Geology in Relation to Availability of Water Along the South Rim Grand Canyon National Park Arizona

By D. G. METZGER

HYDROLOGY OF THE PUBLIC DOMAIN

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By D. G. Metzger

ABSTRACT

A ground-water investigation of the south-rim area, Grand Canyon National Park, Ariz., was made at the request of the National Park Service to determine whether a sufficient water supply could be developed to increase adequately the supply for Grand Canyon (village) and Desert View. The Park Service estimates that an increase of about 1 cfs would be adequate for the expected expansion of the park.

The oldest rock units are the Vishnu schist and the Unkar group of the Grand Canyon series of Precambrian age. The Paleozoic formations are, in ascending order, the Tapeats sandstone, Bright Angel shale, and Muav limestone of the Tonto group of Cambrian age; the Temple Butte limestone of Devonian age; the Redwall limestone of Mississippian age; and the Supai formation, Hermit shale, Coconino sandstone, Toroweap formation, and Kaibab limestone of the Aubrey group of Pennsylvanian and Permian age. The youngest rock units are the Moenkopi formation and the Shinarump member of the Chinle formation of Triassic age.

The principal aquifer in the Grand Canyon village area is the Muav limestone which, in many places, yields water readily to springs. Locally, the Vishnu schist, Tapeats sandstone, Supai formation, and Coconino sandstone yield small quantities of water to springs. Outside the park, large springs issue locally from the Redwall limestone.

The major geologic structures are the monoclinal flexures associated with the East Kaibab monocline, and the Bright Angel fault. The regional dip of the strata is commonly 1° to 2° to the south and southwest.

The occurrence of ground water along the south rim is related not only to the lithology of the sedimentary formations but also to the geologic structure. Ground water occurs in a series of perched water bodies in the sedimentary rock sequence. Where an aquiclude occurs, the overlying rock unit generally contains water if structural conditions are favorable, as exemplified by the small springs that issue from the Supai formation and Coconino sandstone. The main body of water in this area occurs in the Muav limestone, which is underlain by the Bright Angel shale—an aquiclude.

The amount of recharge to the ground-water reservoir is believed to be only a small percentage of the average annual precipitation. Havasu Springs have a discharge of 66 cfs and are the natural discharge point for a drainage area assumed to be the same as that of Havasu Creek above the springs—2,900 square miles.

In the Desert View area monoclinal flexures probably govern the direction of ground-water movement, and near Grand Canyon village the Bright Angel fault exerts an influence. The total discharge of springs between Hermit and Cottonwood Creeks is about 600 gpm. Of this, more than 500 gpm comes from two groups of springs—those at Indian Garden and in Hermit Creek.

Chemical analyses of water samples from springs indicate that the amount of dissolved mineral matter in the water is small. The range in dissolved solids in 14 samples from the report area was from 179 to 667 ppm, and all samples except 2 contained less than 400 ppm.

Two possibilities of developing additional water for the village are capture and transport of more water from springs at Indian Garden and development of the springs in Hermit Creek. If the two sources do not provide the quantity of water needed, or if the cost of development is too high, then studies of the water resources of the north-rim area would be worth while. There is little or no possibility of developing water in the Desert View area.

INTRODUCTION

The Grand Canyon of the Colorado River is a monumental example of the cutting and carrying power of water, which is the chief agent in erosional processes. The canyon is a mile deep and 8 to 10 miles wide, and it divides the Colorado Plateau into the Kaibab Plateau (north rim) and the Coconino Plateau (south rim).

Although the Colorado River—one of the largest in the West—flows along the bottom of this deep gorge, there is a shortage of drinking water along the south rim. As the river cut a canyon through the upper rock units the ground water in them drained into the gorge, and today water issues from rocks near the bottom of the canyon. The ground water draining from rocks along the south rim forms springs, such as the springs at Indian Garden, which issue from the Muav limestone about 3,200 feet below the south rim. The present water supply for the Grand Canyon village area is collected from these springs and the water is pumped to the rim. Plate 12 is an aerial view of the south rim and shows Indian Garden and Grand Canyon (village).

PURPOSE AND SCOPE OF INVESTIGATION

At the request of the National Park Service, the U.S. Geological Survey made a ground-water investigation in the Grand Canyon

National Park, Coconino County, Ariz., along the south rim from Hermit Creek to the Little Colorado River (fig. 22 and pl. 13). The investigation was made primarily to determine the availability of additional water supplies along the south rim.

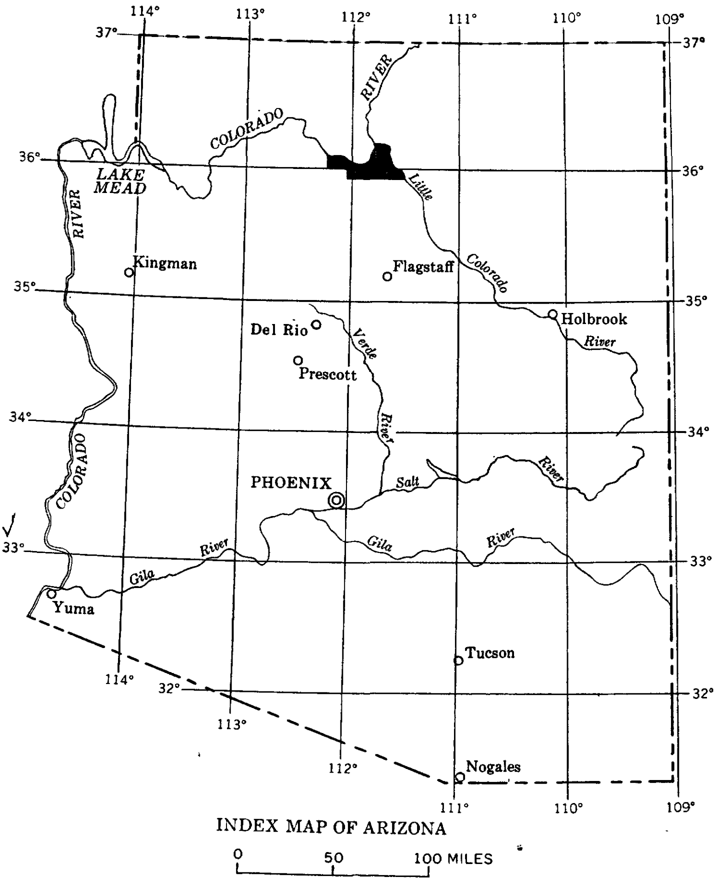

Figure 22.—Map of Arizona showing location of the south-rim area of Grand Canyon National Park.

The development of water supplies along the south rim has been a problem from the earliest days when water was hauled, to the present time when water is pumped from Indian Garden. Two water systems are in use at the Grand Canyon village area: the supply pumped from Indian Garden and used for domestic purposes and reclaimed water from the sewage-disposal plant, which is used for sanitary purposes and sprinkling of lawns.

The water supply cannot adequately meet the demands of the ever-increasing tourist travel nor to meet the future expansions of Grand Canyon village and Desert View. At present, water is hauled from Grand Canyon village to Desert View, a distance of about 23 miles. The Park Service believes that, if the anticipated expansion occurs, a more economical means of getting water to Desert View may have to be found.

Although the present supply is sufficient for domestic purposes, more water would be used if available. For example, there would be more lawns, and the permanent citizens of Grand Canyon village would use the water to grow shrubs and plant gardens. Also, if abundant water were available, the Park Service could discontinue the use of reclaimed water, as it is expensive and corrodes the plumbing. It has been estimated by the Park Service that about 1.00 cfs increase over the present Indian Garden supply would be adequate for the anticipated expansion.

When the tourist looks at the canyon and learns of a water shortage at the village, he is likely to wonder, "Why not use the Colorado River for more water?" One of the reasons for not using the water is the tremendous quantity of sediment carried by the river; it would be expensive to remove the sediment from the water. The additional pumping lift from the mile-deep canyon also would add to the cost.

HISTORY OF WATER SUPPLY ALONG THE SOUTH RIM

Insufficient water has been the history of water supply along the south rim from the time of the earliest settlers to the present. In view of present problems of water supply, it is not difficult to imagine that water was a scarce commodity for the pioneers who settled near the canyon.

The principal settlements along the south rim prior to 1900 were those at Grandview Point and Grand Canyon village. According to files of the Grand Canyon National Historical Association, water for the Grandview Hotel was hauled originally from Hull Tank. Later, reservoirs were built below the rim to store water for the hotel. Water was transported to Grand Canyon village from nearby stock tanks. Some water was carried by burros from springs at Indian Garden. One of the sources of water, "Company Well," was a natural

AERIAL VIEW OF THE SOUTH RIM OF THE GRAND CANYON

Indian Garden, IG, is at lower left and the village of Grand Canyon, GC, at upper right. Bright Angel shale, Ꞓba; Muav limestone, Ꞓm; Redwall limestone, Mr; Supai formation, PIPs; Hermit shale, Ph; Coconino sandstone, Pc; Toroweap formation, Pt; Kaibab limestone, Pk. Photograph by Tad Nichols.

tank in sec. 33, T. 31 N., R. 2 E. Other sources were small catchment areas and cisterns in some of the buildings.

One of the earliest records of the water problems along the south rim is an article printed in the Coconino Sun, Flagstaff, Ariz., on May 28, 1896. It stated that the "water man" at the Grand Canyon was still charging $0.25 a barrel to haul water, and that the rumor that he had upped his price to $0.40 was untrue. The size of the barrels is not known.

The railroad to the canyon (now a part of the Santa Fe system) was completed on October 12, 1901, and a new era in water supply began. Water was hauled in tank cars from Flagstaff and from Del Rio (fig. 22) to the canyon and was distributed by the railroad. The National Monument was given National Park status by Congressional Act of February 26, 1919. The cost of the water to the Park Service installations at that time was $3.09 per 1,000 gallons.

Hauling water in tank cars was expensive, and in 1924 Santa Fe railway engineers began to investigate other sources of water. Four possibilities were advanced: Transport water from the San Francisco Peaks near Flagstaff; drill wells several miles south of the park boundary; pump water from springs at Indian Garden; and pump water from Hermit Creek. The first possibility involved problems of surface-water rights and construction of a long pipeline and, therefore, it was not considered further. One well was drilled in sec. 17, T. 30 N., R. 2 E., south of the park boundary to a depth of 1,000 feet (into the Hermit shale), but it produced no water at that depth. This left only the last two possibilities. However, a fifth possibility for a small amount of additional water materialized later, after the completion of the sewage disposal plant at Grand Canyon village. This plant was completed on May 28, 1926, and it afforded an opportunity for the reuse of water. The reclaimed effluent from the potable-water system has since been used at comfort stations and at other places where potable water is not necessary.

By the early thirties, the Santa Fe engineers had decided to develop springs at Indian Garden, about 3,200 feet below Grand Canyon village. A pipeline was completed on August 26, 1932, and pumps with a capacity of 278,000 gallons per day (gpd) were installed. This new arrangement eliminated the need for hauling water in tank cars and reduced the cost of water to $1.66 per 1,000 gallons.

The amount of water lifted from Indian Garden was adequate until the end of World War II when a large influx of summer tourists beginning then made it necessary to reduce the per capita allowance of

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water. Additional reservoirs were constructed that provided storage for pumped water during the slack winter season. The amount of water in storage by 1958 amounted to slightly less than 4 million gallons. This stored water plus the pumped water meets present demands but it will not be adequate for the expected growth of the park.

TOPOGRAPHY AND DRAINAGE

The slope of the land surface along the south rim is southwestward away from the canyon, in the direction of the regional dip of the strata. This nearly featureless slope is called the Coconino Plateau. The rim marks the northern boundary of the Coconino Plateau east to Grandview Point, beyond which the Grandview section of the east Kaibab monocline forms the northern limit. The area between the Grandview section and the main flexures of the east Kaibab monocline is called the Upper Basin.

The altitude along the south rim ranges from 6,800 to 7,500 feet above sea level. The drainage between Hermit Creek and Grandview Point is southwestward, between Grandview Point and Desert View is southeastward, and between Desert View and Cape Solitude is eastward (pl. 13).

The slope of the land surface on the north rim is in the direction of the regional dip, that is, southwestward. This land surface is called the Kaibab Plateau. The altitude of the north rim is generally more than 8,000 feet about sea level, and the plateau becomes higher northward. The drainage is toward the rim, a fact that accounts for a larger surface runoff into the canyon from the Kaibab Plateau than from the Coconino Plateau.

The canyon has topographic forms much different from those of the plateaus (pl. 12). Whereas the plateaus are rather flat and featureless, the canyon has cliffs and steep slopes, which in succession drop down to the Tonto platform. This platform, formed on the Bright Angel shale, has the gentlest slope found in the canyon. The inner gorge, which is carved in schist and gneiss, is V-shaped. The descent from the rim over the cliff and steep slopes is very abrupt; in the Hermit Creek drainage it is more than 3,500 feet in less than a mile.

Although the Colorado River drains the area, runoff in the south-rim area travels along devious paths before it reaches the river. For example, the drainage from Grand Canyon village is southwestward into Havasu Creek, then northwestward to the Colorado River. From Desert View the drainage is southward to the cliffs formed by the Grandview flexure, then eastward to the Little Colorado River, and finally to the Colorado River. Runoff from the Kaibab Plateau is southward to the Colorado River.

CLIMATE

The climate of Grand Canyon is extremely varied, as would be expected from the marked changes in altitude—from about 2,000 feet above sea level near the Colorado River to 7,000 feet on the south rim and more than 8,000 feet on the north rim. At the higher altitudes there is more precipitation and the temperature is lower. The vegetation grades from Sonoran Desert types in the inner canyon to Canadian forest types on the north rim.

The north rim, or Kaibab Plateau, is more than 8,000 feet above sea level. The winters are cold and there is much snow, but the summers are cool. The annual precipitation is about 23 inches. The vegetation consists of pine, Douglas-fir, spruce, and aspen.

The south rim or Coconino Plateau has an altitude about 1,000 feet lower than the north rim. The precipitation is only about 15 inches per year. The winters are not so cold, although snow is common, and the summers are warmer. Ponderosa, pinyon, and other species of pine are common along the south rim. Oak and juniper also are abundant.

The inner canyon is the driest part of the area, as it receives only about 9 inches of precipitation. The winters are mild and temperatures below freezing are rare, but the summers are hot. In summer the rocks absorb the heat, and the bottom of the gorge is like an oven. Vegetation consists of various desert bushes and cacti. Cottonwoods and other water-loving plants thrive along perennial streams.

PREVIOUS INVESTIGATIONS

The geologic literature is replete with references to the rock sequence exposed at Grand Canyon, as it is one of the classic areas of geologic studies. No attempt will be made to list all the previous reports, but only those pertinent to geologic conditions as they affect ground water.

Most of the discussion of the Paleozoic sedimentary rocks is based on unpublished information in the files of the U.S. Geological Survey, which were compiled, largely by J. H. Irwin and P. R. Stevens of the Survey, for a regional investigation of the Navajo and Hopi Indian Reservations. The discussion of geologic structure is based primarily on the work of Babenroth and Strahler (1945).

FIELDWORK AND MAPS

The fieldwork consisted of a hydrologic and geologic reconnaissance along the south rim to determine the topographic and the stratigraphic position of springs. All springs along the Tonto trail from Grandview Point to Hermit Creek were visited. The geology of that part of the Navajo Indian Reservation shown in the eastern part of plate 13 was mapped by J. H. Irwin, P. R. Stevens, J. P. Akers, and M. E. Cooley on aerial photographs and aerial mosaics. The geology of the larger area to the west was mapped by D. G. Metzger and F. R. Twenter on topographic maps of the Grand Canyon.

Data on wells south of the rim and north of U.S. Highway 66 were compiled from records of the Museum of Northern Arizona and Babbitt Brothers Ranch and selected wells were visited to obtain more information. Personnel from the U.S. Geological Survey who aided in the hydrologic fieldwork were R. E. Cattany, J. M. Cahill, R. S. Stulik, and F. R. Twenter.

The base map (pl. 13) was compiled from a topographic map of the Grand Canyon and from maps prepared by personnel of the Navajo ground-water project of the U.S. Geological Survey. The regional map (fig. 23) was taken from Arizona Highway Planning Maps.

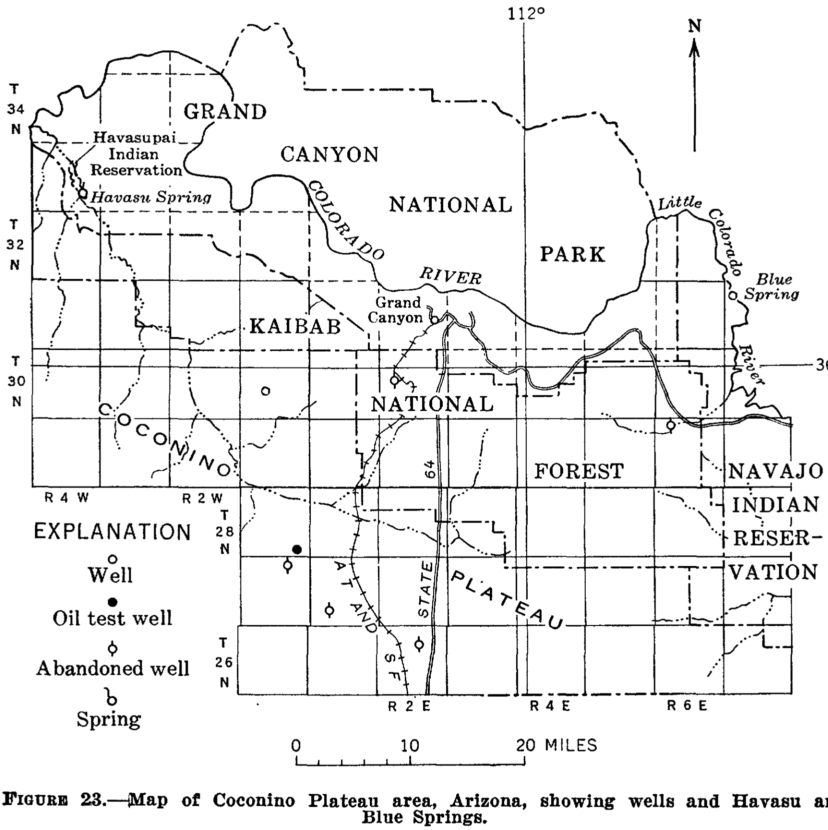

FIGURE 23.—Map of Coconino Plateau area, Arizona, showing wells and Havasu and Blue Springs.

ACKNOWLEDGMENTS

Personnel of the Park Service under the supervision of Mr. J. S. McLaughlin, park superintendent, were very helpful at all times and gave splendid cooperation. Particular thanks are given to Mr. C. E. Shevlin, assistant park superintendent, who helped in assembling many of the basic data; and Mr. J. H. Conn, former park engineer, who gave freely of his experience in dealing with water problems at the park; and to Messrs. P. E. Schultz, park naturalist, and M. W. Wilcox, park engineer. The author extends appreciation to Mr. Jack Watson, trail foreman, and Mr. Jack Hall, trail packer, for their help on the trail.

Appreciation is extended to the Museum of Northern Arizona for much of the information on wells on the Coconino Plateau. Babbitt Brothers of Flagstaff provided information on their many stock wells.

GEOLOGY AND WATER-BEARING PROPERTIES OF THE FORMATIONS

In order to evaluate the ground-water resources of an area it is essential to have an adequate knowledge of the geologic framework. In the Grand Canyon area, the occurrence of water is related not only to the lithologic character of the sedimentary formation,. but also to the geologic structure.

Most of the discussion is limited to rocks of Paleozoic age, which offer the best possibilities for development of ground water, because all but one of the springs issue from these rocks. The Precambrian rocks, found only in the inner gorge of the Grand Canyon, are discussed briefly. The Moenkopi formation and the Shinarump member of the Chinle formation of Triassic age are not considered important because they are exposed only as small erosional remnants east of Desert View, and thus are not considered as potential ground-water reservoirs.

PRECAMBRIAN ROCKS

The Precambrian rocks of the Grand Canyon are the Vishnu schist and the Grand Canyon series. The Vishnu schist is the oldest rock in the area; it is intruded by dikes and is separated by a conspicuous unconformity from the overlying Grand Canyon series. The Grand Canyon series is composed of sedimentary rocks that show little metamorphism, and they are considered younger Precambrian in age.

VISHNU SCHIST

According to Noble and Hunter (1916), about half the rocks assigned to the Vishnu schist are gneisses that were originally igneous rocks, about 20 percent are intrusive rocks, and only about 30 percent are schists. In the area to the west of Hermit Creek, Noble (1914, p. 33) found three types of schist: quartz schist that grades into mica schist, quartz schist that grades into quartz-hornblende schist, and hornblende schist. Basic intrusive rocks, siliceous intrusive rocks, and pegmatite dikes intrude the Vishnu and have been mapped with it.

All rocks of the Vishnu schist and accompanying intrusive rocks are dense and offer little possibility as sources of water. However, where the Vishnu schist is overlain by the Tapeats sandstone, deep disintegration along fractures was observed, and it probably occurred before the deposition of the sandstone. Ground water that moves downward through the Tapeats sandstone or along faults may proceed farther downward into this zone of disintegration. The amount of water available would be very small, however, as shown by the small yield of a spring (pl. 13 and No. 9, table 1) in the small canyon east of Indian Garden.

GRAND CANYON SERIES

The Grand Canyon series is made up of the Unkar and Chuar groups. The Unkar group is exposed along the Colorado River below Desert View (pl. 13) and in isolated remnants below Indian Garden. The Chuar group is exposed only in small areas west of the junction of the Colorado and Little Colorado Rivers, in the north-rim area, and hence is not discussed further.

The Unkar group (Noble, 1914, p. 41) is composed of the Hotauta conglomerate, Bass limestone, Hakatai shale, Shinumo quartzite, and Dox sandstone. The group was tilted and eroded before deposition of the Tapeats sandstone of Cambrian age. The Shinumo quartzite was very resistant to erosion and cropped out as isolated hills during the advance of the Cambrian sea. Locally, these remnants were not buried until during the advance of the Muav sea.

No springs are known to issue from the Unkar group, and because of the depth at which it occurs below the south rim it is not considered a source of ground water. It is recognized that the buried, isolated hills of the Shinumo quartzite may influence the movement of water within the Cambrian sedimentary rocks.

PALEOZOIC ROCKS

The sequence of Paleozoic strata in the Grand Canyon is one of the classic sections of geology and is probably one of the best known. The Paleozoic formations, in ascending order, are as follows: the Tapeats sandstone, Bright Angel shale, and Muav limestone of the Tonto group; the Temple Butte limestone; the Redwall limestone; and the Supai formation, Hermit shale, Coconino sandstone, Toroweap formation, and Kaibab limestone of the Aubrey group.

TONTO GROUP

The three formations of the Tonto group of Middle Cambrian age, in ascending order, are the Tapeats sandstone, the Bright Angel shale, and the Muav limestone. In the Desert View area the lowermost formation of the Tonto group is separated by an angular unconformity from the uppermost formation of the Unkar group, the Dox sandstone. West from the Grandview Point area the Tonto group rests on the Vishnu schist. The surface of the unconformity has relatively small relief except locally, where buried, isolated hills of the Shinumo quartzite create a relief as high as 800 feet. McKee (1945) found that the Cambrian sedimentary rocks thin from west to east across the Grand Canyon.

TAPEATS SANDSTONE

The Tapeats sandstone consists of brown slabby, crossbedded sandstone and lenses of conglomerate containing rounded pebbles. It is separated by an angular unconformity from the Unkar group in the eastern part of the Grand Canyon and from the Vishnu schist to the west. The Tapeats sandstone forms a sheer cliff below the slope-forming Bright Angel shale. McKee (1945, p. 16) stated that its thickness varies considerably because of the relief of the Precambrian surface and because of changes in strand line during stages of transgression by the Tapeats sea. The thickness of the Tapeats is 300 feet north of Desert View (McKee, 1945, p. 142). The Tapeats is conformably overlain by the Bright Angel shale. The gradational contact is arbitrarily placed at the top of the uppermost beds of coarse sandstone typical of the Tapeats.

The Tapeats sandstone is well cemented and forms a sheer cliff. In many places it is a quartzitic sandstone, but locally it is friable near the top. It is overlain by the Bright Angel shale, which retards the downward movement of water. Probably a small amount moves through the shale, especially through fractures. Several springs (pl. 13, Nos. 5, 6, and 7) issue along bedding planes of the Tapeats sandstone.

A common feature associated with seeps issuing from the Tapeats sandstone along Hermit and Monument Creeks is salt crystals. These form stalactites and stalagmites, some as long as 12 inches, similar in appearance to those found in caves. The stalactites are a quarter of an inch to half an inch in diameter and are generally hollow, allowing the downward movement of water. In potholes in the Tapeats sandstone near one of the seeps, perfect crystals of halite were observed. Sturdevant (1926, p. 4), who had some of the crystals analyzed, stated that they were nearly pure sodium chloride, or table salt. Farther to the west on the Haulapai Indian Reservation, F. R. Twenter (1959) observed similar deposits.

BRIGHT ANGEL SHALE

The Bright Angel shale, middle unit of the Tonto group, is composed, in ascending order, of soft green micaceous, sandy shale and thin beds of sandstone; brown limestone; soft green micaceous, sandy shale; and alternating layers of shale and purplish-brown sandstone. The Bright Angel shale is about 325 feet thick at its type locality (McKee, 1945, p. 21), but McKee pointed out that the thickness may be misleading because in many sections one or more tongues of the shale are included in the overlying Muav limestone.

The most important hydrologic characteristic of the Bright Angel shale is the retardation of the downward percolation of ground water. Some water, although probably a very small quantity, percolates downward through the shale, as is evidenced by springs (pl. 13, Nos. 15 and 16) that issue from the shale, as well as by springs that issue from the Tapeats sandstone and underlying rocks. The low permeability of the Bright Angel leads to the accumulation of ground water in the overlying formation, the Muav limestone, in areas where structural conditions are favorable.

MUAV LIMESTONE

The Muav limestone, uppermost unit of the Tonto group, consists of thin- to thick-bedded bluish-gray limestone and dolomite having a mottled appearance and numerous thin bands or lenses of buff or greenish shaly material. In eastern Grand Canyon the limestone is impure and the number and thickness of the clastic beds increase. Including these "undifferentiated dolomites," the Muav is about 415 feet thick near Desert View (McKee, 1945, p. 141), and it thickens westward. Topographically the Muav limestone forms a blocky cliff or steep slope. The Muav limestone rests conformably upon the Bright Angel shale and is unconformably overlain by the Redwall limestone of Mississippian age, except in a few areas in western Grand Canyon where it is unconformably overlain by remnants of the Temple Butte limestone of Devonian age.

McKee (1945, p. 77) redefined the Muav limestone by subdividing it into members and tongues and by reassigning the upper dolomites. The "undifferentiated dolomites" are about 100 feet thick in eastern Grand Canyon and thicken westward. For simplicity in this investigation, the Muav limestone was mapped as defined by Noble (1914, p. 64–65). McKee (1945, p. 102) named the lowermost dolomite of the Muav limestone the "Kanab Canyon member" in eastern Grand Canyon. This unit overlies the Bright Angel shale and is the source of ground water for numerous springs in the Grand Canyon area. On the Hualapai Indian Reservation, Twenter (1959) observed that the lowermost unit of the Muav limestone is the source of some springs in that area. Because the Cambrian seas transgressed eastward, the lowermost unit is older in the Hualapai area than it is to the east, and McKee (1945) gave that unit the name "Rampart Cave member" of the Muav limestone.

Solution channels occur in the limestone units of the Muav limestone, and ground water moves readily through the formation. Most of the springs along the south rim issue from the limestone units of the Muav limestone. Those at Indian Garden are reported by National Park Service officials to yield about 300 gpm. Where the Muav is an aquifer it is underlain by the Bright Angel shale, which retards the downward percolation of ground water.

TEMPLE BUTTE LIMESTONE

The Temple Butte limestone of Devonian age occurs as deposits in channels cut into the Muav limestone. According to Darton (1925, p. 55) it is composed of thin purplish layers of fine-grained sandstone that grade into calcareous sandstone and into limestone containing fossils. The limestone is rarely more than 100 feet thick and was mapped with the Muav limestone because of its limited areal extent.

No springs are known to issue from the Temple Butte limestone, and because of its small outcrop area it is considered of little value for the storage or transmission of ground water.

REDWALL LIMESTONE

The Redwall limestone of Mississippian age is a light-gray and grayish-blue crystalline limestone containing chert. It is more than 500 feet thick in the Grand Canyon and is very thick bedded, giving it a massive appearance. It forms a prominent, high, steep cliff that is generally stained red by wash from the red siltstone of the overlying Supai formation. It rests uncomformably upon the Muav limestone of Cambrian age, or where present, the Temple Butte limestone of Devonian age, and is unconformably overlain by the Supai formation.

One of the most recognizable features of the Redwall limestone is the presence of solution channels that allow the transmission and storage of large quantities of ground water. Along the south rim the ground water has drained from the Redwall limestone, owing to the downcutting of the canyon, and it offers little likelihood of yielding water. Blue Spring to the east and Havasu Springs to the west issue from the Redwall limestone. At these places, regional structure has provided a means for water to collect in the Redwall limestone.

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AUBREY GROUP

The five formations composing the Aubrey group are, in ascending order, the Supai formation, the Hermit shale, the Coconino sandstone, the Toroweap formation, and the Kaibab limestone. This group is overlain by a few scattered erosional remnants of the Moenkopi formation, which are overlain by the Shinarump member of the Chinle formation.

SUPAI FORMATION

The Supai formation of Pennsylvanian and Permian age is composed, for the most part, of alternating siltstone and fine-grained sandstone. The basal unit, about 100 feet thick (Noble, 1914, p. 68), consists of red shale alternating with beds of blue-gray crystalline limestone containing bands and nodules of red chert. The siltstone units are moderately red, weathering to pale reddish brown, and are in flat lenticular beds. The sandstone units are light brown but in many places are stained red by the overlying siltstone. The formation is about 950 feet thick (Noble, 1922, p. 59) west of Hermit Creek along the Bass trail, and it forms a bench-slope type of topography. It is unconformably overlain by the Hermit shale.

The Supai formation is only moderately cemented, but because it is composed of siltstone and fine-grained sandstone, water does not move readily through it, although some downward percolation of water does occur. One spring, Santa Maria Spring (pl. 13, No. 3) in Hermit Basin, issues from the Supai formation. In this locality water has percolated downward in a structurally favorable area and issues along the top of a relatively impermeable layer.

HERMIT SHALE

The Hermit shale of Permian age is composed of red sandy shale and fine-grained friable sandstone. It forms a slope between the bench-slope-forming Supai formation and the cliff-forming Coconino sandstone. It ranges in thickness from about 270 to 320 feet at the type locality (Noble, 1922, p. 64) because of the uneven, channeled surface of the Supai formation upon which it lies. To the east, the Hermit shale becomes thinner and coarser grained. In the eastern Grand Canyon it is not readily differentiated from the Supai formation.

At the type locality in Hermit Basin the Hermit shale contains large amounts of siltstone and claystone and thus it retards the downward percolation of ground water. Under these conditions, water occurs on top of the shale in the basal few feet of the Coconino sandstone. Where the Hermit shale grades into siltstone and sandstone in the eastern part of the Grand Canyon, it permits the downward percolation of water, although the movement may not be very great.

COCONINO SANDSTONE

The Coconino sandstone of Permian age is very fine to medium grained, is crossbedded, and consists of well-sorted rounded to subangular clear, stained, and frosted quartz grains. The cement is dominantly siliceous and accessory minerals are rare. Ripple marks having wide spacing and low crests are common. The Coconino sandstone ranges from pale orange to grayish orange and is almost white in places. It has weathered into a vertical cliff about 600 feet high and rests conformably upon the Hermit shale, and it is conformably overlain by the Toroweap formation.

The lithologic character of the Coconino sandstone permits the downward percolation of ground water. Where the Hermit shale below forms an aquiclude, the downward movement of ground water is retarded and the Coconino standstone is an aquifer. Throughout most of the Kaibab Plateau area, however, the Coconino is above the water table and therefore offers no possibilities for the development of ground water. Where it is water bearing the Coconino transmits water at rather slow rates that are dependent upon the amount of cementation and fracturing within the sandstone. The sandstone is sufficiently porous to provide large potential storage.

TOROWEAP FORMATION

The Toroweap formation of Permian age consists in the western and central Grand Canyon of two red-bed sequences separated by a massive limestone unit and in the eastern Grand Canyon of a light-colored crossbedded and gnarly bedded sandstone. The sandstone is composed of medium-grained to very fine grained subrounded to subangular poorly to well-sorted quartz grains. It is pale orange to white, weathers to grayish orange or yellowish gray, and forms an irregular to vertical cliff. The formation is about 280 feet thick along the Bright Angel trail (McKee, 1938, p. 200–201) and thins to the east. It rests conformably on the Coconino sandstone and is unconformably overlain by the Kaibab limestone.

The water-bearing properties of the Toroweap formation in eastern Grand Canyon are similar to those of the Coconino sandstone. Where these formations have been penetrated in drilling wells they are not readily distinguishable. To the west, no springs are known to occur in the Toroweap formation, and it is of little importance except that it allows the downward percolation of ground water.

KAIBAB LIMESTONE

The Kaibab limestone, youngest of the Permian sedimentary rocks in northern Arizona, is composed of thick- to thin-bedded calcareous sandstone and sandy magnesian limestone. Chert is common in some of the limestone. The sandstone unit is composed of medium-grained to very fine grained rounded to subangular clear, stained, and rarely frosted quartz grains that are fairly well to poorly sorted. The unit ranges from yellowish gray to pale orange and weathers to yellowish gray and light gray. The limestone unit is composed of thick to thin beds of silty, very sandy, fine crystalline yellow-gray to grayish-yellow dolomitic limestone. McKee (1938, p. 13) divided the formation into three members, the Gamma, Beta, and Alpha, in ascending order. The formation is about 300 feet thick along the Bright Angel trail (McKee, 1938, p. 200) and forms a blocky, irregular cliff. It rests unconformably on the Toroweap formation and, except for scattered remnants of Triassic sedimentary rocks, underlies the present erosion surface of large areal extent in the Grand Canyon area.

Although there are few localities in northern Arizona where the Kaibab limestone contains water, it plays an important part in the hydrology of the region because of its permeability and its large outcrop area. The ground water that issues as springs from underlying formations along the south rim is a good indication of the amount of water that percolates downward through the Kaibab limestone, although few springs issue from the Kaibab itself. As the total discharge of springs along the south rim (exclusive of Blue Spring which has sources other than from the Coconino Plateau) is small, considering the large outcrop area of the Kaibab limestone, it is obvious that the recharge per unit area is small. A good soil cover has formed on the Kaibab limestone, and much of the precipitation doubtlessly is lost from the soil by evaporation and transpiration. Evaporation (sublimation) of snow is another form of loss. Locally, small springs and seeps issue on top of relatively impermeable beds in the Kaibab limestone. Rowes Well was dug at such a seep, but the quantity of water available is small.

TRIASSIC SEDIMENTARY ROCKS

The Triassic sedimentary rocks exposed in the Grand Canyon area are the Moenkopi formation and the Shinarump member of the Chinle formation. The Moenkopi formation is composed of siltstone and sandstone, mostly red to red brown, and is 300 to 400 feet thick. The Shinarump member of the Chinle varies greatly, ranging from fine-grained sandstone to conglomerate in irregular lenses.

The Triassic rocks are exposed in the area of this report as erosional remnants of small extent. Thus, they are not considered as potential ground-water reservoirs.

STRUCTURE

The major geologic structures along the south rim of the Grand Canyon are the monoclinal flexures associated with the east Kaibab monocline, and the Bright Angel fault (pl. 13). Minor structures include a small monocline and fault in the Hermit Creek basin, a rather large slump block also along Hermit Creek, and numerous small faults east of Cedar Mesa. The regional dip of the Paleozoic strata is 1° to 2° to the south and southwest. The faults and monoclines, for the most part, have a north-northwest trend; locally, they trend northeast and, rarely, eastward.

The importance of structure to the occurrence and movement of ground water cannot be overemphasized. The regional structure doubtlessly governs the regional movement of ground water, but the monoclinal flexures and faults affect the direction of movement locally. The largest springs near the Grand Canyon village area—those at Indian Garden—are controlled by the Bright Angel fault.

EAST KAIBAB MONOCLINE

The principal structural feature in the Desert View area is the east Kaibab monocline. It bifurcates into two distinct flexures within the area and has been subdivided by Babenroth and Strahler (1945) into the following sections: Grandview section, Waterloo Hill section, Desert View section, and Cedar Mesa section (pl. 13). The difference in altitude of the beds on either side of the monocline in the southeastern part of the area at Coconino Point (what might be called the "throw", similar to the displacement on either side of a fault) is about 1,200 feet. The monoclines dip to the north and northeast.

WATERLOO HILL, DESERT VIEW, AND CEDAR MESA SECTIONS

The Waterloo Hill section is the northwestward extension of the east Kaibab monocline near Coconino Point (pl. 13). This monoclinal flexure extends about 7 miles and then bifurcates again, forming the Desert View and Cedar Mesa sections. The "throw" in the Waterloo Hill flexure is about 600 feet near the southeastern bifurcation and about 1,000 feet at the northern bifurcation. The maximum dips range from 22° to 30° to the northeast.

The Desert View and Cedar Mesa sections result from the bifurcation of the Waterloo Hill section about 3 miles southeast from Desert View (pl. 13), and the flexures rejoin on the north side of the Colorado River outside the area of this report. The flexures are shown on plate 13 on cross section *B–B′*, which extends from Desert View to the canyon of the Little Colorado River near Blue Spring.

The Desert View flexure trends westward from the bifurcation to near Desert View, then turns northward and parallels the Canyon rim for about 6 miles, to the place where it is cut by the Colorado River. The flexure has a "throw" ranging from 600 feet at its origin at the bifurcation to 900 feet at Desert View.

The Cedar Mesa flexure trends northward from the point of bifurcation for 3 miles, then northwestward to where it enters the canyon. The "throw" in the flexure increases from about 400 feet at the bifurcation to 600 feet northward near the canyon rim. The flexure passes into a fault on the north side of the Colorado River.

GRANDVIEW SECTION

The Grandview section is the westward extension of the east Kaibab monocline from Coconino Point (pl. 13). The attitude of the strata between the Grandview section and Desert View is shown on cross section *A–A′* on plate 13. The Grandview section extends westward for about 10 miles and then trends northwestward to where it intersects the Grand Canyon rim about 2 miles east of Grandview Point. North of Grandview it turns more to the west, passing through Cottonwood and Grapevine Canyons; then it trends more to the north to where it occurs at Cremation Canyon. It passes from a monocline to a normal fault, and the fault appears to fade out near the Colorado River because the trace of the fault is not reflected in the Tapeats sandstone on the north side of the Colorado River. The "throw" of the Grandview section is about 600 feet near the point of bifurcation and about 400 feet to the northwest where the flexure passes into the canyon. Where the monocline passes into a fault in Cremation Canyon, the throw is about 300 feet and there is pronounced bending of the strata on both sides of the fault.

BRIGHT ANGEL FAULT

The Bright Angel fault intersects the canyon at the west side of Grand Canyon village and trends northeastward. It passes along the slope east of Indian Garden into a small canyon east of Garden Creek, crosses the Colorado River, and extends up Bright Angel Creek on the north side. It has a throw of about 180 feet near Indian Garden, the strata being dropped to the east. McKee (1931a, p. 20) stated that it is a Cenozoic fault but that it follows closely a Precambrian fault which had a throw of nearly 1,000 feet.

The springs at Indian Garden are closely associated with the fault, which has been an effective "collection gallery" for ground water in the vicinity and yield about 300 gpm. The largest spring issues from the east slope of the canyon along the fault, at the base of the Muav limestone.

Minor geologic structures are common in the Grand Canyon. Many faults of small displacement are present, as pointed out by McKee (1931b, p. 27). He stated that minor faults occur in all the eight canyons used to descend the main canyon. He counted more than 50 faults in the Hermit Basin in less than a mile along the contact of the Toroweap and Coconino. These faults had a throw ranging from a few inches to a maximum of 30 feet. A large slump block was observed in the Hermit Creek area. It extended for about half a mile along the old Hermit trail.

GROUND-WATER RESOURCES

The ground-water resources of the Grand Canyon area are related to the lithology of the sedimentary formations and to the geologic structure. One of the important lithologic characteristics is the grain size. The rocks range from very fine grained clay through silt and sand to coarse gravel. Although clay and silt may contain large amounts of water, very little can move through them or drain from them, and consequently they offer little hope for the development of water. Another consideration is the degree of sorting—whether the sediment is made up essentially of one grain size or is a combination of grain sizes. If a sand is well sorted, it will transmit water readily and will have good storage capacity. Also, the amount of cement in the sedimentary rocks may be important. Well-cemented rocks hinder or completely block the movement of water. In limestone, the most important characteristic is the occurrence of solution channels. Most limestone is dense, and water will not move through the rock unless it contains solution channels.

Geologic structure also is important. The regional dip, monoclinal flexures, and faults control the movement and occurrence of ground water. In the Grand Canyon area the regional dip is small (1° to 2°) and water tends to move downdip on top of relatively impermeable layers. Where the regional dip is interrupted by monoclinal flexures, water may follow these flexures. Faulting may bring fine-grained rocks against permeable rocks and provide a dam against which water accumulates in the permeable rocks.

OCCURRENCE

Ground water in the Colorado Plateau occurs as a series of perched water bodies in permeable strata, as shown diagrammatically in plate 14. A rock unit that does not readily transmit ground water and prevents or retards the downward percolation of ground water is termed an aquiclude, or confining bed. The occurrence of an acquiclude beneath a permeable bed under favorable structural conditions provides conditions for the entrapment and storage of ground water. The principal formations constituting aquicludes in the Grand Canyon area are the Vishnu schist, the Bright Angel shale, and the Hermit shale (pl. 14).

The Vishnu schist and other Precambrian rocks generally form an aquiclude. Seeps were observed in many places along the contact between the Precambrian rocks and the Tapeats sandstone. They occur only where the Precambrian rocks are dense and are not much fractured and disintegrated. Locally, disintegration has created some porosity in the Vishnu schist, and some water seeps down into the schist.

Another important aquiclude in the Grand Canyon area is the Bright Angel shale. From Hermit Creek to Cottonwood Creek, numerous springs issue from the overlying Muav limestone along the top of the Bright Angel shale. The basal unit of the Muav limestone is a cliff-forming limestone about 30 feet thick (the Kanab Canyon member of McKee, 1945, p. 102), which contains numerous solution channels. Many of the springs, including the ones at Indian Garden, which yield about 300 gpm, issue from this unit. Where the Muav limestone has a large saturated thickness, springs issue higher in the formation. In Hermit Creek canyon it was observed that the uppermost spring of Hermit Creek issues from dolomite in the Muav immediately below the Redwall limestone. This spring yields about 1 gpm. Downstream, numerous springs were observed and the flow of the stream was larger. The flow where the stream crosses the Tapeats sandstone was measured at 210 gpm on May 8, 1958 by the Geological Survey.

The absence of springs in the Muav limestone in the Desert View area is attributed to structural conditions. The dip of the strata throughout the Upper Basin is southward at about 100 feet per mile except in the vicinity of the monoclinal flexures (pl. 13, cross section *A–A′*). Therefore, water probably moves southward toward the Grandview flexure, and as the upthrown Bright Angel shale is a hindrance to water moving in the Muav limestone, the water probably moves eastward along the flexure. The absence of springs along the rim indicates that not enough water is stored in the Muav limestone in the Upper Basin to overflow along the rim.

The only potential aquifer in the Desert View area is the Muav limestone. As no wells have tapped the Muav, its productivity is not known. However, there are three possibilities related to the occurrence of ground water in the Muav limestone in the Upper Basin:

(1) the Grandview section of the east Kaibab monocline on the south and the Waterloo Hill section on the east may impede the movement of water, causing it to accumulate in the Muav limestone and to "back up" toward, though not reaching, the canyon rim. (2) There are neither major barriers or local structural conditions to allow accumulation of water. (3) There is no major barrier, but local structures are favorable for ground-water storage.

If there are effective barriers to ground-water movement along the Grandview and Waterloo Hill flexures, ground water will occur in the Muav limestone along the base of the flexures and for some distance updip. If water is present, the amount that might be obtained would depend upon the number and size of the solution channels penetrated in the Muav.

If a barrier does not exist along the Waterloo Hill flexure and local structures that might trap water are missing along the Grandview flexure, there would seem to be little or no chance of developing locally the amount of water needed for Desert View.

The last possibility is that local structures along the Grandview flexure are favorable for ground-water storage, even if there is no barrier along the Waterloo Hill flexure. Such local structures would have to be nearly perpendicular to the Grandview flexure and would be in the form of either faults or monoclines. In either case the rocks would have to be lifted to the east. This would allow for storage of water in the Muav limestone against the Bright Angel shale, but the amount of storage probably would be small. It is doubtful if such local storage could produce the amount of water needed for Desert View.

Ground water occurs in the Redwall limestone only where the underlying Muav limestone is completely saturated. These conditions exist at only two localities along the south rim of the Grand Canyon—one at Blue Spring (fig. 23 and pl. 13) about 9 miles northeast of Desert View, and the other at Havasu Springs (fig. 23) about 30 miles northwest of Grand Canyon village. In both places, structure is a governing factor for the saturation of the rocks. The rocks in the vicinity of Blue Spring have been bent downward below the level of Desert View by the east Kaibab monocline. Thus, the Muav limestone is below stream level and ground water occurs stratigraphically higher in the Paleozoic section. Havasu Springs are structurally lower than Grand Canyon village because of the regional dip to the southwest. The rim is about 1,000 feet lower at Havasu Canyon than at Grand Canyon village.

Small deposits of travertine were observed along Hermit Creek, and it appears that the stream is still depositing the material. The uppermost spring in Hermit Creek is not very far below the Redwall limestone. Apparently the water from the Redwall is actively building up travertine deposits downstream from the outlets of Blue and Havasu Springs. The presence of travertine in Hermit Creek may indicate that some of the water has moved through the Redwall limestone. None of the springs that issue from the basal part of the Muav limestone have deposited travertine.

The Hermit shale in Hermit Basin is fine grained and forms an aquiclude. Two springs (pl. 13, Nos. 1 and 2) issue from the basal part of the Coconino sandstone, at the top of the shale. A stock well in sec. 21, T. 30 N., R. 1 W., southwest of Grand Canyon village, obtains water from the Coconino sandstone where the water is upheld by the Hermit shale. At this location, structural conditions are favorable for the entrapment and storage of water on the shale. The Hermit shale grades into more permeable siltstone and sandstone to the east, and in the Desert View area it cannot be readily distinguished from the Supai formation. Therefore, it does not act as a barrier to downward movement of water or allow storage in the Coconino sandstone. This fact is demonstrated by a dry hole drilled at the base of the Grandview flexure in sec. 5, T. 29 N., R. 6 E., into the red beds of the Supai beneath the Coconino sandstone that disclosed no water in the Coconino.

Small seeps occur in the Kaibab limestone where the downward movement of ground water is retarded by relatively impermeable beds. Rowes Well is an example. According to Mr. Art Metzger (oral communication) Rowes Well is shallow and was dug at a seep. Other small seeps were observed coming from the Kaibab limestone, but the amount of water available is very small. In dry years, little or no water would be available.

RECHARGE

The Kaibab limestone has, by far, the largest outcrop area of any formation in the Grand Canyon area. Outcrops of the other formations are much smaller and are restricted to the canyons of the Colorado and Little Colorado Rivers. Thus, the major part of the water that recharges the ground-water reservoir must percolate downward through the Kaibab limestone.

The greater part of the drainage area above Havasu Springs is on the Kaibab limestone. The discharge of these springs gives some indication of the amount of water that recharges the ground-water reservoir. Havasu Springs have a discharge of about 66 cfs (U.S. Geological Survey, 1954). If it is assumed that the underground drainage area contributing to the springs is the same as the surface drainage area of Havasu Creek, which may not be the case, the springs represent the natural discharge point for a drainage area of 2,900 square miles. This gives a discharge of 0.02 cfs per square mile of drainage area, or about 20 acre-feet per year per square mile, equivalent to about 0.3 inch of water per year over the entire drainage area.

According to U.S. Weather Bureau records, the amount of precipitation falling on the Havasu Creek drainage area ranges from about 10 to 20 inches per year, or about 500 to 1,000 acre-feet per year per square mile of drainage. Thus the amount of water infiltrating into the Kaibab limestone and later discharging from the ground-water reservoir represents only a small fraction of the precipitation.

MOVEMENT

One of the most dominant controls on the movement of ground water in the Grand Canyon area is the geologic structure. In the Desert View area monoclinal flexures probably govern the direction of movement, whereas to the west the Bright Angel fault exerts an influence on the movement.

Although there are no wells in the Desert View area, it is believed that the general ground-water movement can be ascertained from the geologic structure. The dip of the strata in the Upper Basin is southward at about 100 feet per mile, and the movement of ground water also is probably southward. The Grandview flexure probably forms an effective barrier to this general ground-water movement, as the Bright Angel shale and other formations of low permeability are upthrown across the path of movement. In all probability ground water turns eastward and parallels the flexure, crosses the northern sections of the east Kaibab monocline, and ultimately discharges through Blue Spring. Because of the large "throw" on the monocline that lowers the Muav limestone, the ground water seems to occur in the Redwall limestone as well as in the Muav, at least near Blue Spring, which discharges from the Redwall.

The occurrence of the springs at Indian Garden is due to a restriction of movement caused by the Bright Angel fault. The upthrow is to the west, bringing the relatively impermeable Bright Angle shale against the lowermost cliff-forming unit of the Muav limestone.

The many springs issuing from the Muav limestone in the stretch from Hermit Creek to Cottonwood Creek indicates that the direction of movement of ground water along the rim is northward. But there is no evidence as to how far south of the rim this direction is maintained. Surely there is a drainage divide south of the rim because the regional dip is southwestward. Sufficient data are not available from wells south of the canyon to give any indications as to the location of the divide.

DISCHARGE

Ground water discharges through springs in the Grand Canyon (table 1) and from a stock well south of the rim. Only small seeps are found in the Kaibab limestone on the rim. The stock well in sec. 21, T. 30 N., R. 1 W. is the only well shown on figure 23 that was producing water during this investigation.

The springs that issue from the Coconino sandstone are Dripping Springs (pl. 13, No. 1) and an unnamed spring (pl. 13, No. 2) along the Hermit trail. Both springs are very small and yield less than 1 gpm. "Dripping Springs" is a good descriptive name, because the springs bearing that name occur in a recess under the Coconino sandstone and the water drips from the contact of the Hermit and Coconino.

Only one spring was observed that issues from the Supai formation. It is Santa Maria Spring and may flow as much as 1 gpm. The water seeps from sandstone about 20 feet thick.

Most of the springs issue from the Tonto group, at several stratigraphic positions. The stratigraphically highest springs within the Tonto group issue from the dolomites of the Muav limestone immediately below the Redwall limestone, where the spring flow forms Hermit Creek (pl. 13, No. 4). The Muav limestone is almost saturated at spring 4, and many other springs enter the creek from the Muav in the stretch downstream toward the Colorado River. The total flow was 210 gpm on May 8, 1958. Indian Garden Springs (pl. 13, No. 8) issue from the basal cliff-forming limestone of the Muav limestone. According to Park Service records, the flow is about 300 gpm. Some small springs occur in the Bright Angel shale (pl. 13, Nos. 15 and 16). Three springs (pl. 13, Nos. 5, 6, and 7) were observed to be issuing along bedding planes in the Tapeats sandstone, although Monument Spring (pl. 13, No 5) is supplied in part from other sources higher in the Tonto group.

One spring (pl. 13, No. 9) issues from the Vishnu schist. The occurrence is related to a disintegration zone in the schist, and the water has percolated downward from the Tapeats sandstone.

Only two springs in the south-rim area between Hermit Creek and Cottonwood Creek yield significant quantities of water. Indian Garden Springs are the largest (about 300 gpm). Hermit Springs yield about 210 gpm. All other springs yield less than 10 gpm and most yield less than 1 gpm. The total flow from the springs is about 600 gpm.

Two large springs along the south rim are Blue Spring on the Little Colorado River and Havasu Springs in Havasu Creek (fig. 23). Blue Spring, which forms the perennial flow of the Little Colorado River, *Description of wells in Coconino Plateau area, Arizona*

Location			Owner	Date drilled	Reported depth (feet)	Casing diameter (inches)	Depth to water below land surface (feet)	Date	Pump		Remarks
Township (N)	Range	Section							Type	Power	
26	2 E.	10	Valle airport		1,817	10			None	None	Abandoned.
27	1 E.	29		1946	1,470	8	(1)		do	do	Do.
29	6 E.	5	Richardson Ranch		1,200		(1)		do	do	Drilled to red beds below Coconino sandstone. Abandoned.
30	2 E.	17	Santa Fe Railway	1930(?)	1,000		(1)		do	do	Abandoned.
27	1 W.	3	Babbitt Bros. Ranch			8	1,400	5-4-58	do	do	Do.
28	1 W.	35	Sinclair Oil and Gas Co	1952	3,540	8			do	do	Oil test. Bottomed in Bright Angel shale.
30	1 W.	21	Babbitt Bros. Ranch	1942	1,000		[2] 900		Cylinder	Gasoline	Production from Coconino sandstone.

[1] Reported dry.
[2] Reported.

flow about 220 cfs and Havasu Springs, about 66 cfs. (U.S. Geological Survey, 1954). They issue from the Redwall limestone.

Only one of the wells listed in the table and shown on figure 23 produced water in the spring of 1958. The well in sec. 21, T. 30 N., R. 1 W., was drilled in 1942 to a depth of 1,000 feet, and the water level was reported to be 900 feet below the land surface. Although the yield is not large, the water is reported to be satisfactory for stock use. The water tapped by this well is perched on the Hermit shale, and the ground-water reservoir is probably not very extensive. Farther south in sec. 3, T. 27 N., R. 1 W., the depth to water in an abandoned well in the Supai formation is 1,400 feet. Data are insufficient to determine whether the depth to water represents the regional water table or another perched water table.

PRESENT WATER SUPPLY AT INDIAN GARDEN

Two of the largest springs at Indian Garden are developed and piped to a storage reservoir. One of the springs issues from the slope east of Indian Garden and the other issues from the creek bed at the uppermost end of Indian Garden. The flow of the other small springs is not collected at Indian Garden; however, downstream, some of the water is collected and pumped to the storage reservoir at Indian Garden. The combined flow is then pumped to the south rim, a lift of 3,200 feet. At present, the Park Service operates a weir with recording gage downstream from the lower pumphouse, in order to determine the amount of water not being used.

RELATION OF SPRING DISCHARGE TO SIZE OF DRAINAGE BASIN

In the Colorado Plateaus there probably is a general relation between the discharge of springs and the size of the surface drainage basin above the springs. It has been observed that large springs generally discharge from large drainage basins, and vice versa. It would be desirable if this qualitative observation could be translated into a quantitative answer.

A related problem is the position of the ground-water divide between areas of ground-water discharge. In many places on the Colorado Plateau there are not sufficient data to locate a divide with any degree of accuracy. It is not known whether the movement of ground water in geologic time has been stabilized so that the ground-water and surface-water divides coincide at least approximately or whether the two divides are many miles apart.

Three springs along the south rim of the Grand Canyon—Blue, Havasu, and Hermit—may add evidence to the relation of spring discharge to size of drainage basin and, by inference, to the position of the ground-water divide between areas of discharge. Pertinent facts concerning the three springs are given in the following table:

Springs	Drainage area	Discharge (cfs)	Surface drainage area (sq mi)	Discharge per unit drainage area (cfs per sq mi)
Blue Spring	Little Colorado River	220	25,600	0.01
Havasu Springs	Havasu Creek	66	2,900	.02
Hermit Springs	Hermit Creek	.5	11	.04

The springs have a large range in discharge, the ratio of largest to smallest being 440 to 1; and a large range in surface drainage area, the ratio being 2,300 to 1. However, the discharge per unit drainage area shows a small range, the ratio being only 4 to 1.

Geologically, the drainage areas above Havasu and Hermit Springs are similar—both are on Paleozoic rocks (Kaibab limestone). Blue Spring are in the drainage area of the Little Colorado River, and the surface geology is much different from that of the other two areas. Also, there are other points of ground-water discharge, and not all the available water issues from Blue Spring.

If the springs represented all the ground-water discharge and if the drainage divides for both ground water and surface water coincided, the figures of 0.01, 0.02, and 0.04 cfs per square mile would represent the approximate recharge to the ground-water reservoir. The discrepancy in recharge between Blue and Havasu Springs could be explained as due to the difference in geologic environments, as well as the pressence of other ground-water outlets in the Little Colorado drainage area, but because of their geologic similarity the discrepancy in recharge between Havasu and Hermit Springs could not be thus explained. It is tentatively concluded that the ground-water and surface-water divides do not coincide, or that the discharges and drainage areas of Havasu and Hermit Springs are too different to permit a direct comparison on a unit-area basis.

QUALITY OF WATER

Fourteen samples of water from springs along the south rim were analyzed for their mineral content. These analyses, and analyses for Blue and Havasu Springs also, are given in table 1. The waters, with the exception of that of Blue Spring, are all of good chemical quality, although they are hard, and are satisfactory for domestic use according to the standards for drinking water of the U.S. Public Health Service. The dissolved solids in the 14 samples from the report area ranged from 179 to 667 ppm; only 2 samples contained more than 400 ppm.

TABLE 1.—*Chemical analyses of water from springs, Grand Canyon area, Arizona*

[Chemical constituents in parts per million except as indicated. Discharge: <, less than; E, estimated; M, measured; N, see remarks]

[Analyses by U.S. Geological Survey, Albuquerque, N. Mex.]

No. (pl. 13)	Name	Source	Discharge (gpm)	Temperature (°F)	Date of collection	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	Dissolved solids: Tons per acre-foot	Hardness as $CaCO_3$: Total	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	Remarks
1	Dripping Springs	Coconino sandstone	<1E	62	10-8-57	9.3	32	24	6.0	193	0	10	13	0.2	4.7	194	0.26	178	20	347	
2		do	<1E	61	10-8-57	9.8	26	24	6.2	177	0	8.2	15	.2	2.6	179	.24	164	18	328	
3	Santa Maria Spring	Supai formation	1E	58	5-9-58	15	34	34	18	232	0	28	28	.7	4.4	276	.38	225	35	483	Had been developed for rest camp on Hermit Trail.
4	Hermit Spring (uppermost spring).	Muav limestone	5E	67	10-15-57	9.0	48	27	3.4	219	16	16	9.5	.2	2.5	239	.33	231	26	421	
	Hermit Springs (all springs).	do	210M	--	10-16-57	9.2	52	31	27	267	0	33	44	.2	.1	328	.45	257	38	584	
5	Monument Spring	Tapeats sandstone	5E	69	10-16-57	10	80	47	99	289	0	98	190	.2	1.0	667	.91	393	156	1,190	
6	Cedar Spring	Tapeats(?) sandstone.	<1E	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	Issues from alluvium overlying Tapeats sandstone.
7	Salt Creek Spring	Tapeats sandstone	<1E	61	10-16-57	9.5	46	69	31	172	6	271	23	.2	.1	540	.73	398	248	833	
8	Indian Garden Spring No. 1.	Muav limestone	--	63	4-9-58	13	42	29	9.0	254	0	16	12	.2	1.8	248	.34	224	16	454	Water supply for Grand Canyon Village.
	Indian Garden Spring No. 2.	do	--	59	4-9-58	14	54	32	11	308	0	17	13	.2	1.0	293	.40	266	14	523	Do.
	Indian Garden Springs (all flow).	do	N	53	4-9-58	12	54	35	11	308	0	28	14	.2	.2	305	.41	278	26	543	Flow of all springs reported as 300 gpm.
9		Vishnu schist	<1E	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
10	Pipe Spring	Muav limestone	1E	62	10-17-57	11	68	42	11	337	0	63	17	.2	.0	378	.51	342	66	648	
11	Burro Spring	do	1E	65	10-17-57	11	59	35	17	295	0	55	20	.2	.0	342	.47	291	49	588	
12	Lonetree Spring	Bright Angel shale	<1E	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
13	Boulder Spring	do	<1E	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
14	Grapevine Spring	Muav(?) limestone	10E	--	11-5-57	11	63	40	7.8	366	0	21	11	.4	.2	334	.45	322	22	590	Issues from talus overlying Tapeats sandstone.
15		Bright Angel shale	<1E	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
16		do	<1E	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
17	Cottonwood Spring	Muav(?) limestone	5E	53	11-4-57	16	75	42	10	399	0	33	14	.2	.5	387	.53	360	32	661	Do.
	Blue Spring	Redwall limestone	N	--	6-14-50	19	264	79	534	964	0	147	815	.2	3.2	2,340	3.18	984	194	3,940	Has flow of 220 cfs.
	Havasu Springs	do	N	69	10-20-50	18	133	48	27	588	0	36	48	.2	1.4	602	.82	530	48	1,030	Has flow of 66 cfs. Not shown on pl. 13.

An inspection of the analyses indicates that along the south rim, as the water percolates downward (pl. 14), there is an increase in mineral content of the water. The water from the Coconino sandstone has 179 and 194 ppm of dissolved solids, from the upper part of the Muav limestone 239 ppm, from the rest of the Muav 248 to 387 ppm, and from the Tapeats sandstone 540 and 667 ppm. It has been mentioned previously that there are "salt seeps" issuing from the Tapeats sandstone. These are very small and no samples were collected. It may be postulated that the quality of water from these seeps is not as poor as would be suggested by the presence of the salt stalactites and stalagmites, for some of the concentration of this mineral content leading to salt deposition doubtless is due to evaporation of the small quantities of water seeping from the rocks.

CONCLUSIONS

Not all the spring discharge at Indian Garden is developed and pumped to the south rim. A part of the water is allowed to go downstream in sufficient amounts to maintain the growth of cottonwoods and other vegetation. A weir with recording gage has been installed by the Park Service downstream from the area of desirable vegetation, to determine the amount of water not used. The data from the weir records should indicate the amount of additional water that could be obtained from Indian Garden.

The only other springs along the south rim within a short distance to Grand Canyon village that could be developed to increase the water supply are the Hermit Creek springs. The spring flow in Hermit Creek increases downstream and below the Muav limestone, where it is about 210 gpm. As this is based on only one measurement, there is no indication of the magnitude of fluctuation or the annual average flow. The pumping lift to a point directly above on the south rim would be about 3,800 feet, and the water would then have to be piped about 4 miles to the storage reservoirs at Grand Canyon village. Before any attempt is made to develop water from Hermit Creek, records should be kept for a sufficiently long period to determine the range in flow and the average flow.

The two largest springs along the south rim are Blue Spring and Havasu Springs. The water of Blue Spring has a high mineral content and is unsuitable for domestic use. Havasu Springs, although yielding water of good chemical quality, are about 30 miles from the village.

One drilled well south of the park boundary in sec. 21, T. 30 N., R. 1 W., is 1,000 feet deep and obtains water at the base of the Coconino sandstone at a depth of about 900 feet. The amount of water available is probably small, as the geologic structure that traps the water is probably of local extent. It is questionable whether similar wells could be located practicably that would produce enough water for the anticipated expansion of the park.

A well in sec. 3, T. 27 N., R. 1 W., about 25 miles southwest from Grand Canyon village, had a water level 1,400 feet below the land surface. This water occurs in the Supai formation. As this is the only well where a measurement could be obtained, it is difficult to arrive at any conclusions concerning the water in the area. Wells in the Flagstaff area produce only about 10 to 35 gpm from the Supai formation and are expensive to operate. These factors, plus a pipeline about 25 miles long and a lift of an additional 1,000 feet to reach the village, offer little encouragement for the development of water from wells.

In the Desert View area, the only probable water-bearing formation is the Muav limestone. Because of the depth at which the limestone occurs and because of the fact that the zone of saturation in it may be thin, or even absent, for some miles to the south, it offers essentially no encouragement for the successful development of a water supply.

In conclusion, the best possibilities for development of water along the south rim are: capture and transport of additional water from springs at Indian Garden and development of springs in Hermit Creek. If these two prospects do not provide the water needed, or if the cost of development at Hermit Creek is too high, then investigation of the possibility of obtaining water from the north side of the Colorado River would be worth while.

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