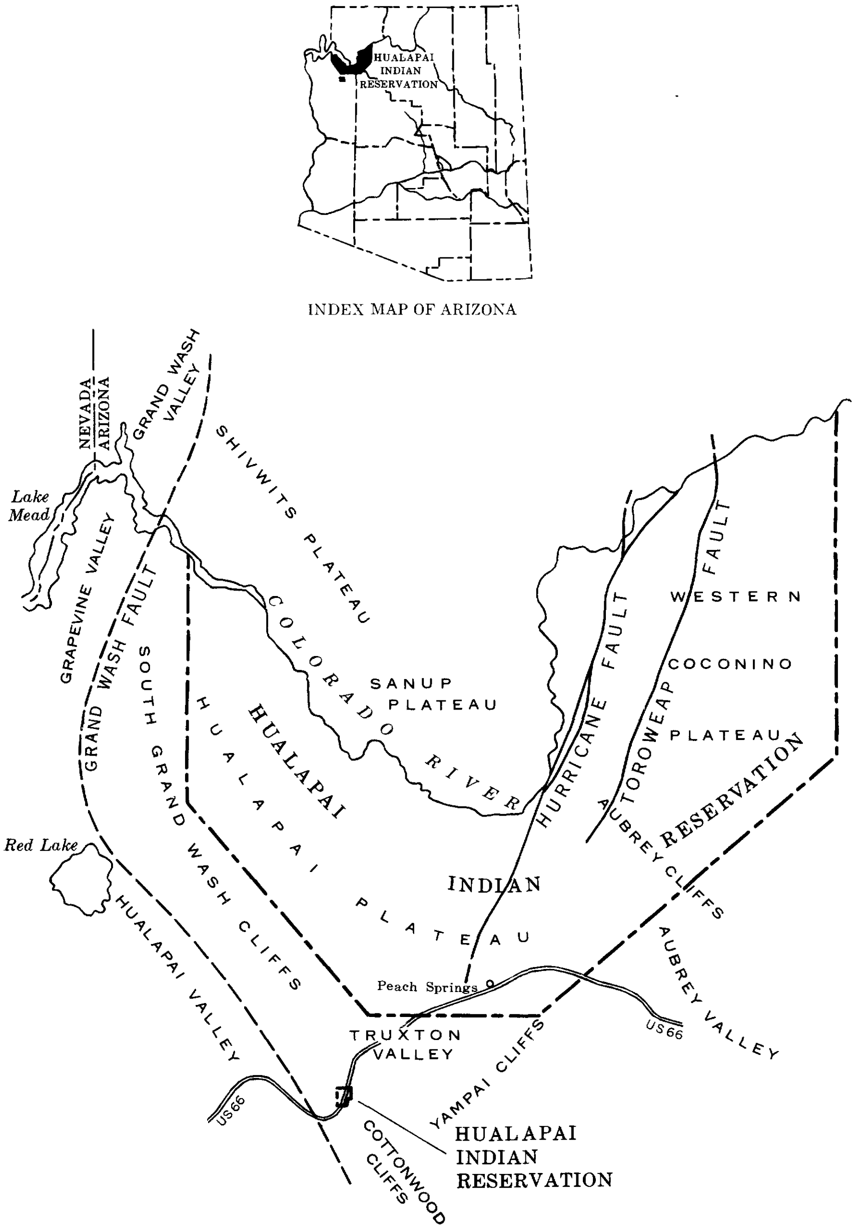

Figure 1.—Index map of Hualapai Indian Reservation and adjacent area, Arizona.

Mohave Counties but a small part lies in northwestern Yavapai County (fig. 1). The reservation is U-shaped. Each arm of the U is about 50 miles long, and the overall width of the area is about 60 miles.

The area of this report includes the Hualapai Indian Reservation and an area extending on the west and southwest to Grapevine and Hualapai Valleys and on the south to Truxton Valley. The Colorado River forms the northern boundary for a distance of 165 miles.

U.S. Highway 66 crosses the southern part of the area and serves the towns of Peach Springs, Truxton, and Valentine. The Buck and Doe road (pl. 1) branches off U.S. Highway 66 about 1 mile west of Peach Springs and extends generally along the entire length of the west boundary of the reservation. The road terminates at the U.S. Guano Corporation's packing plant and living quarters. The Frazier Well-Havasupai road (pl. 1) branches off U.S. Highway 66 about 8 miles east of Peach Springs, extends northeastward through the logging camp at Frazier Well, crosses the east boundary of the reservation and ends near the head of a small tributary to Hualapai Canyon. A trail leads from the end of this road down into the canyon to Supai, the village of the Havasu Indians. The Atchison, Topeka, and Santa Fe Railway parallells U.S. Highway 66 through the area and has stations at Peach Springs, Valentine, and Nelson.

Peach Springs, Ariz., is the site of the Hualapai Indians trading post and tribal-council headquarters, and most of the Hualapai Indians live in this community. Valentine, about 16 miles southwest of Peach Springs, is the headquarters for the Truxton Canon Subagency of the Bureau of Indian Affairs. The community of Nelson is outside the reservation about 7 miles east of Peach Springs and is the site of a limestone quarry and cement plant.

PHYSIOGRAPHY

The southwest and west boundaries of the area of this report are along the southern part of the Grand Wash Cliffs. These cliffs form a large westward-facing escarpment extending from the Cottonwood Cliffs northward for more than 100 miles. The escarpment forms a sharp and distinct line of demarcation between the Basin and Range province and the Colorado Plateaus province (fig. 2).

The Grand Wash Cliffs were carved by erosion from the upthrown eastern block of the Grand Wash fault, which parallels the cliffs (fig. 1). The wide Grand Wash, Grapevine, and Hualapai Valleys to the west of the Grand Wash Cliffs are underlain by alluvium deposited on the downthrown block of the fault. These valleys lie at an average altitude of 3,000 feet above sea level.

FIGURE 2.—Southern part of the Grand Wash Cliffs near Clay Spring (pl. 1, No. 4). This escarpment is the line of demarcation between the Basin and Range province and the Colorado Plateaus province. Red Lake playa can be seen in the valley on the left. Clay Spring is in the canyon on the right. Precambrian granite, gneiss and schist (pꞒg); Tapeats sandstone (Ꞓt); Bright Angel shale (Ꞓb); Muav limestone (Ꞓm); and Devonian limestone (Dl).

The Colorado River flows in a deep canyon cut through the central part of the Grand Wash Cliffs into Lake Mead and the Basin and Range province. The extension of the Grand Wash Cliffs southward from the Colorado River is referred to in this paper as the south Grand Wash Cliffs (fig. 1).

The Hualapai Plateau is a large block of sedimentary rocks dissected by many deep canyons. The plateau is 2,500 to 3,500 feet higher than the valleys to the west (pl. 1) and is a cuesta sloping gently toward the northeast. As Darton (1925, p. 77) stated, it is "the first great step in the rise from the deserts and granitic lowlands of western Arizona to the high Coconino Plateau". The altitude of the Hualapai Plateau along the Grand Wash Cliffs is from 5,500 to more than 6,500 feet above sea level. The central part of the plateau has an average altitude of about 5,000 feet. Music Mountain (pl. 1) in the southwest corner of the Hualapai Plateau has an altitude of 6,761 feet. Truxton Valley (pl. 1), at an average altitude of 4,300 feet, lies south of Music Mountain. The southern boundary of Truxton Valley is formed by the Cottonwood and Yampai Cliffs.

The Hualapai Plateau extends eastward to the Juniper Mountains, Aubrey Valley, and Blue Mountain Canyon. North and northeast of Blue Mountain Canyon is the Coconino Plateau (fig. 1). The Hurricane fault forms the western boundary of the Coconino Plateau and the Toroweap fault lies about 6 miles to the east. The western part of the Coconino Plateau has an average altitude of 6,500 feet and slopes gently toward the northeast. Deep canyons dissect the northern and western parts of the plateau; to the east and southeast it has relatively little relief.

The major streams of the Hualapai and Coconino Plateaus are northeastward-flowing ephemeral tributaries of the Colorado River. Diamond and Spencer Creeks drain to the northwest but have a perennial flow as a result of spring inflow. Streams in a small part of the Coconino Plateau drain to Aubrey Valley. The drainage of Truxton Valley is southwestward through the relatively deep gorge at Valentine, then northwestward into Red Lake (fig. 1) which is the playa in Hualapai Valley. The numerous, short, intermittent streams along the south Grand Wash Cliffs flow into Hualapai and Grapevine Valleys.

CLIMATE

Climatological data for the Hualapai Plateau and the western part of the Coconino Plateau are almost nonexistent. Both plateaus lie at a relatively high altitude and thus receive a moderate amount of precipitation. Data from the U.S. Department of Agriculture (1941, p. 771) indicate that the Hualapai Plateau probably receives an average annual precipitation of 7 to 10 inches, and the higher Coconino Plateau receives 10 to 14 inches. Part of the precipitation in the Coconino Plateau falls as snow, which sometimes reaches a depth of several feet.

The difference in the vegetation on the two plateaus gives some indication of the difference in climate. The vegetation of the Hualapai Plateau is of the shrub type and consists almost entirely of several varieties of juniper, whereas on the western part of the Coconino Plateau ponderosa pine grows in abundance.

FIELDWORK AND MAPS

The fieldwork for the investigation was started in November 1957 and completed in May 1958. The geology was mapped on high-altitude aerial photographs (approximate scale: 1:63,360) and later transferred to a base map prepared from maps published by the Bureau of Indian Affairs and the Bureau of Land Management.

The location of the Moenkopi formation was taken from the Geologic Map of the State of Arizona (Darton and others, 1924) and the areal extent of the Tertiary gravel beds from a map prepared by Koons (1948a, p. 54).

PREVIOUS INVESTIGATIONS

Early work on the geology of the Hualapai Indian Reservation and the surrounding areas was reconnaissance. It includes the work of such famous geologists as J. S. Newberry (1860), C. E. Dutton (1882a and 1882b), W. T. Lee (1908), F. C. Schrader (1909), and N. H. Darton (1910, 1915, and 1925).

The history of the Cambrian deposits in the Grand Canyon area has been summarized by E. D. McKee (1945). This work subdivides the Cambrian formations into tongues and members and includes interpretations of facies, sedimentation, paleogeography, and paleoecology. McKee (1934 and 1938) also published stratigraphic sections and geologic histories for the Coconino, Toroweap, and Kaibab formations in northern Arizona.

A report by E. D. Koons (1948a) describes the Tertiary gravel beds and the major faults in the western part of the Coconino Plateau. Koons (1945) also described the volcanic rocks in Prospect Canyon.

Stratigraphic sections and descriptions of the Paleozoic rocks in the report area and a general summary of the Paleozoic history in northwestern Arizona were published in a report by A. H. McNair (1951).

H. V. Peterson of the Geological Survey (1942, written communication) located and described 18 prospective well sites on the reservation. Most of the well sites were on rocks of Tertiary and Quaternary age.

ACKNOWLEDGMENTS

The author wishes to acknowledge the assistance given by Mr. W. L. Schroeder and the other personnel of the Truxton Canon Subagency of the Bureau of Indian Affairs, who supplied helpful information concerning the area. Appreciation is expressed also to the local residents of the area who supplied information pertaining to the roads, wells, and springs.

GEOLOGY AND ITS RELATION TO GROUND WATER

A knowledge and understanding of the geologic conditions are prerequisite to an appraisal of the ground-water resources of the Hualapai Indian Reservation. A study of the lithologic, erosional, and structural features of the rocks is important because any one or any combination of these features may significantly influence the occurrence of ground water.

The discussion in this report is related primarily to the geology and water-bearing properties of the sedimentary rocks. These rocks offer the best possibilities for development of ground water, as evidenced by the numerous springs in rocks of Paleozoic age and the successful wells in rocks of Cenezoic age. The Precambrian rocks in the canyons of the Colorado River and in the Grand Wash Cliffs, and the Cenozoic volcanic rocks in the Hualapai Plateau contain small quantities of water and are discussed briefly.

PRECAMBRIAN GRANITE, GNEISS, AND SCHIST

The Precambrian rocks in the area are granite, gneiss, and schist intruded by many coarse-grained granite dikes. In the Diamond Bar Ranch area (pl. 1) the granite has disintegrated in a thick zone at the top. The Precambrian rocks form moderately steep cliffs. Thick sections are exposed in the south Grand Wash Cliffs, in Peach Springs, Spencer, and Diamond Creek Canyons, and in the Colorado River Canyon (fig. 3). The Precambrian erosional surface on which Paleozoic rocks were deposited is one of relatively low relief.

Most of the small springs and seeps in the Precambrian rocks in the south Grand Wash Cliffs issue from fracture zones; however, the largest spring flows from the disintegrated granite at Diamond Bar Ranch. The disintegrated granite has the ability to store and yield water like that of a moderately cemented sandstone. South of Dia-

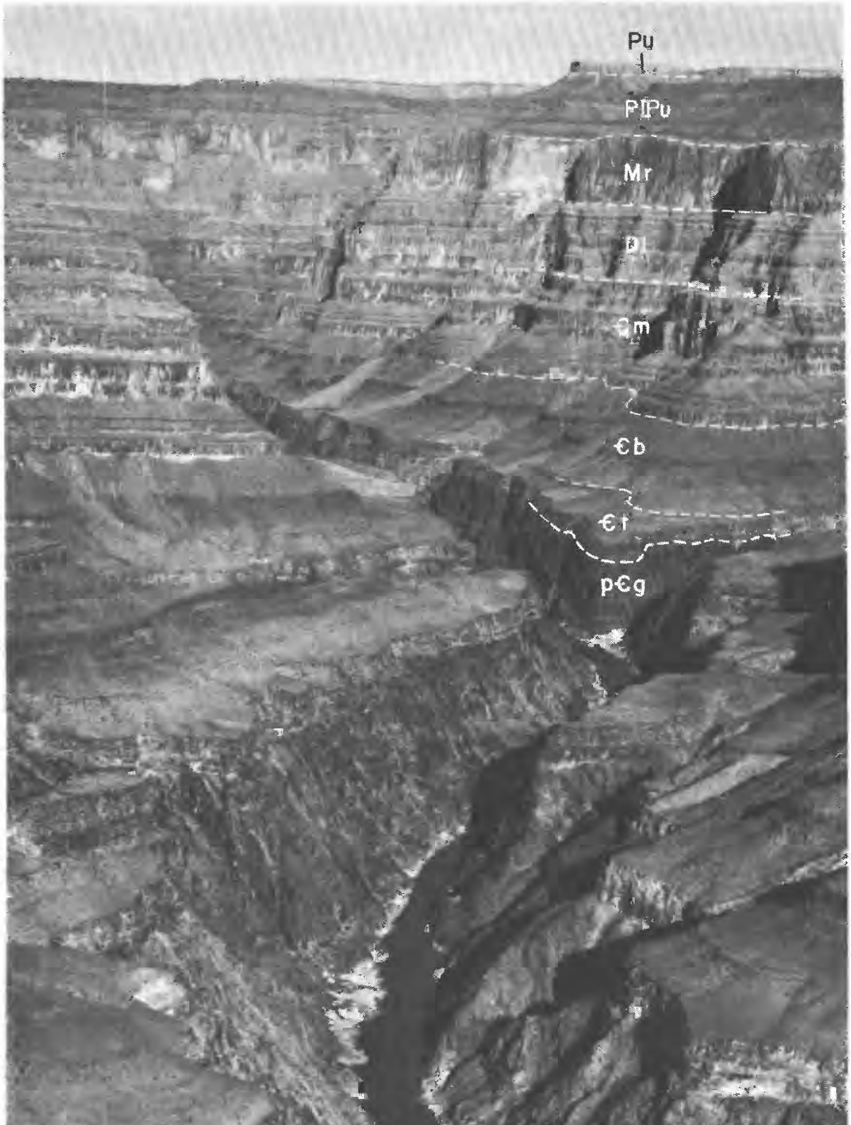

FIGURE 3.—Precambrian and Paleozoic rocks in the Colorado River Canyon near Bridge Canyon. The Hualapai Plateau is southwest (left) of the Colorado River and the Sanup and Shivwits Plateaus are northeast. Precambrian granite, gneiss, and schist (p€g); Tapeats sandstone (€t); Bright Angel shale (€b); Muav limestone (€m); Devonian limestone (Dl); Redwall limestone (Mr); Pennsylvanian limestone, Supai formation and Hermit shale undifferentiated (PPu); and the Coconino sandstone, Toroweap formation, and Kaibab limestone undifferentiated (Pu).

mond Bar Ranch the Precambrian rocks cover a large area, and there also the source of the springs is disintegrated granite. Throughout a major part of the remainder of the area the Precambrian rocks are overlain by relatively impermeable Paleozoic beds that retard the downward movement of water. In this part of the area the Precambrian rocks yield practically no water and are not considered in the development of water supplies for the reservation.

PALEOZOIC ROCKS

The Paleozoic rocks lie on the Precambrian erosional surface. In the Hualapai Plateau these rocks dip 4° to 6° toward the northeast, and in the western part of the Coconino Plateau they dip to the northeast about 1° to 3° (pl. 1).

The Paleozoic rocks in the area, in ascending order, are the Tapeats sandstone, Bright Angel shale, and Muav limestone of the Tonto group of Cambrian age; limestone of Devonian age; the Redwall limestone of Mississippian age; limestone of Pennsylvanian age; and the Supai formation, Hermit shale, Coconino sandstone, Toroweap formation, and Kaibab limestone of the Aubrey group of Pennsylvanian and Permian age.

TONTO GROUP (CAMBRIAN)

TAPEATS SANDSTONE

The Tapeats sandstone, the basal formation of the Tonto group, is coarse grained well cemented brownish gray to blackish red. Most of the grains in the sandstone are subrounded to subangular quartz. Locally, a conglomerate composed of fragments of granite, gneiss, schist, and quartzite occurs at the base. The lower part of the formation is quartzitic and thick bedded. Crossbedding is evident in many of the thick beds. The Tapeats unconformably overlies Precambrian rocks. The average thickness of the formation is about 200 feet, although there is local variation in the thickness due to the undulating nature of the Precambrian erosional surface. In the south Grand Wash Cliffs (fig. 2) and along the Colorado River (fig. 3) the Tapeats sandstone forms two distinct topographic units; the lower part of the formation forms a steep cliff unit and the upper part a steep slope unit.

The well-cemented and quartzitic nature of the Tapeats sandstone indicates that it is of little value for the storage and transmission of ground water. Furthermore, no springs are known to issue from the Tapeats in the area, although small seeps emerge from the basal beds in lower Peach Springs Canyons. The Tapeats sandstone is not considered to be a source of water on the reservation.

BRIGHT ANGEL SHALE

The Bright Angel shale is the middle formation of the Tonto group. In the Hualapai Plateau the formation consists, in ascending order, of shale, siltstone, shale, dolomite, shale, dolomite, and alternating shale and limestone. These units are rather consistent throughout the northern and northeastern parts of the Hualapai Plateau; however, they are not recognizable in the southwestern part of the plateau. In the Coconino Plateau the Bright Angel shale consists, in ascending order, of sandstone, siltstone and shale, and sandstone and dolomite. The shale units are micaceous and greenish gray. The weathered dolomite, sandstone, and siltstone units are reddish orange to reddish brown.

The Bright Angel shale conformably overlies the Tapeats sandstone. The average thickness of the Bright Angel is about 300 to 350 feet, although the formation thickens toward the northwest. The Bright Angel shale forms moderately steep ledge-slope topography; the siltstone and dolomite units form ledges and the shale units form slopes. The exposures of the Bright Angle form a nearly continuous band around a large part of the Hualapai Plateau. The only exposures in the western part of the Coconino Plateau are in the cliffs along the Colorado River. McKee (1945, p. 80–82) subdivided the Bright Angel shale into several tongues and members.

In the area of this report the Bright Angel shale retards the downward movement of ground water, and water collects in the overlying beds. The upper alternating shale and limestone unit in the Diamond Bar Ranch area is slightly permeable, and water flows through it as indicated by a small spring (pl. 1, No. 2). This is the only spring issuing from the formation. Thus the Bright Angel shale is not considered important in the development of ground-water supplies.

MUAV LIMESTONE

The Muav limestone is the upper formation of the Tonto group. The formation is light to dark-gray limestone and siltstone, limestone, and dolomite. Thin-bedded limestone in the lower part of the formation intertongues with the platy limestone and siltstone of the Bright Angel shale. The upper part of the Muav limestone consists of massive beds of mottled limestone and dolomite. The base of the formation is at the bottom of the cliff-forming unit overlying the slope formed on the Bright Angel shale (fig. 3).

McKee (1945, p. 77) redefined the Muav limestone by designating the upper dolomites as the "undifferentiated dolomites." They are white to light gray and contain nodules and thin zones of chert. As used in this report the Muav limestone includes McKee's "undifferentiated dolomites." McKee (1945, p. 84–109) subdivided the formation into members and named the basal cliff-forming unit the Rampart Cave member of the Muav limestone.

The upper part of the Muav limestone forms a high cliff and the lower part forms a steep cliff and slope. The average thickness of the Muav is about 700 feet. In the Hualapai Plateau and the western part of the Coconino Plateau the limestone crops out as a continuous band in the cliffs along the Colorado River. It is the surface rock in the western and southwestern parts of the Hualapai Plateau also.

The Muav limestone is highly fractured and channeled and is underlain by the impervious Bright Angel shale. Therefore, it fulfills the necessary lithologic and structural requirements of a good aquifer. Where it is recharged freely, the Muav is capable of yielding large quantities of water, as indicated by the springs issuing from McKee's Rampart Cave member. The formation is of considerable potential importance in the development of water supplies for the Hualapai Indian Reservation.

DEVONIAN LIMESTONE

Longwell (1921, p. 45–53) described a thick section of Devonian rocks in the Muddy Mountains, about 50 miles west of the Grand Wash Cliffs in southern Nevada, and called it the Muddy Peak limestone. McNair (1951, p. 514–517) described Devonian rocks in the Virgin Mountains about 20 miles west of the Grand Wash Cliffs, which he considered to be stratigraphically equivalent to Longwell's Muddy Peak limestone. The lithology and stratigraphic position of the limestone that overlies the Muav limestone in the area of this report are similar to those of the Muddy Peak limestone as described by Longwell and McNair and it is therefore referred to the Devonian.

The Devonian limestone unconformably overlies the Muav limestone and is mainly a pale yellowish-brown to olive gray limestone and dolomitic limestone, locally containing zones of dark-gray nodular chert. The lowermost beds are purplish to olive-gray limestone. The contact between the limestone of Devonian age and the underlying Muav limestone is uncomformable. The average thickness of the Devonian limestone is 350 to 400 feet, and the unit thickens to the north and northwest. The limestone of Devonian age crops out in the canyon walls along the Colorado River (fig. 3) and forms the surface rock at many places in the Hualapai Plateau.

Although the Devonian limestone is highly fractured, the lack of confining layers at its base allows water to move downward into the underlying aquifer. Thus, because no water is stored in the unit, it is not capable of yielding water to wells.

REDWALL LIMESTONE (MISSISSIPPIAN)

The Redwall limestone is light to medium gray fine to coarse grained and contains several crinoidal beds. Thin zones of modular chert are scattered throughout the formation; however, the concentration of chert is highest in the beds near the lower and upper limits. The light-gray weathered surface of the Redwall limestone and olive-gray weathered surface of the underlying Devonian limestone makes the unconformable contact between these two formations easily recognizable. The Redwall limestone in the reservation area is 500 to 600 feet thick and forms a high vertical cliff.

The Redwall limestone is exposed in the cliffs along the Colorado River (fig. 3) and forms the surface in about 30 percent of the Hualapai Plateau. The cavernous nature of the formation indicates that it contained large quantities of water at one time. However, in the Hualapai Plateau this formation now lies above the zone of saturation and is drained. In the western part of the Coconino Plateau there are no indications that the formation contains water and it possibly is now drained there also. The formation therefore is not considered further in the development of deep-aquifer water supplies.

PENNSYLVANIAN LIMESTONE

The Pennsylvanian limestone is a thin-bedded gray to medium reddish-brown limestone and shale. Pink to reddish-brown chert is abundant throughout the unit. McNair (1951, p. 520–523) restricted the limestone to the Pennsylvanian on the basis of evidence from fossils, and correlated it with the Callville limestone of southern Nevada. In the Coconino Plateau the limestone intertongues with beds of the Supai formation. The contact between the limestone of Pennsylvania age and the underlying Redwall limestone is unconformable, although it has a gradational appearance in the northern part of the Hualapai Plateau. Because only the lower part of the limestone is present in the Hualapai Plateau and the unit intertongues with the Supai formation in the Coconino Plateau, it is difficult to assign an average thickness to the unit. McNair (1951, p. 522) gave a thickness of about 280 feet for the Pennsylvanian limestone near the mouth of Prospect Valley, and about 430 feet in the north Grand Wash Cliffs. The limestone forms a moderately steep slope. It is the youngest Paleozoic unit in the Hualapai Plateau, where it forms a thin cap on the underlying Paleozoic formations along the Colorado River. The Pennsylvanian limestone was not differentiated from the Supai formation and the Hermit shale in the Coconino Plateau.

In the Hualapai Plateau the limestone is above the zone of saturation and is not water bearing. In the western part of the Coconino

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Plateau the ground water drains from the unit into the underlying beds. The Pennsylvanian limestone is not considered important in the development of water supplies for the reservation.

AUBREY GROUP (PENNSYLVANIAN AND PERMIAN)

The Aubrey group are rocks of Pennsylvanian and Permian age. This group is represented by five formations, the Supai formation, Hermit shale, Coconino sandstone, Toroweap formation, and Kaibab limestone. In the Coconino Plateau the Pennsylvanian limestone, the Supai formation, and the Hermit shale were mapped as a single unit.

SUPAI FORMATION

The Supai formation is a moderate-red to reddish-brown siltstone and very fine-grained sandstone in the southeastern part of the reservation. For the most part the typical beds of the Supai are absent in the northeastern part of the reservation and the formation is represented by a light-gray to red thin- to thick-bedded fine-grained sandstone (fig. 4). McNair (1951, p. 525) applied the name "Queantoweap sandstone" to this distinct topographic and lithologic unit and indicated that it intertongues with the typical Supai beds. The Queantoweap sandstone of McNair forms a ledge and cliff topography, whereas the typical beds of the Supai formation form a slope. The contact between the Supai formation and the underlying limestone of Pennsylvanian age is gradational. No accurate thickness can be given for the Supai formation as a single unit; however, the combined thickness of the Pennsylvanian limestone, the Supai formation, and the Hermit shale in the western part of the Coconino Plateau is about 1,500 feet.

Because it is sandy and lacks impermeable confining layers the Supai formation is not water bearing and, therefore, is not considered in the development of water supplies.

HERMIT SHALE

The Hermit shale is moderate-red thin-bedded fine-grained to very fine grained sandstone and is exposed only in the Coconino Plateau. The formation contains no shale in the area of this report. The contact of the Hermit shale with the underlying Supai formation is transitional. The topographic expression of the formation is influenced by the overlying, more resistant Permian formations. Where there are no overlying formations the Hermit shale is easily eroded and forms a gentle slope. Where capped by more resistant formations it forms a relatively steep slope (fig. 4). McNair (1951, p. 528) gives

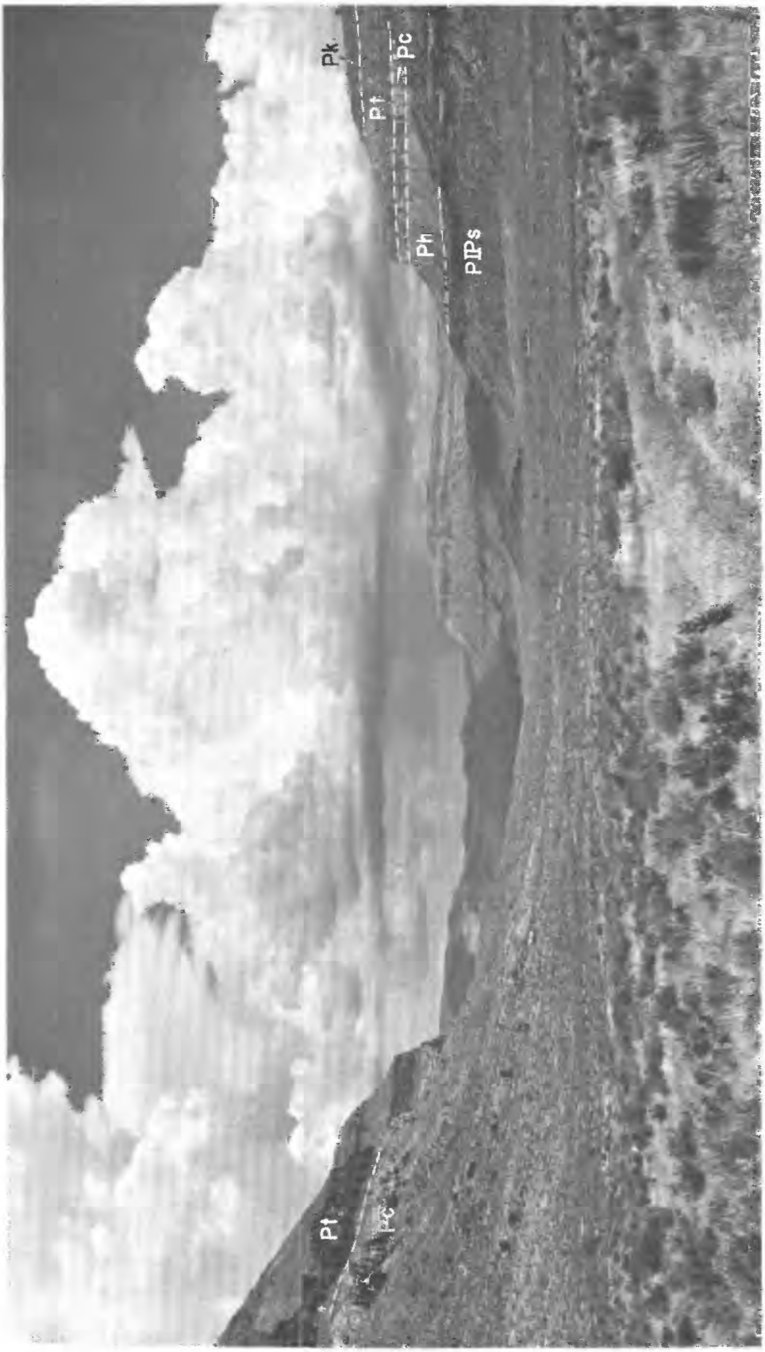

FIGURE 4.—Prospect Valley near the Colorado River. The valley has been formed along the Toroweap fault. The downthrown limb is to the west (left). Vulcans Throne near center of picture is a volcanic cone and is north of the Colorado River. The small cone on right is south of Colorado River. Supai formation (PPs); Hermit shale (Ph); Coconino sandstone (Pc); Toroweap formation (Pt); and Kaibab limestone (Pk).

a thickness of about 930 feet for the Hermit shale near the mouth of Prospect Canyon.

Because the Hermit shale is of moderate permeability and the beds beneath it also are permeable, the water in it tends to drain out. Therefore, the Hermit is not considered to be a source of water for the reservation.

COCONINO SANDSTONE

The Coconino sandstone is fine grained, very light gray to pinkish gray, and crossbedded. White to clear quartz grains constitute about 95 percent of the sandstone. The grains are loosely cemented and relatively uniform in size. Large-scale wedge-type crossbedding is a distinctive feature of the formation. The contact between the Coconino sandstone and the underlying Hermit shale is unconformable and is easily identified by the contrasting colors and the difference in topographic expression. The Coconino sandstone is about 270 feet thick near Blue Mountain Canyon; it thins to the north and west to about 100 feet thick near the mouth of Prospect Canyon (fig. 4). McNair (1951, p. 533) gives a thickness of 42 feet for the formation in the north Grand Wash Cliffs. The Coconino sandstone is exposed as a nearly continuous band along the margins of the Coconino Plateau.

Because it is well sorted and contains little cement, saturated sections of the Coconino sandstone yield moderate quantities of water to wells. At several places in Arizona impermeable beds underlie the formation and it is a good aquifer. However, in the eastern part of the reservation the beds underlying the Coconino sandstone are permeable and the ground water moves downward into the underlying formations. In general, the Coconino in the reservation is not an aquifer and will not yield water to wells.

TOROWEAP FORMATION

The Toroweap formation is exposed only in the Coconino Plateau. The formation consists of two distinct units that can be identified on the basis of lithologic characteristics and topographic expression (fig. 4). The upper unit forms a slope and is a white to gray massive gypsum. The lower unit forms a cliff and is a light to olive gray limestone containing several siltstone, sandstone, and gypsum beds at the base. Many irregular stringers of white chert are present in the limestone unit. The flat-lying basal beds of the Toroweap formation rest on the beveled surface of the underlying crossbedded Coconino sandstone and thus form a sharp and distinct contact between the two formations. This contact is virtually conformable, however, and apparently represents only a change in the conditions of sedimentation. McKee (1938, p. 15) states that "extensive truncation of sloping Coconino laminae to a perfectly flat surface can be accounted for only by a beveling of the sediments while still unconsolidated, and the water that did this probably at the same time spread out the red mud and sand now forming the flat-lying beds on top." The thickness of the Toroweap formation in the western part of the Coconino Plateau ranges from 325 to 375 feet.

Because ground water percolates down through the Toroweap formation and into the underlying permeable sandstones, the formation is not here considered as a source of water.

KAIBAB LIMESTONE

The Kaibab limestone is the uppermost formation of the Aubrey group and is the youngest Paleozoic formation in the Hualapai Indian Reservation area (fig. 4). It is exposed only in the Coconino Plateau. The limestone is light to dark gray and contains many nodules and stringers of white to pink chert. Sinkholes and small solution channels have been formed in the Kaibab, and in many localities the upper beds have been eroded. Complete exposed sections are almost nonexistent, and the thickness in a large part of the area cannot be determined. However, McNair (1951, p. 536) gave a thickness of about 260 feet for a locality near the mouth of Prospect Canyon. The contact between the Kaibab limestone and the underlying Toroweap formation is unconformable and easily identified. The Kaibab forms a steep cliff above the moderate slope-forming beds of the Toroweap.

In a large part of the Coconino Plateau, the Kaibab limestone is covered by deep soil that readily absorbs surface water. However, much of the water is lost by evaportranspiration, and only a small part percolates down into the fractures, solution channels, and sinkholes in the Kaibab limestone. No large springs issue from the limestone, indicating that ground water probably drains from the formation into the underlying rocks. Therefore, the Kaibab limestone is not considered in the development of water supplies for the reservation.

MESOZOIC ROCKS

MOENKOPI FORMATION (TRIASSIC)

In the area of this report the Triassic system is represented only by the Moenkopi formation, which rests unconformably on the Kaibab limestone of Paleozoic age. The Moenkopi formation is composed of red mudstone, siltstone, and sandstone and contains beds of gypsum. The formation was not mapped and the extent of the formation on the geologic map (pl. 1) is from the Geologic Map of the State of Arizona by Darton and others (1924). Nearly all the Moenkopi formation has been eroded; only a small part of the formation remains in the Coconino Plateau.

Because the Moenkopi formation is composed of very fine grained material, it retards the downward movement of water and supports a perched water body in the overlying rocks. However, the formation itself is not water bearing.

CENOZOIC ROCKS

On the basis of lithologic character and extent, the sedimentary rocks of Cenozoic age have been separated into four units: gravel beds in the western part of the Coconino Plateau and fluvial beds of the Hindu Canyon area, both of Tertiary age; lake beds in Truxton Valley of Tertiary and Quaternary age; and alluvium of Quaternary age. The volcanic rocks in the area are of Tertiary and Quaternary age.

TERTIARY GRAVEL BEDS

The Tertiary gravel beds, as described in this report, are found only in the Coconino Plateau. The deposits are unconsolidated to semiconsolidated and are predominantly gravel although beds of red clay, silt, and sand are present. For the most part, the gravel is composed of well-rounded fragments of granite, gneiss, schist, and quartzite; however, at several localities it contains locally derived limestone and sandstone. The Tertiary gravel beds were deposited in ancient stream channels cut in the Permian and Triassic rocks. These beds have a maximum thickness of about 300 to 400 feet and are found at altitudes from 5,500 to more than 6,500 feet.

The Tertiary gravel beds include the two units described by Koons (1948a, p. 58–60; 1948b, p. 475–476). He suggested that the unit containing igneous and metamorphic pebbles and boulders was pre-Pleistocene and had a source to the south, whereas the unit containing locally derived limestone, sandstone, and chert pebbles was younger. The extent of the Tertiary gravel beds shown on the geologic map (pl. 1) is from a map prepared by Koons (1948a, p. 54).

The Tertiary gravel beds are only slightly cemented and have a relatively high porosity. Where the gravel beds are saturated, relatively large quantities of water are available from storage. The sand and gravel beds near Frazier Well yield moderate quantities of water, and further exploration of these deposits may provide new sources of water.

FLUVIAL BEDS OF THE HINDU CANYON AREA

The fluvial beds of the Hindu Canyon area, as described in this report, are restricted to the Hualapai Plateau. They occur from Peach Springs northwestward to Milkweed Canyon and probably were deposited in a body of water formed by ponding of the Colorado River. The beds are divided into a lower and an upper unit.

The lower unit is exposed best in Hindu and Lost Man Canyons and for the most part is fine- to coarse-grained material typical of a playa-lake deposit. This unit consists of semiconsolidated to consolidated red to light-gray sandstone, siltstone, and claystone interbedded with well-rounded locally derived limestone gravel. The gravel at the base of the lower unit is composed of fragments of igneous material.

The upper unit of the fluvial beds of the Hindu Canyon area is predominantly gravel and is exposed best in Milkweed Canyon (fig. 5). The gravel is composed of locally derived fragments of limestone, sandstone, and volcanic rocks and is probably of fluvial origin. The upper unit is interbedded with volcanic sediments and lava.

The estimated thickness of the fluvial beds of the Hindu Canyon area is 900 to 1,200 feet. These beds may occur in Truxton Valley, but more detailed work would be necessary to differentiate them from the overlying lake beds.

No paleontological evidence is available to substantiate the Tertiary age designation of these sediments. However, their lithologic characteristics are similar in some respects to those of the Tertiary deposits in the Lake Mead area described by Longwell (1928, p. 90–96).

The fluvial beds of the Hindu Canyon area contain little cement and in part have a high porosity and permeability. However, no springs or seeps issue from the beds, and previous drilling exploration has been unsuccessful. The ground water in the fluvial beds probably has drained to the deep canyons to the northeast and the beds are now above the zone of saturation. They are not considered as a source of ground water.

LAKE BEDS OF TRUXTON VALLEY

The lake beds of Truxton Valley are composed of semiconsolidated to consolidated sandstone, siltstone, and claystone interbedded with gravel and volcanic rocks. The gravel contains well-rounded pebbles and cobbles of locally derived limestone, sandstone, and lava. The sandstone, siltstone, and claystone can be separated on color characteristics into two distinct units; the older unit is red to light gray and the younger is greenish gray. The younger unit probably was deposited in a shallow, sinuous lake and contains at least one thin

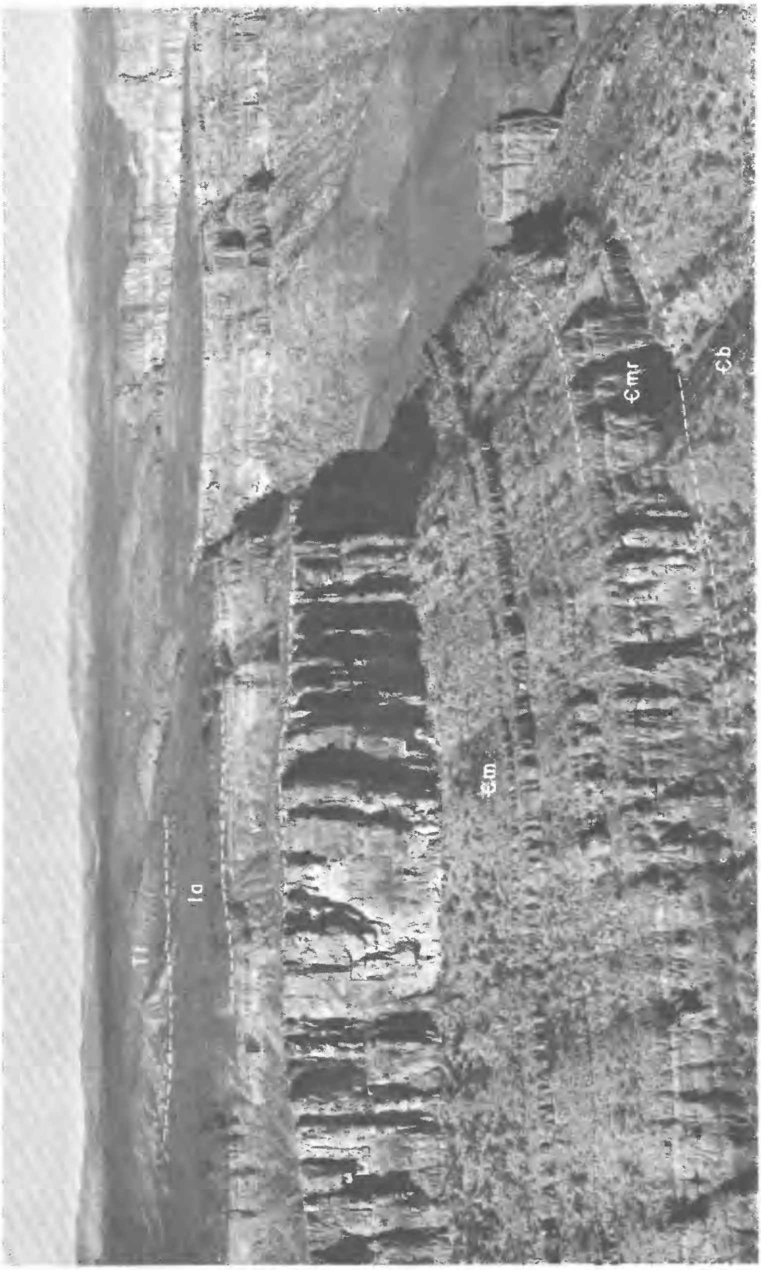

FIGURE 5.—Paleozoic and Cenozoic rocks in Milkweed Canyon. Bright Angel shale (Ꞓb); McKee's Rampart Cave member of the Muav limestone (Ꞓmr); Muav limestone (Ꞓm); volcanic sediments (vs); lava (la); and the fluvial beds of the Hindu Canyon area (Tf). Note the nearly horizontal surface of the Hualapai Plateau.

limy zone. Gastropods, pelecypods, and ostracods, probably of Pleistocene age, have been found in the greenish-gray unit at several localities. The total thickness of the lake beds is estimated to be 300 to 400 feet.

The lake beds were deposited in an ancient, deeply eroded valley. The thick beds of lava along the western margin of Truxton Valley probably formed a dam ponding the westward-flowing water in which the lake beds were deposited.

The relationship of the lake beds of Truxton Valley and the fluvial beds of the Hindu Canyon area was not determined. However, it is possible that the older unit of the lake beds is correlative with the lower unit of the fluvial beds because the two units are, in many respects, lithologically similar.

The lake beds of Truxton Valley contain little cement and are underlain by relatively impervious rocks. Thus, they are permeable and are so situated that they support a perched water body, and several successful wells have been drilled near the town of Truxton. Because the lake beds of Truxton Valley will yield water they are considered as a possible source of water for the reservation.

ALLUVIUM

Alluvial deposits in the reservation area consist of unconsolidated gravel, sand, silt, and clay, and travertine deposits at Spencer, Meriwitica, and Quartermaster Springs. The alluvium occurs extensively in Hualapai and Grapevine Valleys in the western part of the report area and in Aubrey Valley in the east (fig. 1). The alluvium in Hualapai and Grapevine Valleys was deposited in the trough on the downthrown side of the Grand Wash fault and is relatively thick. In Aubrey Valley the alluvium is sheetlike. Shallow alluvial deposits occur also in the bottoms of all the large canyons in the reservation.

The alluvium is only slightly cemented; thus, the pore spaces between the grains, pebbles, and cobbles provide space for storage for moderate quantities of water. In Hualapai and Grapevine Valleys the alluvium is water bearing; however, because it is far below the level of the plateaus and is outside the reservation it could not be used as a source of water for the reservation. Along the eastern boundary of the reservation the alluvium is practically not water bearing. The alluvial deposits in the deep canyons contain water only where large springs exist upstream. Thus, the alluvium is not considered important in the development of water supplies.

VOLCANIC ROCKS

The volcanic rocks in the area include lava and bedded tuff. The lava includes two distinctive lithologic types—dark-gray to black basalt and brownish-gray to pink andesite. The tuff deposits cover a small area and are thin bedded; however, one relatively thick sequence of these rocks is in Milkweed Canyon (fig. 5). In the southern part of the Hualapai Plateau the volcanic rocks are interbedded with, or rest on, the Tertiary and Quaternary sediments. At other localities in the plateau the lava and volcanic sediment rests on rocks of Precambrian and Paleozoic age. A volcanic cone capped with lava is near the head of Quartermaster Canyon. Small deposits of volcanic rocks and two volcanic cones are at the mouth of Prospect Canyon (fig. 4) in the Coconino Plateau.

The volcanic rocks contain many voids and fractures and absorb water readily. Several springs flow from the thicker deposits in the Hualapai Plateau, the most noteworthy being the springs in Milkweed Canyon. The flow is small and fluctuates in response to annual rainfall. The outcrops of volcanic rocks are generally thin and isolated, and ground water drains from them. Therefore, they are not considered important in the development of ground-water supplies.

GEOLOGIC STRUCTURE

The geologic structure at the earth's surface is the result of adjustment of the rocks to unbalanced earth forces manifested by the breaking, folding, and tilting of the rocks. A break that results in displacement of the rock units is termed a fault. Folding or tilting occurs when the relative position of the beds is changed without their breaking. The two types of folds found in the reservation area are the monocline and dome. A monocline is formed when the rocks on one side of the fold are uplifted, without breaking, in relation to the beds on the other side. A dome is a circular structure in which the rocks in the central part are uplifted in relation to the surrounding rocks.

The term "dip" is used to describe the angle of inclination of a bed and is measured at right angles to the line of intersection formed between the bed and a horizontal plane. The sedimentary beds in the Hualapai Plateau dip about 4° to 6° toward the northeast, and the beds in the western part of the Coconino Plateau dip about 1° to 3° to the northeast (pl. 1).

The dip of the sedimentary beds in the area of this report is of great importance because ground water flows in the direction of dip. In the Hualapai and Coconino Plateaus the ground water flows downdip to the northeast and issues as springs along the Colorado River.

Locally, the direction of ground-water flow has been altered by faults and folds.

GRAND WASH FAULT

The Grand Wash fault is one of the major faults in northwestern Arizona. Exact location of this fault is prevented by alluvium in Hualapai and Grapevine Valleys; however, the general location is shown in figure 1. The Grand Wash fault is a normal fault trending northward, downthrown to the west. The maximum displacement along the fault at the Colorado River is about 4,000 to 6,000 feet. The displacement south of the Colorado River is probably similar.

Although the Grand Wash fault is outside the area of this report, it is of general importance. The impervious granite basement of the Hualapai Plateau has been uplifted to a higher altitude than the sediments in Hualapai Valley, thus eliminating the possibility of water moving from the valley into the sedimentary rocks of the Hualapai Plateau. Thus the water-producing wells drilled during 1957 in Hualapai Valley cannot be considered an indication that similar water-producing beds exist in the reservation.

The Rampart Cave fault (pl. 1) is a small branch of the Grand Wash fault and has a maximum displacement of more than 800 feet. The downthrown block of this fault is to the east.

HURRICANE AND TOROWEAP FAULTS

Two major northeastward-trending faults, the Hurricane and the Toroweap, are present in the east-central part of the reservation area (pl. 1).

The Hurricane fault is a normal fault downthrown to the west. The displacement of this fault at the Colorado River in the northern part of the Coconino Plateau is about 1,500 feet. Near the mouth of Diamond Creek the displacement is about 1,300 feet. The displacement diminishes southward to only 250 feet near the head of Peach Springs Canyon. The Hurricane fault forks in the Granite Park Canyon area, but near the mouth of Peach Springs Canyon it again becomes a single fault. Associated with the Hurricane fault are many small faults which have displacements from less than 100 to more than 400 feet. A fault with a displacement of about 700 to 800 feet is located west of the Hurricane fault at the mouth of Granite Park Canyon.

The Toroweap fault parallels the Hurricane fault and is about 6 miles to the east. It is a normal fault downthrown to the west. The displacement of this fault is about 700 feet at the Colorado River and about 1,000 feet near the head of Diamond Creek. Near its southernmost extension the fault splits into three segments.

The Toroweap fault has changed the normal downdip movement of water in the Coconino Plateau. The impermeable beds underlying the Muav limestone east of the fault have been uplifted so that they abut the permeable beds of the Muav limestone on the west. Thus, the eastern block of the Toroweap fault forms a natural barrier to water moving downdip toward the east and northeast. Upon reaching this barrier, water is forced to flow to the north or south along the fault zone.

MERIWITICA AND PEACH SPRINGS MONOCLINES

Perhaps the most unusual and spectacular geologic structure is the Meriwitica monocline in the Hualapai Plateau (fig. 6). The structure begins as a fault north of the Colorado River, extends to the south for 5 or 6 miles, and then becomes a sharply flexured monocline. The monocline continues to the south for about 6 miles to Meriwitica Canyon. An excellent cross-sectional view of the monocline is obtained in Meriwitica Canyon, where a vertical displacement of about 700 to 900 feet occurs within a lateral distance of about 1,500 feet (fig. 6). The Meriwitica monocline is partly concealed south of Meriwitica Canyon and its southern extension is difficult to determine; however, the major part of the fold makes a sharp bend to the east. In Spencer Canyon the flexure has a displacement of 300 to 500 feet. The monocline in Spencer Canyon extends for about 4 miles to the south and then bends sharply to the southwest. The southernmost extension of the monocline in Milkweed Canyon is covered by thick deposits of volcanic rocks. The downthrown limb of the monocline is eastward.

The Meriwitica monocline has one apparent effect on the movement of ground water in the area. The impervious rocks underlying the Muav limestone are exposed in the uplifted western limb for a considerable distance in Meriwitica and Spencer Canyons, thus delineating the recharge area from which water is available to Meriwitica and Spencer Springs.

The Peach Springs monocline (pl. 1) trends generally northeastward. The displacement of the monocline is about 300 to 400 feet a mile east of the town of Peach Springs, and the downthrown limb is to the southeast. The southwest extension of the monocline through the town of Peach Springs is covered; however, the structure probably continues into Truxton Valley as a sharp flexure or fault.

The upthrown side of the Peach Springs monocline probably acts as a natural barrier to the ground water moving downdip toward the northeast in the Muav limestone. The railroads have drilled several successful wells at the town of Peach Springs in the vicinity of this structure.

FIGURE 6.—Meriwitica monocline at Meriwitica Canyon. The vertical displacement is about 700 to 900 feet within a lateral distance of about 1,500 feet; downthrown limb is to the east (right). The monocline extends across the canyon and tilted beds can be seen in the foreground. Bright Angel shale (€b); Muav limestone (€m); Devonian limestone (Dl); Redwall limestone (Mr); and Pennsylvanian limestone (₱l).

MINOR STRUCTURAL FEATURES

The Nelson dome is on the southeastern boundary of the Hualapai Indian Reservation near the town of Nelson (pl. 1). The beds in the central part of the dome have been uplifted more than 1,000 feet. Basaltic dikes along the southwestern extremity of the dome indicate that these beds were probably uplifted by magma. The Nelson dome has a relatively small area and therefore probably has little or no bearing on the general occurrence of water.

Numerous small folds and faults are scattered throughout the report area. They have displacements ranging from about 25 to 300 feet. Generally, the small structural features have relatively little effect on the hydrology of the area as a whole; however, in exploratory drilling they may be of great local importance because they may form barriers to the movement of water, thus providing for storage of ground water.

GROUND WATER

WATER-BEARING CHARACTERISTICS OF THE ROCKS

The availability of ground water in the Hualapai Indian Reservation area is related to the lithologic and structural features and to the solubility of the rocks. Any one or combination of these features locally may determine the ability of the rocks to store and transmit water.

Some lithologic features of a rock that affect its water-bearing characteristics are the degree of sorting, cementation, and grain size. Well-sorted, uncemented rocks consist of grains that are mostly of one size containing open spaces between the grains; poorly sorted rocks consist of grains of many different sizes, and the fine-grained materials fill the pore space between the coarser grains. Thus, unconsolidated well-sorted rocks generally make the best aquifers. Cement is a material, such as calcite and quartz, deposited in the pore spaces of the rocks, after they are laid down. In rocks that contain only small amounts of cement, the pore spaces remain open, permitting storage and movement of water; rocks in which the pore spaces are completely filled with cement are relatively impervious. Grain size has considerable influence on the movement of ground water. Although a decrease in grain size may not bring a decrease in the total percentage of pore space, the smaller the size of the individual pore spaces the greater are the forces necessary to move water through the rocks.

Faults, other fractures, and folds are structural features that affect the occurrence and movement of ground water. Fractures may act as conduits for water to move through rocks that would otherwise be impervious. Fractures occur in most of the rocks in the area of this report. Faults are significant in that they deflect ground water from its previous direction of movement. Where impermeable beds abut permeable beds along a fault, a natural barrier to the movement of ground water is formed. Monoclines affect the movement of ground water like faults. Where impervious beds on one side are warped up against the pervious beds on the other a natural barrier is formed, and water tends to collect and move along the fold rather than across it.

Solution channels and sinkholes also affect the water-bearing characteristics of a rock. Nonclastic rocks that are otherwise compact and relatively impervious such as limestone, dolomite, and gypsum may have solution channels and sinkholes. In these kinds of surface rocks the channels and sinkholes permit part of the precipitation to percolate downward.

OCCURRENCE AND MOVEMENT

Ground water in the area of the report is mainly in perched water zones. The rocks that support these perched water zones are called aquicludes and are an important factor in the ground-water system. An aquiclude retards the movement of water; an aquifer stores and transmits ground water. Potential aquifers are rock units that contain fractures and solution channels or are composed of material that is well sorted, uncemented, and relatively coarse grained. Aquicludes are rock units that are relatively impermeable.

MAJOR AQUICLUDE AND AQUIFER

The most effective aquiclude in the reservation area is the Bright Angel shale. The downward movement of ground water is retarded near the upper limits of this formation and the water collects in the overlying Muav limestone. The Bright Angel shale is extremely fine grained and very little water moves through it. However, in the Diamond Bar Ranch area a small quantity of water issues from the upper zone of alternate limestone and shale beds. This water percolates downward through fractures from the overlying Muav limestone.

The Muav limestone stores and transmits large quantities of water in fractures and solution channels. The numerous springs that issue from this formation indicate that it is the best aquifer in the reservation area.

In the Hualapai Plateau, the large springs in the deep canyons along the Colorado River issue from McKee's (1945) Rampart Cave member of the Muav limestone. The Muav limestone dips generally to the northeast and a large part of the ground water moves downdip toward the Colorado River. Several small springs in the south Grand

Wash Cliffs also flow from McKee's Rampart Cave member. These springs may indicate either that the aquifers in the Muav limestone are saturated to a point where water overflows on the updip side or that water is being drained from the overlying beds.

In the Coconino Plateau, the Toroweap fault forms a natural barrier that retards the northeastward-flowing ground water west of the fault, causing the water to collect and flow along the fault. Two large springs (pl. 1, Nos. 11 and 12) flow from McKee's Rampart Cave member of the Muav limestone near the southernmost extension of the Toroweap fault. Another spring (pl. 1, No. 13) flows from the upper part of the Muav limestone at the point where the fault crosses the Colorado River. East of the Toroweap fault the ground water in the Muav limestone moves northeastward toward the Colorado River.

OTHER AQUICLUDES AND AQUIFERS

The disintegrated and fractured Precambrian rocks in the south Grand Wash Cliffs yield small quantities of water to springs and seeps. The unweathered Precambrian rocks underlying the disintegrated rocks in the Diamond Bar Ranch area form an aquiclude above which water accumulates.

The seeps at the base of the Tapeats sandstone in Peach Springs Canyon probably are the result of very small quantities of ground water draining from the overlying beds. The water contains considerable sodium chloride, and small deposits of halite at the seep outlets have been formed by evaporation. Similar deposits are found at the base of the Tapeats sandstone in the Grand Canyon.

The Tertiary and Quaternary deposits yield small to moderate quantities of water to wells in the Frazier Well area and in Truxton Valley. Exploratory drilling in the fluvial beds of the Hindu Canyon area indicates that the deposits there are not water bearing. The Moenkopi formation probably forms the acquiclude for the channel-type deposits in the Frazier Well area. The Precambrian rocks are the aquiclude in Truxton Valley.

The fractures in the volcanic rocks in the report area act as conduits for part of the water that falls on their surface. The water percolates downward through the rocks, and either issues as small springs or drains into underlying permeable beds.

RECHARGE

There are two major possibilities for recharge to the aquifers in the Hualapai Indian Reservation area—recharge from precipitation and recharge from the Colorado River. Because of the impervious nature of the rocks in the south Grand Wash Cliffs, the ground water in the valleys to the west is not a source of recharge to the reservation area.

Precipitation is the most important source of recharge to the aquifers in the area. The surface rocks absorb part of the precipitation, and the part that is not evaporated or transpired moves downward through the permeable beds until it reaches a perched water body or the main zone of saturation.

In the Hualapai Plateau the rocks exposed are chiefly limestone, lava, and unconsolidated sediments, all of which are capable of absorbing water. Thus, a large part of this plateau is a potential recharge area. Direct absorption of surface water by the Muav limestone, the most important aquifer in the area, occurs along the south Grand Wash Cliffs where this formation crops out over a large area.

The Kaibab limestone crops out over much of the recharge area in the western part of the Coconino Plateau. Throughout this area the formation has a deep soil cover that readily absorbs surface water. A large part of the water is lost by evapotranspiration; however, a small part percolates downward into the fractures, solution channels, and sinkholes in the Kaibab limestone. The absence of springs issuing from this formation probably indicates that the water passes through it into the underlying rocks.

The relatively impervious rocks in the Colorado River Canyon extend eastward from the south Grand Wash Cliffs to Granite Park Canyon and eliminate the possibility of recharge from the river water. Although the permeable Muav limestone is at river level in the northern part of the western Coconino Plateau, the northeastward dip of the beds prevents water from the Colorado River from moving more than a short distance south of the river.

DISCHARGE

Ground water discharges in the area through springs and wells. Large quantities of water are discharged from springs in the deep canyons along the Colorado River, and small quantities are discharged from springs in the south Grand Wash Cliffs. Small to moderate quantities of water are pumped from the wells near the Diamond Bar Ranch and at Frazier Well. Moderate to large quantities of water are pumped from wells in the town of Peach Springs and in Truxton Valley.

SPRINGS

Of the springs and seeps issuing from the Precambrian rocks in the report area, only one spring (pl. 1, No. 1)[1] is worthy of mention. This spring issues from a deeply weathered zone in granitic

[1] Records of springs are given in table 1.

rocks at Diamond Bar Ranch and has several outlets. The flow was estimated to be less than 2 gpm (gallons per minute) and some is used for domestic purposes.

Hillside Spring (pl. 1, No. 2), about 3 miles southeast of the Diamond Bar Ranch, flows from the upper part of the Bright Angel shale. This is the only spring known to issue from this formation, and the discharge was estimated to be less than half a gallon per minute. The spring has been developed and the water is now collected in a stock tank.

Quartermaster Spring (pl. 1, No. 3) in Quartermaster Canyon flows from the base of a large travertine deposit. A part of the deposit extends over McKee's (1945) Rampart Cave member of the Muav limestone and obscures the original outlet. Although the spring was not visited during the course of the fieldwork, an excellent view of it was obtained from the north rim of Quartermaster Canyon, and the discharge appeared to be considerable. The spring is almost inaccessible, and the water flowing from it is not considered as a source of water for the surrounding plateau.

Clay Spring (pl. 1, No. 4) issues near the base of the Muav limestone (probably McKee's Rampart Cave member) in the south Grand Wash Cliffs. The discharge was estimated to be less than half a gallon per minute. The spring at one time supplied water for a gold mill which was nearby. The mill is no longer in existence, and the water is now piped to steel troughs and used for watering stock.

Meriwitica and Spencer Springs (pl. 1, Nos. 5 and 6) issue from McKee's Rampart Cave member of the Muav limestone. The discharge from Spencer Spring was measured in the channel of Spencer Canyon about 1½ miles northwest of the spring outlet. The surface flow at this point was about 300 gpm. However, this was only a part of the total flow, as water was moving also through the alluvium on the canyon floor. The water flowing from Meriwitica Spring spreads out over the alluvium and travertine deposits at the outlet. A measurement of about half the flow indicated that the total discharge from the spring was about 700 to 800 gpm. Thus, the total discharge from Meriwitica and Spencer Springs is at least 1,000 gpm and possibly as great as 1,500 gpm. No significant attempts have been made to develop these springs, and their location in the bottoms of the deep canyons discourages their use as a source of water for the plateau.

The travertine deposits at the outlets of Quartermaster, Meriwitica, and Spencer Springs are about 400 feet thick and have a minimum width of about half a mile. The travertine at Meriwitica Springs has formed a dam in the bottom of Meriwitica Canyon, and the area behind the dam has been filled with alluvium (fig. 7).

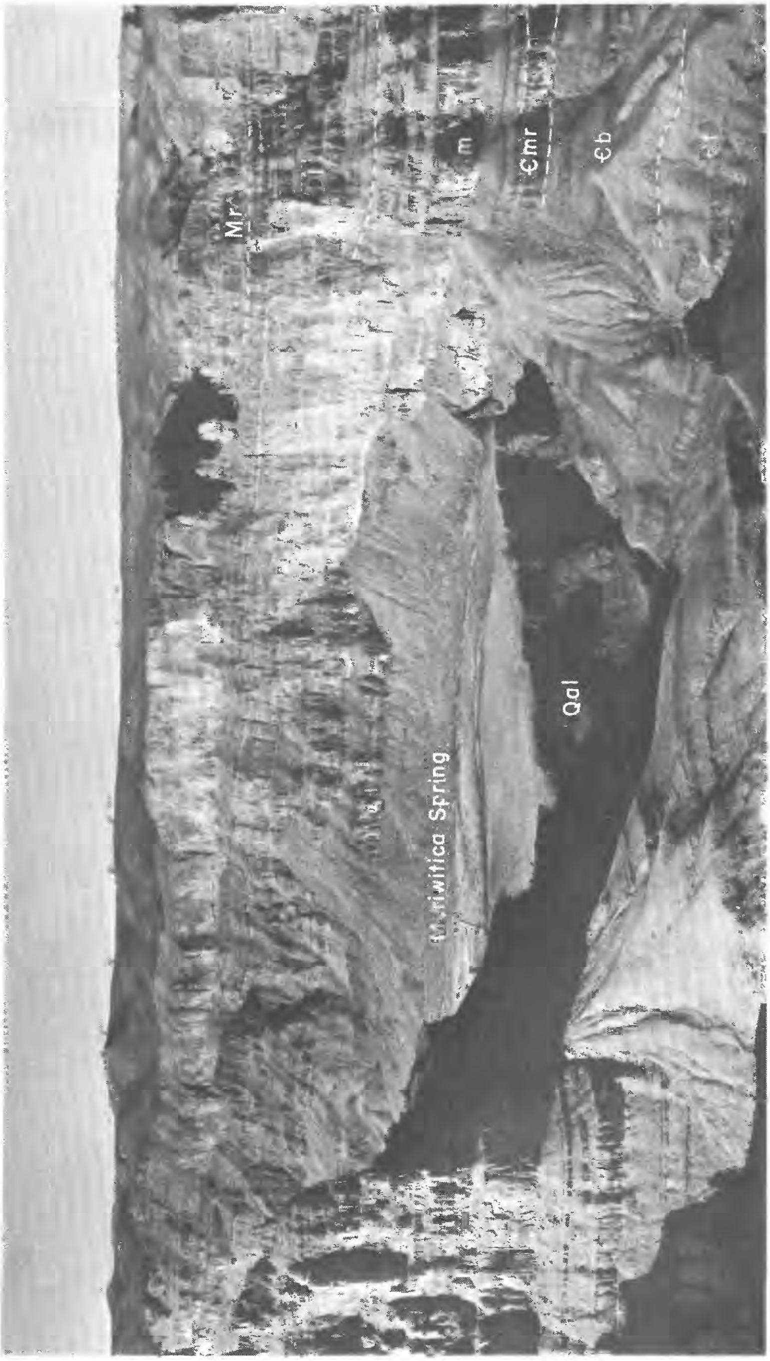

FIGURE 7.—Meriwitica Spring in Meriwitica Canyon. Tapeats sandstone (Ꞓt); Bright Angel shale (Ꞓb); McKee's Rampart Cave member of the Muav limestone (Ꞓmr); Muav limestone (Ꞓm); Devonian limestone (Dl); and Redwall limestone (Mr). The steep cliff-forming unit (Qal) in the bottom of the canyon is travertine which has formed a dam behind which alluvium has been deposited. The travertine deposit is about 400 feet thick and about half a mile wide.

Two small springs flow from the lower part of the Muav limestone along the southern part of the south Grand Wash Cliffs. The discharge from Coyote Springs (pl. 1, No. 7) is estimated to be less than a quarter of a gallon per minute, and Horse Trough Spring (p. 1, No. 9) is even smaller.

Peach Spring (pl. 1, No. 10), about 3 miles north of the town of Peach Springs, flows from McKee's (1945) Rampart Cave member of the Muav limestone. The water is collected and stored in large metal tanks and is then pumped to the town of Peach Springs where it is used to supplement the domestic water supply. Although the discharge from this spring could not be measured it is probably less than 50 gpm.

In the western part of the Coconino Plateau the natural barrier formed by the Toroweap fault controls the location of Diamond and Upper Diamond Spring (pl. 1, Nos. 11 and 12) and Warm Spring (pl. 1, No. 13). The ground water in the Muav limestone collects and moves along this fault until it reaches a natural outlet. These springs are relatively inaccessible and cannot be considered as a source of water for the plateaus.

The discharge from Diamond Spring near the outlet was about 300 gpm. The flow from Upper Diamond Spring about 1 mile below the outlet in the alluvium-filled channel of Diamond Creek was about 50 gpm, although a large quantity of water may flow through the alluvium. In June 1953 the total discharge near the mouth of Diamond Creek was about 950 gpm (U.S. Geological Survey, 1955, p. 461). During the winter, when less water is lost by evapotranspiration, the discharge may be somewhat greater.

Warm Spring (pl. 1, No. 13) at the mouth of Prospect Valley just above the level of the Colorado River issues from the upper part of the Muav limestone. In June 1953 the discharge from Warm Spring was estimated to be about 8 cubic feet per second (cfs) or about 3,500 gpm (U.S. Geological Survey, 1955, p. 461).

Milkweed Spring (pl. 1, No. 8) is one of several small springs flowing from the volcanic rocks in the vicinity of Milkweed Canyon. In May 1958 its discharge was estimated to be about 1 to 2 gpm. However, this spring is near its recharge area, and its flow probably fluctuates annually with precipitation, being greatest during the winter and decreasing during the summer.

WELLS

The most important wells in the area of this report are near Frazier Well, near Diamond Bar Ranch, at Peach Springs, and in Truxton Valley.

The shallow wells near Frazier Well pass through and obtain water from the Tertiary gravel beds. These wells are about 150 feet deep, and their discharge ranges from about 10 to 30 gpm. The water is used for domestic purposes by the residents of a small logging camp at Frazier Well.

The well near Diamond Bar Ranch (T. 28 N., R. 16 W.) obtains water from the Muav limestone. This water is used to supplement the supply in a nearby stock tank. The ground-water storage reservoir is limited in this area by the proximity of the south Grand Wash Cliffs.

The wells drilled for the Santa Fe Railway in the town of Peach Springs are about 800 to 1,000 feet deep and obtain water from the Muav limestone. The discharge from several of the wells was reported to range generally from 5 to 40 gpm. However, one or two other wells drilled to about the same depths were reported to be dry. The success in obtaining water from some of these wells and the failure of others may be related to their location on the Peach Springs monocline.

The wells in Truxton Valley have been drilled in the beds of Tertiary and Quaternary age to depths of about 300 to 400 feet. The water level in one of the wells is about 150 feet below the land surface. The water from another well is used for domestic purposes in the town of Truxton.

In 1957 several wells were drilled at the south edge of Red Lake in Hualapai Valley outside the area of this report. Test pumping of these wells indicated that they would yield about 1,500 to 2,000 gpm of water of good chemical quality. The wells were drilled in unconsolidated and semiconsolidated rocks to about 700 feet below the surface. The impervious Precambrian rocks to the east of the Grand Wash fault form a natural barrier to the ground water in Hualapai Valley; thus, water supplies in this valley are not related to the ground water in the reservation area.

QUALITY OF WATER

The chemical analyses of the water from the sampled springs in the Hualapai Indian Reservation area are shown in table 1. Six of the samples were collected from springs that issue from the Muav limestone. Two other samples were collected from springs that issue from the Precambrian rocks and the Bright Angel shale. The chemical analyses show that the sum of the dissolved solids in the water from the springs ranges from 255 to 453 ppm (parts per million).

TABLE 1.—*Records and chemical analyses of ground water for springs, Hualapai Indian Reservation area, Arizona*

[Analyses in parts per million except as indicated. Number: refers to spring location as numbered on pl. 1. Discharge: gpm, gallons per minute; <, less than; >, more than; E, estimated, M, measured; R, see remarks.]

No.	Name	Date of collection, 1958	Source	Discharge (gpm)	Temperature (°F)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (sum)	Hardness as ($CaCO_3$)	Sodium (percent)	Specific conductance (micromhos at 25°C)	Remarks
1	Diamond Bar Spring.	May 1	Precambrian rocks.	<2E	55	36	71	27	55	375	0	37	41	1.8	.2	453	288	29	724	
2	Hillside Spring	do	Bright Angel shale.	<½E	57	16	60	50	16	416	0	21	17	.3	1.7	387	355	9	664	
3	Quartermaster Spring.	---	Muav limestone	R	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	Flow appears to be considerable.
4	Clay Spring	May 1	do	<½E	61	15	67	46	22	415	0	24	25	.4	4.4	408	356	12	701	
5	Meriwitica Spring	May 20	do	>700M, R	76	21	71	50	17	451	0	16	16	.3	11	424	382	9	724	Measurement of about half the flow was approximately 350 gpm.
6	Spencer Spring	do	do	>300M, R	80	25	61	48	28	396	0	31	32	.6	9.5	430	350	15	725	Measured about 1 mile north of spring. Part of flow in alluvium not measured.
7	Coyote Spring	---	do	<¼E	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	
8	Milkweed Spring	---	Volcanic rocks	<2E, R	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	Probably decreases during summer.
9	Horse Trough Spring.	---	Muav limestone	R	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	Flow occurs as seeps only.
10	Peach Spring	May 19	do	<50E	68	22	60	32	24	280	0	26	40	.4	24	366	281	16	624	Water supply for the town of Peach Springs.
11	Diamond Spring	May 15	do	>300M	72	26	50	21	18	228	0	15	24	.5	15	282	212	15	460	
12	Upper Diamond Spring.	do	do	>50M, R	87	23	39	22	18	199	0	15	26	.4	14	255	188	17	423	Measured about 1 mile west of spring. Part of flow in alluvium not measured.
13	Warm Spring	---	do	R	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	Flow estimated at 8 cfs. (U.S. Geological Survey, 1955, p. 461.)

The water from Diamond Bar Spring (pl. 1, No. 1) flows from Precambrian rocks and has the highest content of silica, sulfate, sodium and potassium, chloride, and dissolved solids of any of the samples. The fluoride content of this water was about four times greater than in the other samples.

The analysis of the water from the Bright Angel shale (pl. 1, No. 2) indicates that its chemical quality is similar to that of water from the overlying Muav limestone.

The chemical analyses of water from the sampled springs flowing from the Muav limestone indicate that the magnesium, bicarbonate, dissolved solids, hardness, and specific conductance are higher in the western part of the report area than in the eastern part. However, the water from the Muav limestone in both parts is of good quality and is satisfactory for domestic use according to the standards of the U.S. Public Health Service. The water is hard to very hard, however.

PROMISING AREAS FOR DEVELOPMENT

The results of this investigation on the ground-water resources of the Hualapai Indian Reservation indicate that moderate quantities of good-quality water probably can be obtained from deep aquifers and small to moderate quantities can be obtained from the shallower aquifers. The factors that should be considered in the development of the ground-water resources are as follows:

1. The Muav limestone contains moderate to large quantities of good-quality water and is the best aquifer in the area of this report. Moderate quantities of water probably can be developed from McKee's Rampart Cave member of the Muav limestone in the Hualapai Plateau west of Peach Springs Canyon. In the western part of the Coconino Plateau the depth to the water-bearing zones in the Muav limestone is about 2,500 to 3,500 feet and may discourage the development of water from this formation.
2. The Tertiary and Quaternary rocks yield small to large quantities of good-quality water to wells in Truxton Valley and at Frazier Well. Additional water supplies probably can be developed from these water-bearing rocks within the area of this report.
3. The prospects of obtaining water from the large springs in the reservation are discouraging because the springs are in the bottoms of deep, relatively inaccessible canyons.

The areas that are promising for the development of moderate water supplies from the Muav limestone are identified as H–1, H–2, and H–3 on plate 1. More detailed geologic information would be necessary before specific well sites could be recommended.

The area identified as H–1 appears to be the most favorable for development. The large springs in Meriwitica and Spencer Canyons indicate that McKee's Rampart Cave member of the Muav limestone is water bearing in this area. The relatively large area covered by the Muav limestone provides an adequate recharge area. A well drilled in the H–1 area would penetrate about 700 feet of the Muav limestone before reaching the top of the Bright Angel shale. Ground water probably would be found near the base of the Muav limestone, and to obtain maximum production the well should penetrate the entire thickness of the Muav and the upper 20 to 30 feet of the Bright Angel shale. The total depth of the well would be about 750 feet.

The area that appears to be the second most favorable for development of ground water from the Muav limestone is identified as H–2. The geologic and hydrologic conditions in this area are similar to those in the H–1 area; however, no large springs are known to issue from the Muav in the canyons to the northeast. About 2 miles southwest and updip from the H–2 area, Clay Spring (pl. 1, No. 4) issues from the Muav indicating that the limestone in the vicinity of the H–2 area does contain some water. The entire thickness of the Muav limestone, about 750 feet in this area, and the upper part of the Bright Angel shale should be penetrated to obtain maximum production. The total depth of a well in this area would be about 800 feet.

The area identified as H–3 appears to be the least favorable of the three for the development of ground water from the Muav limestone. No large springs flow from the formation in this area, and the area of recharge and storage is relatively small. However, the basal part of the Muav limestone may contain small to moderate quantities of water. As the area is surrounded by good rangeland, it is worth considering for development of water for livestock. The Muav limestone is about 650 to 700 feet thick in this area. The upper part of the formation has been eroded; thus, a well in the H–3 area would have to penetrate less than 650 feet of rock to obtain maximum production.

Ground water possibly can be obtained from the Muav limestone in other parts of the reservation west and northwest of Peach Springs Canyon, but the depth to water would be greater than in the areas described above.

Several successful wells have been drilled in the water-bearing Quaternary and Tertiary rocks in Truxton Valley. On the basis of these results, the area identified as H–4 (fig. 3) is considered a possible source of water, although it does not appear to be as favorable for development as the other three areas described above. A well drilled in the H–4 area should penetrate the entire thickness of the Tertiary and Quaternary rocks to obtain maximum production. The total depth of the well probably would be 400 or 500 feet.

The Tertiary gravel beds yield water to several wells in the Frazier Well area. No attempt was made to determine prospective well sites in the area; however, more detailed study of these deposits might provide information for locating successful well sites.

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