Ground water in Black Mesa Basin and adjacent areas

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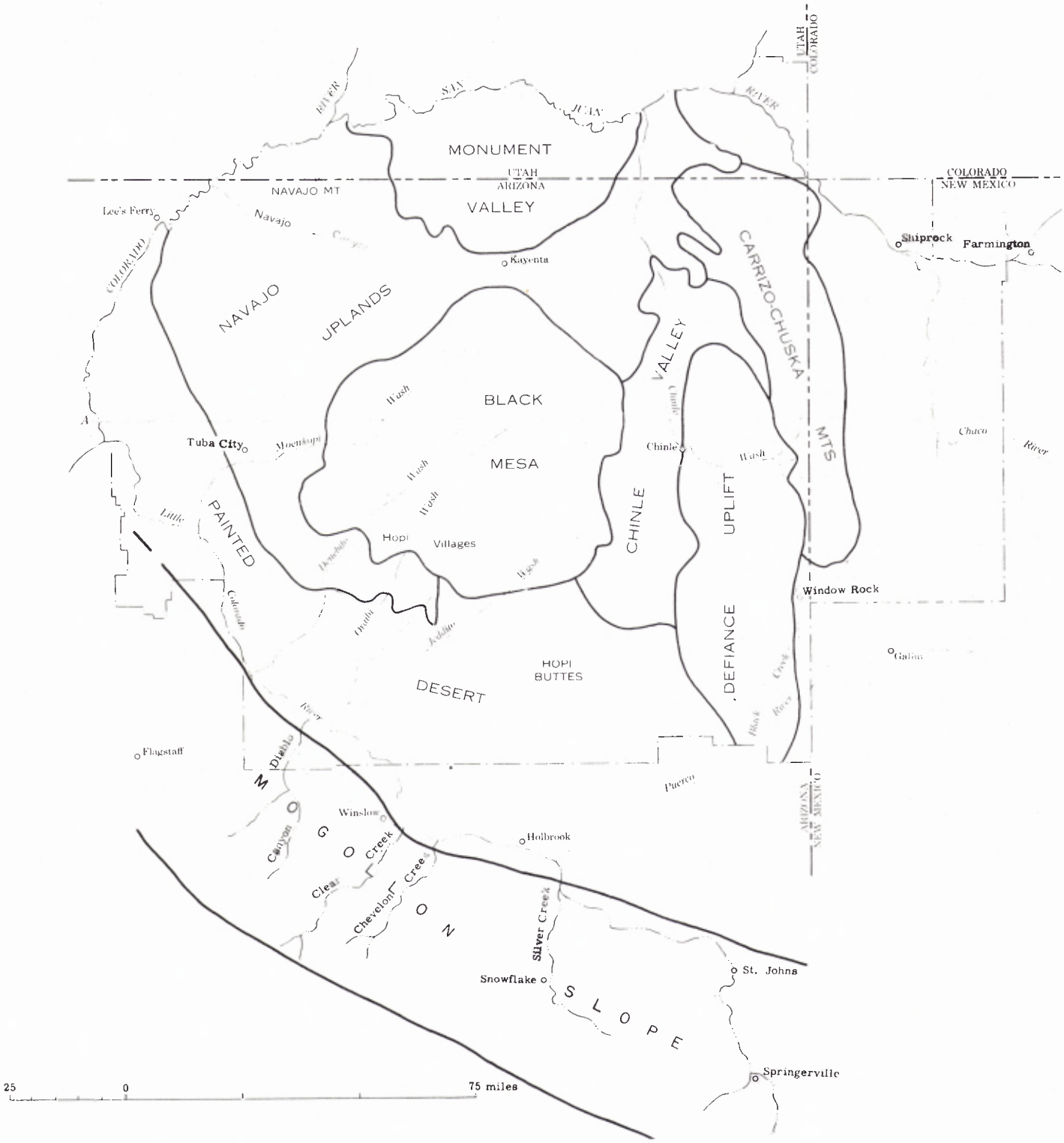

FIGURE 1.—Map showing principal subdivisions of Black Mesa basin and adjacent areas.

GROUND WATER IN BLACK MESA BASIN AND ADJACENT AREAS[1]

By J. P. AKERS[2] AND J. W. HARSHBARGER[2]

INTRODUCTION

The scarcity of water in Black Mesa basin and adjacent areas is a dominating factor in the everyday life of the Navajo and Hopi people. Many families in this area haul water as much as 10 miles for domestic purposes and drive their livestock even further for water. Perennial streams and springs are widely scattered in this region. In many places the available water is not suitable for consumption by man or livestock, or ground water is not available within the practical reach of drilled wells. Throughout much of the area the limited water supply is reflected by arid-type vegetation and grazing lands of low productivity. The main occupation of the Navajo Indians is raising livestock and farming small plots of land. Owing to the seasonal flucuation of water supplies, they must of necessity move from place to place to find better grazing and farm lands.

The demand for adequate water supplies for the Navajo and Hopi people prompted the Bureau of Indian Affairs to request the U. S. Geological Survey to undertake a regional study of the ground-water resources of the Navajo country in 1950. During the course of this study the U. S. Geological Survey has furnished technical assistance on the drilling of about 250 water wells in the Navajo and Hopi reservations. Study of drill cuttings from these wells, stratigraphic studies, and detailed geologic mapping have provided substantial information on the ground-water resources of Black Mesa basin and adjacent areas.

At the present time the expanding economy of the Navajo country is creating an unprecedented demand for stock, domestic, municipal, and industrial water. A forest-products processing plant will be built by the Navajo Tribe in the near future. This plant and the adjoining town will require 1½ mgd (million gallons per day) of water. The amount of water required by the community of Window Rock has more than doubled in the last two years. New interest in water for irrigation in the areas south of the reservation and the expanding economy of towns along U. S. Highway 66 are creating large demands for ground water. The city of Flagstaff, in recent years, has developed a series of deep wells which are expected to yield about 5 mgd of water.

Not everywhere in this area, however, is it possible to develop adequate ground-water supplies. No potable ground water is available in large areas such as the Painted Desert country and in the extreme western part of the Navajo Reservation. Only meager supplies are available in Monument Valley and in the southern part of the Hopi Buttes area. In a few areas of the Navajo reservation, such as near Tuba City and along the western flank of the Chuska Mountains, relatively large amounts of good water can be developed.

The yield and chemical quality of water in individual aquifers vary widely from place to place. Some wells in the Navajo sandstone near the Glen Canyon dam site yield only 5 gpm (gallons per minute), whereas others in the same formation about 15 miles away are reported to yield about 1,000 gpm. The Coconino or DeChelly sandstone yields 5 to 20 gpm in the area near Window Rock and as much as 3,000 gpm in the Snowflake-Taylor area. At Holbrook water from the Coconino sandstone contains about 500 ppm (parts per million) of dissolved solids; at Castle Butte, several miles north of Winslow, it contains more than 10,000 ppm of chloride alone.

The depths of wells in Black Mesa basin and adjacent areas range from 10 feet in dug wells to more than 1,800 feet in drilled wells. Several wells to be drilled in the near future by the Navajo Tribe will penetrate to depths of more than 2,000 feet.

SUBDIVISIONS OF THE BLACK MESA BASIN AREA

The Black Mesa basin and adjacent areas comprise eight physiographic subdivisions, each of which constitutes an area having a distinct ground-water potential (fig. 1). The following paragraphs briefly summarize the conditions in each subdivision.

Mogollon Slope

This subdivision includes the area between Flagstaff and St. Johns and between the Mogollon Rim and the Little Colorado River. Water in this area is obtained largely from Permian aquifers in wells 200 to 700 feet deep. However, several wells near Flagstaff are about 1,600 feet deep. The chemical quality of ground water in the area between St. Johns and Hunt is generally poor to fair, but elsewhere it is excellent. Production of wells in this area ranges from 200 to 3,000 gpm. Static water levels range from zero along the Little Colorado River between Hunt and Holbrook to more than 1,100 feet in the Flagstaff area.

Painted Desert

The dry and barren Painted Desert subdivision is a wide band of "badland" country along the southern and western periphery of the Navajo reservation north of the Little Colorado River and east of the Colorado River. Included in this area is the spectacular array of the volcanic Hopi Buttes. Water is extremely scarce in this subdivision. The Triassic and Permian rocks are either dry or contain water having a very high concentration of chloride. Essentially all potable water is obtained from springs issuing from the base of lavas capping the Hopi Buttes or from shallow dug wells in the alluvium. One well east of Dilcon obtains good water from cinders within a diatreme.

Navajo Uplands

The Navajo uplands is an extensive terraced plain in the northwestern part of the Navajo reservation. Most of the rock exposures in this subdivision are of Jurassic age. Nearly all wells in this area obtain excellent water from the Navajo sandstone, the most dependable source of ground water in the Navajo country. Most of the wells in this subdivision yield only small amounts of water, but a few in the Tuba City area yield about 200 gpm. Depths of wells range from 200 feet in the Tuba City area to more than 1,400 feet north of Kaibito.

Black Mesa

Black Mesa is a partly wooded area about 85 miles in width ranging in altitude from about 5,000 feet in the southern part to about 7,000 feet in the northeastern part. Included in the southern part are First, Second, and Third Mesas where the Hopi people have their communities.

Except for several shallow wells in the alluvium, nearly all ground water in this area is obtained from Cretaceous rocks. Springs that issue from the contact of the Toreva formation and underlying Mancos shale are an important

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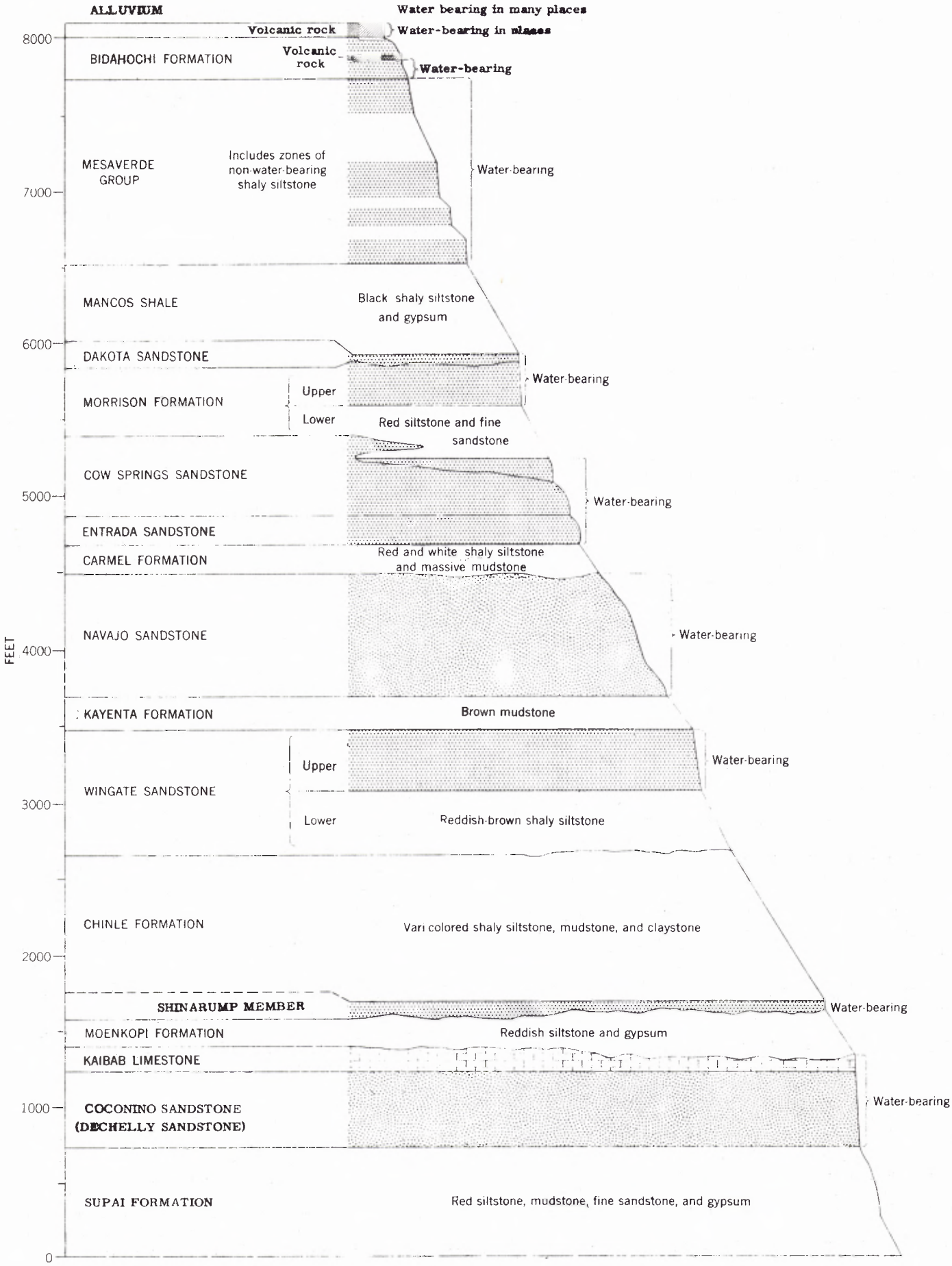

FIGURE 2.—Water-bearing formations of Black Mesa basin adjacent areas.

source of domestic water. Most of the drilled wells obtain water from sandstone in the Mesaverde group at depths of 200 to 600 feet, but several obtain water from the Dakota sandstone at depths from of 200 to 1,000 feet. Water from alluvium and the Dakota sandstone often is of marginal quality for domestic use; water from the Mesaverde group is of fair to good quality. Yields of wells in this subdivision range from 5 to 30 gpm.

Monument Valley

The Monument Valley subdivision lies in the north-central part of the Navajo reservation and is dependent, to a large extent, on springs for a water supply. No ground water is available to wells in much of the outcrop area formed by Permian rocks. Only two successful wells have been completed to date in Permian rocks in Monument Valley. These are 400 and 900 feet deep, respectively, and are located on Douglas Mesa where fractures in the Cedar Mesa sandstone member of the Cutler formation are favorable for the movement of water. Several other holes drilled into this formation were dry. A few dug wells obtain water from alluvium in Monument Valley, but the alluvium in many of the washes is dry. Water from both the alluvium and the Permian rocks is good.

Chinle Valley

The Chinle Valley subdivision includes the area lying between the Defiance uplift and the Chuska Mountains on the east and Black Mesa on the west. Ground water is available from the alluvium along Chinle Wash at depths of less than 300 feet or from Triassic and Permian rocks at depths of as much as 2,000 feet. Wells in the alluvium yield from 25 to more than 200 gpm of fair to poor water. Triassic and Permian aquifers yield from 15 to more than 100 gpm of fair water.

Defiance Uplift

The heavily wooded Defiance uplift is a broad, elongate structure. The crest is about 8,000 feet above sea level in the southeastern part of the Navajo reservation. This area receives considerable rainfall and has many natural watering places; therefore ground water has not been extensively developed. Small amounts—10 to 20 gpm—of good water are available from Permian aquifers at depths of 200 to 500 feet in most of the area, but several holes in the southern part were dry.

Chuska-Carrizo Mountains Area

This subdivision lies along the Arizona-New Mexico State line in the northeastern part of the Navajo country. The area receives about 20 inches of precipitation a year and is heavily wooded. No wells have been drilled in this area, as adequate water for domestic and stock use is obtained from many springs, clear lakes, and several perennial streams. The base flow from nearly all the springs and streams in the Carrizo-Chuska Mountains is discharged from Tertiary lava or sandstone.

WATER-BEARING FORMATIONS

Rocks representing every geologic period except Silurian are present on the surface or in the subsurface in Black Mesa basin and adjacent areas. However, only the rocks of Permian age or younger are important for the development of ground water. Rocks older than Permian are either dry or beyond the practical reach of water wells. Water has been encountered in all Permian or younger formations, but not all of these formations yield water adequate in chemical quality or sufficient in quantity for wells (fig. 2).

The following discussion is a brief resume of the principal water-bearing formations in the Black Mesa basin area.

Recent Sediments

Alluvium

Shallow wells, dug and drilled in alluvium produce a large part of the water supply in the Navajo and Hopi Reservations. In large areas of the Painted Desert and Monument Valley subdivisions, water is not available from any other source.

The alluvium along the small drainage courses ranges from about 25 to 80 feet in thickness. In some of the large streams, such as Chinle Wash and the Rio Puerco, the alluvium is more than 200 feet thick. The yield from alluvial aquifers varies widely. Most wells in the alluvial deposits yield 10 to 50 gpm; however, large-diameter, gravel-packed wells along Todilto Wash and the Rio Puerco produce 50 to 1,000 gpm. The chemical quality of water from alluvial materials is usually fair, but in many places in the Hopi Buttes area the water is not suitable for human consumption.

Tertiary Rocks

Bidahochi formation

The Bidahochi formation is present in the southern part of the Navajo Reservation and extends southeastward to the vicinity of St. Johns. It is composed of three members: the upper member consisting of coarse- to medium-grained sandstone with minor amounts of siltstone, claystone, and tuff in the lower part; the middle volcanic member consisting of lava flows, volcanic detritus, and spring deposits; and the lower member consisting primarily of claystone and siltstone and minor amounts of tuff.

Water is present in the upper member of the Bidahochi formation in some localities. Southeast of the Hopi Buttes area the lower and middle members of the Bidahochi formation are not present, and the upper member unconformably overlies older rocks. Water is present in the upper member, where the unit occupies low areas on the buried erosion surface, and is dry where it overlies buried high areas. Wells in the upper member yield from 4 to 25 gpm of excellent water from depths of as much as 450 feet. Springs at the base of the lava in the middle member of the Bidahochi formation are an important source of domestic water in the Hopi Buttes area, where potable water is extremely scarce.

Diatremes

Three of the diatremes in the Hopi Buttes area have been drilled in search of water. All contain water, but only one contained enough good water for a well. The diatreme to be visited during this field trip was drilled to a depth of 620 feet. The well produced about 75 gpm of very bad water and was abandoned. A well 522 feet deep in a diatreme about 7 miles east of Dilcon produced 20 gpm of good water. Another well drilled in a diatreme 3 miles south of White Cone produced 1 gpm of good water from a depth of more than 600 feet. The large diatreme at Buell Park on the east flank of the Defiance uplift was drilled recently to a depth of 480 feet. The well produced 175 gpm with a drawdown of 50 feet from a static water level of 21 feet.

The Navajo Tribe is currently planning to drill several more diatremes in the Hopi Buttes area, as they offer the best possibility for developing ground water in this area.

Chuska sandstone

The Chuska sandstone, named for exposures in the Chuska Mountains, is a thick deposit of clean, medium- to coarse-grained quartz sand and minor amounts of siltstone and claystone. The large amount of precipitation falling in this area percolates downward rapidly into the formation. As there are few aquicludes in the Chuska sandstone,

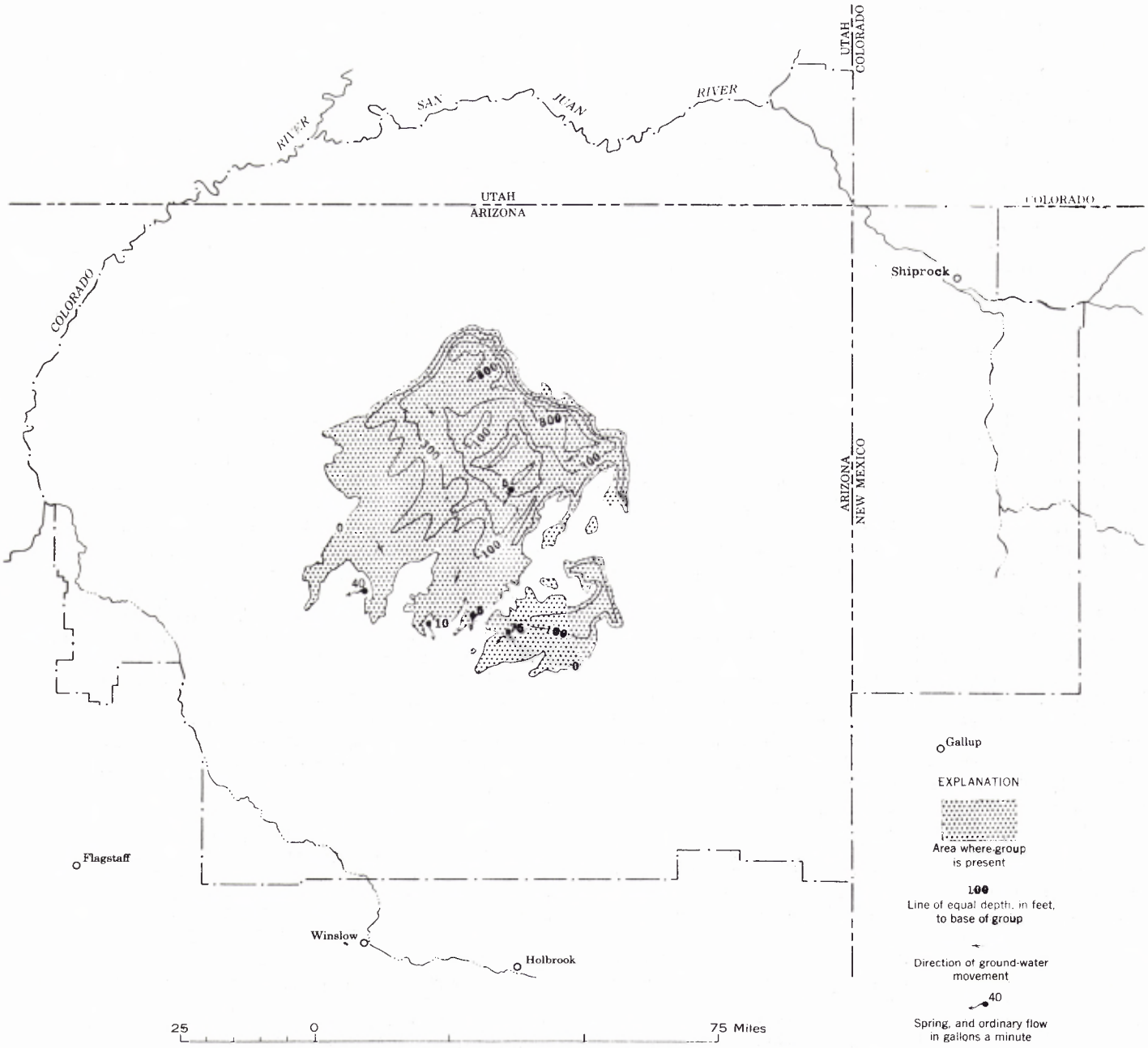

FIGURE 3.—The Mesaverde group and its water in Black Mesa basin.

the water moves to the base of the formation and then downdip to the west, and discharges as spring flow at the contact with the underlying rocks. These springs constitute the base flow for several perennial streams used for irrigation.

Cretaceous Rocks

Mesaverde group

The Mesaverde group on Black Mesa comprises three formations, from the top down the Yale Point sandstone, the Wepo formation, and the Toreva formation. The Toreva formation is the only important aquifer and consists of about 300 feet of medium- to coarse-grained arkosic sandstone and shale. The recharge area and the storage capacity of this formation are limited, and wells do not yield large amounts of water. The average yield is about 15 to 30 gpm from wells ranging in depth from 200 to 600 feet.

Where the Toreva formation occurs in the subsurface and is overlain by younger rocks, the water may be under artesian pressure, but no flowing wells have been drilled to date on Black Mesa. Water in the Mesaverde group moves downdip toward the south and discharges in springs at the heads of canyons (fig. 3). The chemical quality of the water is fair to good.

Gallup sandstone

The basal member of the Mesaverde group east of the Defiance uplift is the Gallup sandstone, which consists of fine- to coarse-grained sandstone and shale. The Gallup sandstone is the main aquifer in the area between U. S. Highway 666 and the Window Rock-Lupton road and between New Mexico State Highway 68 and U. S. Highway 66. The city of Gallup drilled two wells at the western edge of town. Each of these wells obtains about 200 gpm from the Gallup sandstone at a depth of 180 to 350 feet. Several other wells drilled by the Navajo Tribe northwest of Gallup produce 15 to 50 gpm from the Gallup sandstone at depths of 200 to 1,200 feet. The chemical quality of water in these wells is fair for domestic use (fig. 4).

Dakota sandstone and Westwater Canyon sandstone member of the Morrison formation

The Westwater Canyon sandstone member of the Morrison formation of Jurassic age and the Dakota sandstone of Cretaceous age are discussed here, as these two units form a single water-bearing unit in this area. The Dakota sandstone is fine to coarse grained and ranges in thickness from a few feet to more than 100 feet. The Westwater Canyon sandstone member of the Morrison formation is a medium- to coarse-grained sandstone ranging in thickness from 150 to 275 feet. Both these formations are present in the subsurface of Black Mesa and in the area between Gallup and Window Rock (fig. 5). Several wells have been drilled to the aquifer formed by the Dakota and Westwater Canyon in Black Mesa. These wells yield 2 to 10 gpm of water. In most areas the chemical quality of the water from these formations is fair. However, in the southeastern part of Black Mesa, near Tochee, the water contains as much as 1,600 ppm of sulfate (fig. 4). Water is recharged into these formations along the periphery of Black Mesa in the north, east, and west, and is discharged in the south as springs.

Jurassic Rocks

Cow Springs sandstone and Entrada sandstone

The Cow Springs sandstone and underlying Entrada sandstone are treated here as a single water-bearing unit. Both are medium grained, have about the same water-bearing characteristics, and have adjacent outcrop areas along the periphery of Black Mesa and on the east side of the Defiance uplift. Both formations have low permeabilities and limited recharge which are reflected in low yield. Most of the wells that obtain water from these sandstones yield 2 to 10 gpm. The chemical quality of water in the Cow Springs sandstone and Entrada sandstone is fair to good (fig. 4). However, in the Four Corners area and northeast of Black Mesa, water from the Entrada has a high concentration of dissolved salts and this formation must be cased off in wells.

Navajo sandstone

The Navajo sandstone is composed of well-sorted, fine- to medium-grained quartz sand with very little cementing material. It is about 1,500 feet thick in the northwestern part of the reservation near Lees Ferry and about 800 feet thick in the Tuba City area, and it thins to a featheredge in the vicinity of the Hopi Buttes and the Four Corners (fig. 5). Nearly everywhere that the Navajo sandstone is penetrated by wells it yields water. Exceptions occur near Copper Mine, where structural conditions have modified the underlying impermeable formations and the water table is below the Navajo sandstone.

The water in the Navajo sandstone in most areas occurs under watertable conditions. However, in the Tuba City area intertonguing relationships with the underlying Kayenta formation results in artesian conditions. The yield from the Navajo sandstone ranges widely—from less than 10 to 300 gpm in the Navajo reservation to about 1,000 gpm north of Page, Arizona. The quality of the water in this formation is excellent everywhere that it has been penetrated by wells (fig. 4).

Movement of water in the Navajo sandstone is southeastward in Black Mesa basin and toward the Colorado River in the northwestern part of the reservation (fig. 6).

Triassic Rocks

Wingate sandstone, Lukachukai member

The Lukachukai member of the Wingate sandstone is composed of very fine firmly cemented quartz grains. It crops out mostly as cliffs, so there is little opportunity for recharge. Wells in the Wingate sandstone have low yields or are practically dry. Less than five wells in the Navajo country obtain their water exclusively from the Wingate sandstone. These are near the southeastern flank of Navajo Mountain and west of Chinle. However, several large springs issue from joints in the Wingate sandstone in the bottom of Desha Canyon northeast of Navajo Mountain. The chemical quality of the water from both the wells and springs is excellent (fig. 4).

Chinle formation

There are two aquifers in the Chinle formation—the Sonsela sandstone bed in the Petrified Forest member and the basal Shinarump member. Both units are conglomeratic sandstone composed of medium- to coarse-grained quartz and contain pebbles up to 4 inches in diameter. The Sonsela sandstone bed is present only in the area east of Black Mesa. Wells in the Sonsela generally yield 5 to 15 gpm. However, in one well completed recently near Red Lake northeast of Fort Defiance, the Sonsela sandstone had yielded 75 gpm. Water from the Sonsela is of poor to fair chemical quality except near recharge areas, where the quality is good to excellent.

The Shinarump member of the Chinle formation is not consistently a good aquifer everywhere. In many areas where the Moenkopi formation is present, such as in the southern and western parts of the reservation, the Shina-

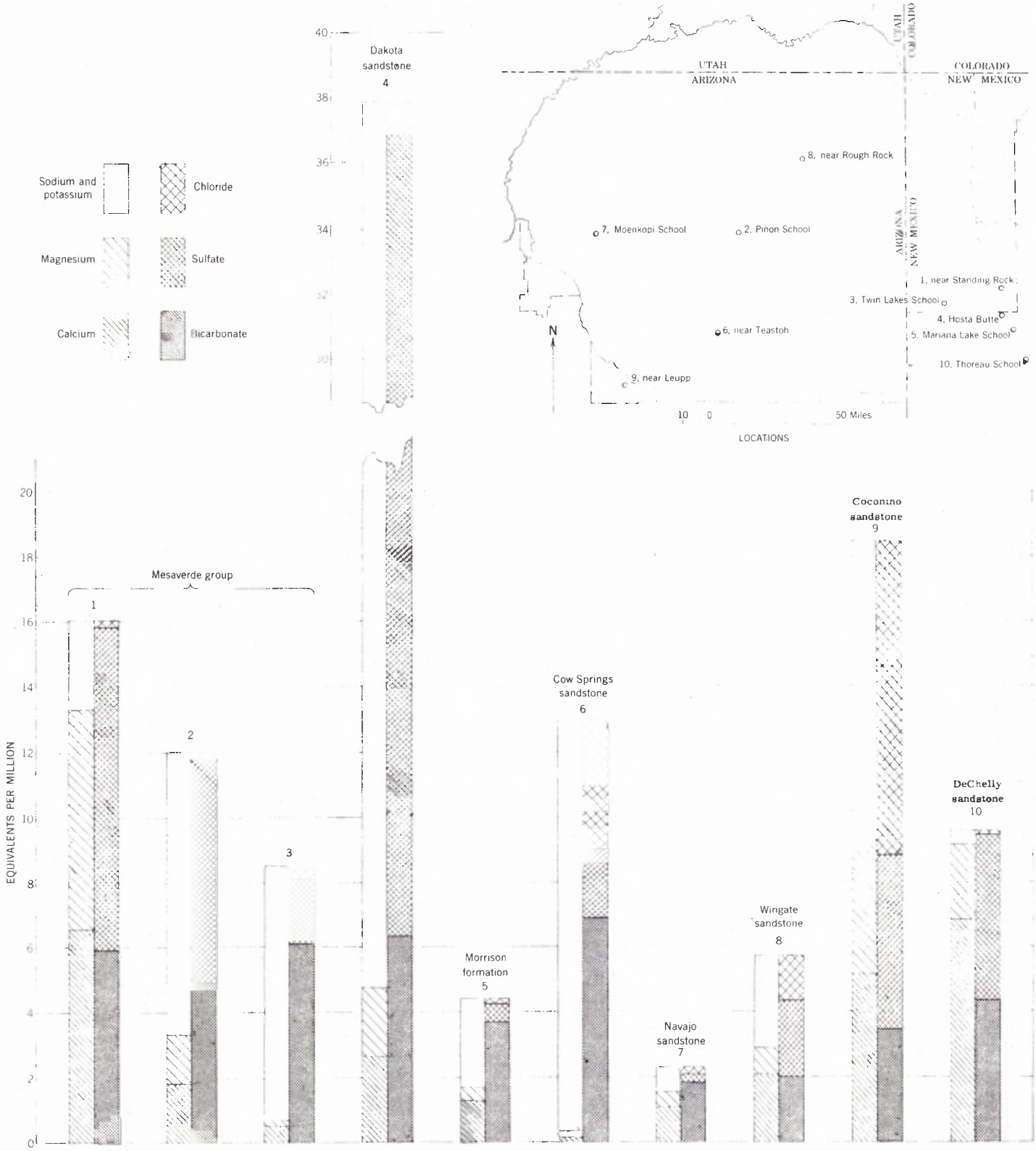

FIGURE 4.—Dissilved mineral matter in typical ground water in the Navajo country.

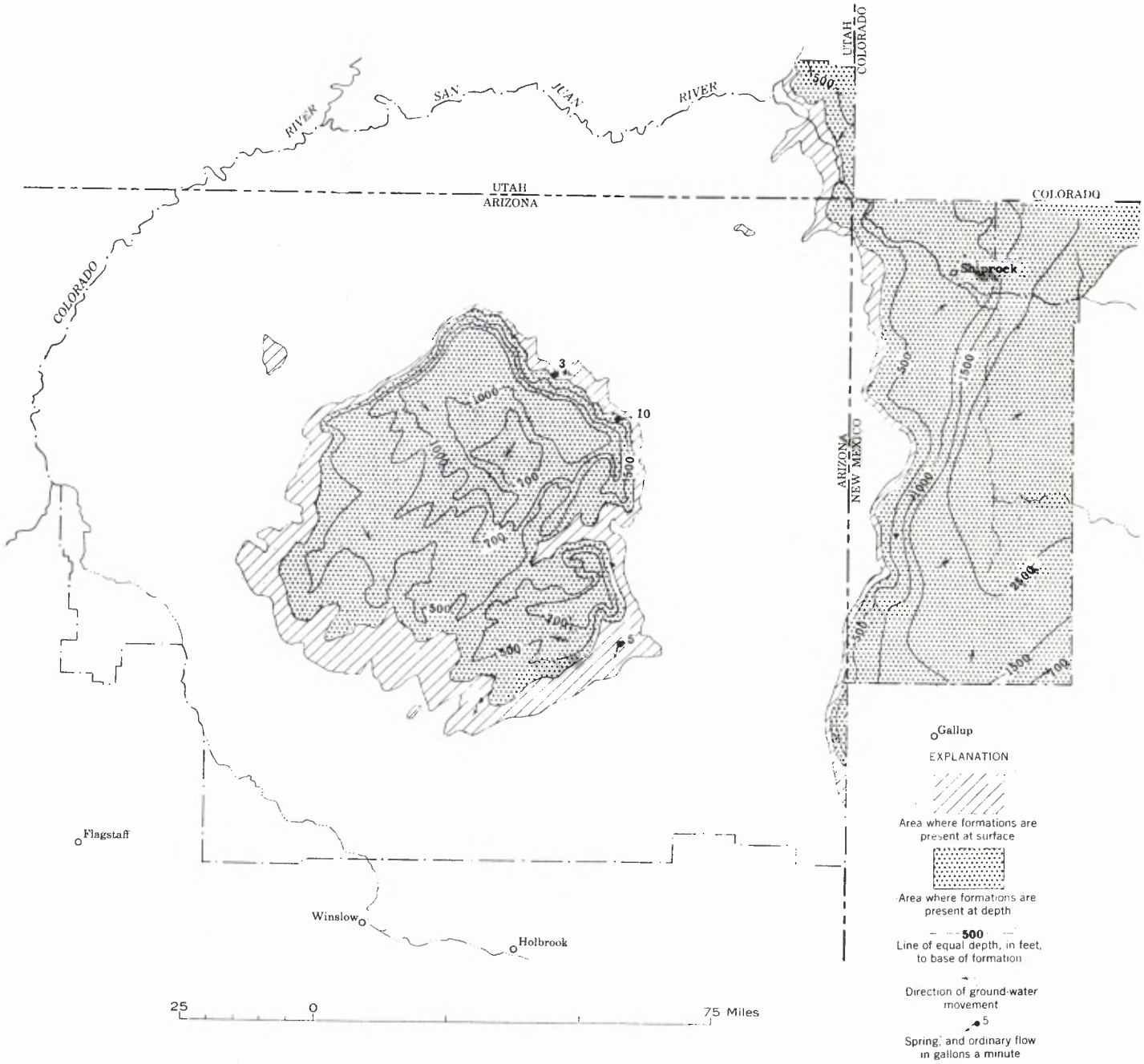

FIGURE 5.—The Dakota sandstone and the Westwater Canyon member of the Morrison formation and their water.

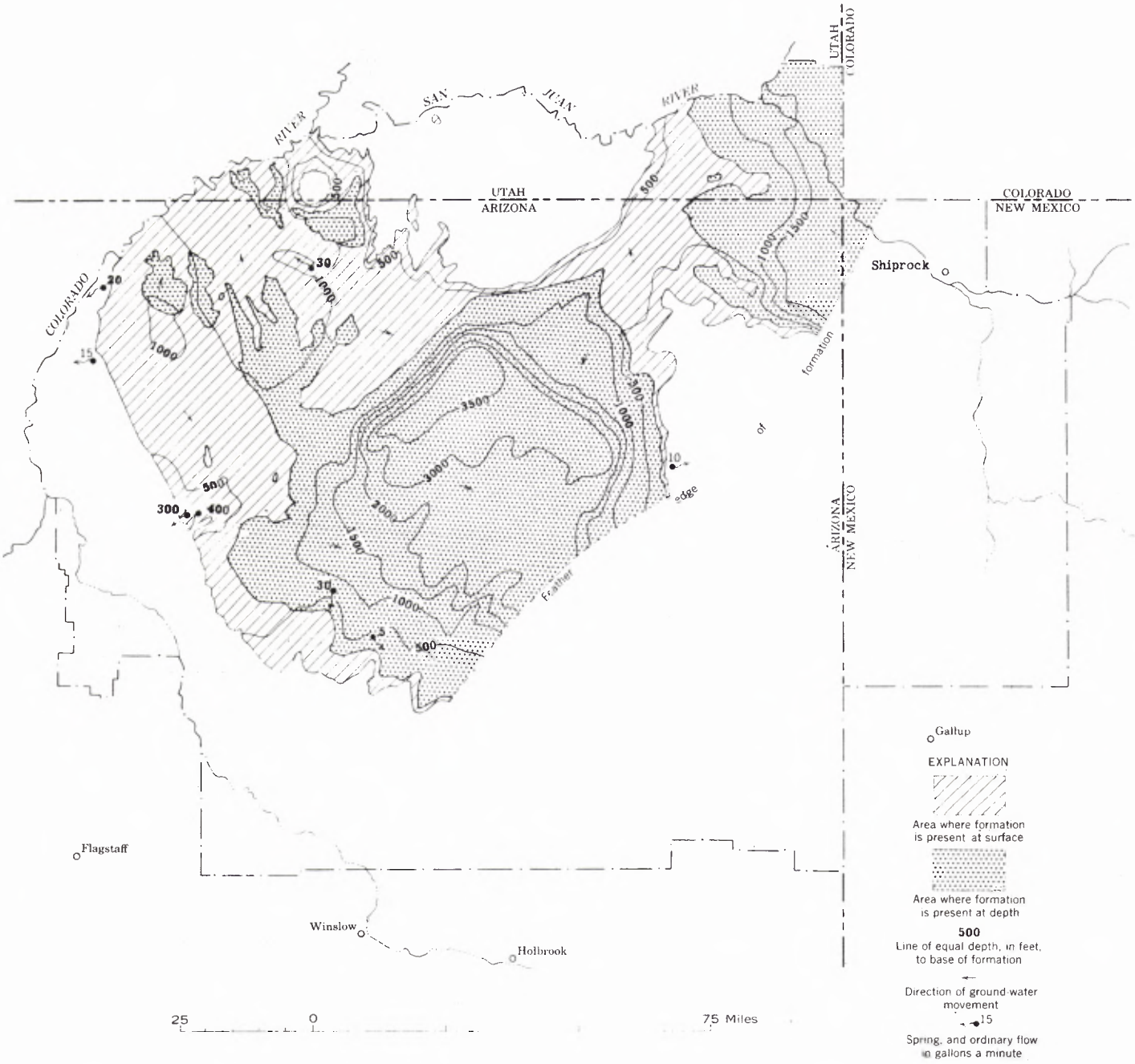

FIGURE 6.—The Navajo sandstone and its water in Black Mesa basin.

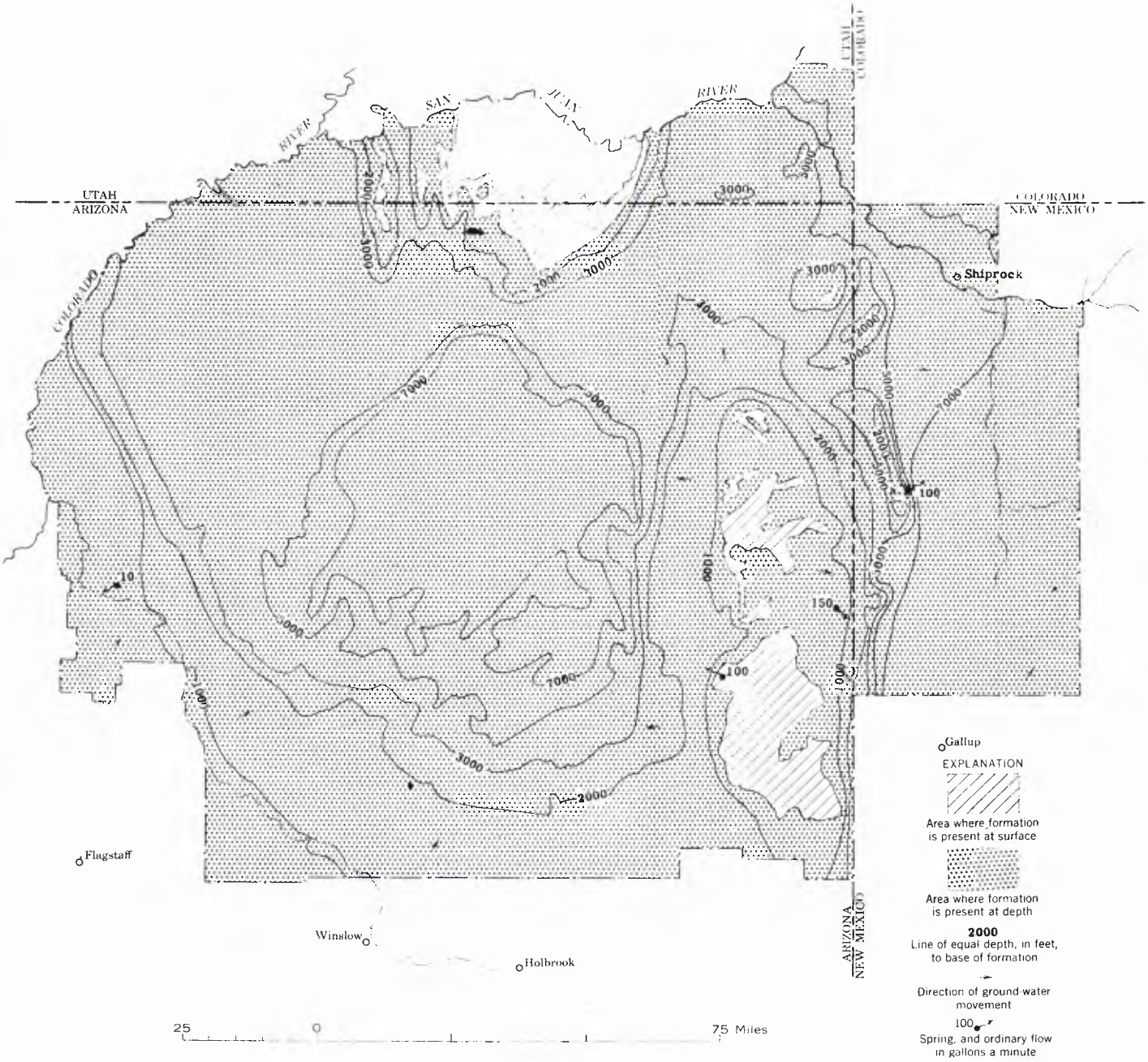

FIGURE 7.—The Coconino sandtone (DeChelly sandstone) and its water.

FIGURE 8.—Water-bearing formations of the Defiance uplift, Chuska Mountains area.

rump yields only small amounts of water or is dry. In the area east of the Defiance uplift, where the Moenkopi formation is absent, the Shinarump member rests unconformably on the DeChelly sandstone of Permian age. In this area the Shinarump member and the DeChelly sandstone act as a single aquifer, but the Shinarump member yields most of the water as it has a greater permeability. The chemical quality of the water in the Shinarump member of the Chinle formation is fair to good.

Permian Rocks

DeChelly sandstone and Coconino sandstone

The DeChelly sandstone and the equivalent Coconino sandstone crop out or are present at depth in nearly all the Black Mesa basin area. The DeChelly sandstone crops out in large areas along the axis of the Defiance uplift. The Coconino sandstone occurs in the Mogollon slope and forms the walls of deep gorges along the Little Colorado and Colorado Rivers (fig. 7). The thickness of the unit ranges from 800 feet in Canyon De Chelly to the vanishing point at Monitor Butte in the northwestern part of Monument Valley. Near Lees Ferry it is 57 feet thick and on the Mogollon slope it is 400 to 800 feet thick. It is composed of fine to medium well-sorted and rounded quartz grains, but at many places it contains large amounts of cementing material or the quartz grains have been re-crystallized, causing a low permeability. In other places, especially on the Mogollon slope, there is little cementing and the formation is extensively fractured, thus allowing large yields to wells. In such places wells produce 1,000 to 3,000 gpm and have about 100 feet of drawdown. In the area between Lupton and Fort Defiance on the east side of the Defiance uplift, wells in the Shinarump and DeChelly yield about 5 to 40 gpm (fig. 8). A few holes in the DeChelly sandstone along U. S. Highway 66 near Houck are dry.

Water from the DeChelly or Coconino sandstone is fair in chemical quality along the Defiance uplift and excellent in most of the Mogollon slope area. North of the Little Colorado River, however, water in the Coconino sandstone contains large amounts of chloride (fig. 4).

Movement of water in the Coconino or DeChelly sandstone is northward from the recharge area on the Mogollon slope and westward from the Defiance uplift toward Black Mesa basin. East of the Defiance uplift the water moves toward the San Juan basin (fig. 6).

Supai formation

The Supai formation is a thick sequence of alternating sandstone, shale, limestone, and evaporite deposits. In most of Black Mesa basin and adjacent areas the Supai is not an aquifer. However, in two widely separated areas, near Flagstaff and on the Defiance uplift, sandstone in the upper 100 feet of the Supai formation yields excellent water. This sandstone is composed of well-rounded and well-sorted medium-grained quartz.

Three wells near Flagstaff produce 10 to 75 gpm each from this sandstone where the water table is below the Coconino-Supai contact at depths of more than 1,100 feet. Several wells about 600 feet deep on the western flank of the Defiance uplift obtain water from the Supai formation under similar conditions. Water in all these wells is of excellent chemical quality.

CONCLUSIONS

Most aquifers in the Black Mesa basin area consist of fine-grained, well-sorted, clean sandstone. They contain large amounts of ground water in storage under both water-table and artesian conditions. The depths of wells needed to penetrate the aquifers range from several tens of feet to more than 2,000 feet. The exact depth at a particular point is dependent upon a number of geologic conditions, which are the primary controls on the occurrence and yield of water to wells. Although there are large amounts of water in storage, the yield to wells is not large owing to the low permeability of the fine-grained sandstones. Where faulting and fracturing have occurred the permeability in specific formations has been greatly increased and yields several times the normal can be expected. In the main, sufficient ground-water supplies can be developed for domestic, livestock, and small industrial demands. There are several specific areas where adequate water is available for large industrial demands and limited irrigation projects. On the other hand, there are several areas where the ground water is beyond practical reach of wells or the chemical quality of the water is unfit for any purpose.

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