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Synopsis of ground-water conditions on the
San Francisco Plateau near Flagstaff,
Coconino County, Arizona.

By

J. P. Akers, M. E. Cooley, and R. E. Dennis

Flagstaff Copy

Prepared in cooperation with the city of Flagstaff

Open-File report

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MONTGOMERY

George Johnson
January 1964

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SYNOPSIS OF GROUND-WATER CONDITIONS ON THE
SAN FRANCISCO PLATEAU NEAR FLAGSTAFF,
COCONINO COUNTY, ARIZONA

By

J. P. Akers, M. E. Cooley, and P. E. Dennis

ABSTRACT

Ground water on the San Francisco Plateau is withdrawn principally from the Coconino Sandstone and the uppermost 100 to 200 feet of the Supai Formation. Most static water levels in wells penetrating these units are between 500 and 1,000 feet below the land surface. The alluvium and the volcanic rocks yield a small amount of water locally. The glaciofluvial deposits on San Francisco Mountain, however, are a major source of water for Flagstaff, the largest community of the area.

The occurrence and yield of water in the Coconino Sandstone and the uppermost part of the Supai Formation are controlled largely by the Oak Creek and Anderson Mesa faults. Deep wells drilled in fractured zones along these faults at the Woody Mountain well field and at Lake Mary furnish Flagstaff with a dependable water supply, which supplements water obtained by the city from the glaciofluvial sediments and from Lake Mary.

INTRODUCTION

The San Francisco Plateau is an uparched highland lying astride the drainage divide between the Little Colorado and Verde Rivers in the southwestern part of the Colorado Plateaus. The plateau is characterized by expanses of lava flows, cinder cones, and striped plains cut on the gently dipping sedimentary rocks. Several deep canyons--Oak Creek, Sycamore, Walnut, and others--border or interrupt the plateau surface. The plateau is bounded on the southwest by the Mogollon Rim, which makes a conspicuous escarpment between it and Verde Valley, and on the southeast it merges with the broad Mogollon Slope. The summit of the plateau generally is between 6,500 and 7,500 feet; however, the entire plateau seems to be dominated by San Francisco Mountain, a decadent volcano, whose crest (altitude 12,830 feet) is the highest point in Arizona. Relatively intensive investigation of the ground-water conditions was restricted to a triangular-shaped area between Lake Mary, Woody Mountain, and San Francisco Mountain, although reconnaissance was made on most of the area to the south of the Little Colorado River (fig. 1).

Flagstaff, having a population of 18,814 in 1930, is the principal user of ground water in the area. The city obtains most of its supply from deep wells near Woody Mountain and Lake Mary and from springs and collection galleries in the glacial and glacioluvial material

in the Interior Valley on San Francisco Mountain. In addition to these supplies, the city receives water from Lake Mary. As the city has increased in population, so has its demand for water been increased: the amount of water now used is about 600 million gallons per year.

Other users of ground water are ranchers and residents who live in communities outside the city limits. Deep wells tapping principally the Coconino Sandstone and (or) the upper part of the Supai Formation furnish water to the area north of Anderson Mesa. Wells completed in the alluvium, in sediments associated with volcanic rocks, and in the volcanic rocks supply water locally on Anderson Mesa and in part of the area flanking San Francisco Mountain. Springs are developed in many parts of the plateau and are used for domestic and stock purposes.

The first detailed study of the geology in a part of the Flagstaff area was made by Robinson (1913) in the San Francisco volcanic field. A regional report on the Navajo Indian Reservation, adjacent to the Flagstaff area, was made by Gregory (1917). Colton (1937) classified the basaltic lava flows and cinders in the San Francisco volcanic field on the basis of weathering characteristics. Sharp (1942) studied and mapped the glacial sediments on San Francisco Mountain. Yost and Gardner (1961) made a study of the water requirements for the city of Flagstaff. Cooley (1963a) summarized the regional hydrology of the part of the Colorado Plateaus (including the San Francisco Plateau) that

is in Arizona. Ground water has been investigated in specific areas on the plateau including Doney and Black Bill Parks (Feth, 1963), Wupatki and Sunset Crater National Monuments (Cosner, 1962), and the Flagstaff area (Akers, 1962).

The general geology of the area is shown on a map of Coconino County prepared by the Arizona Bureau of Mines (Moore, Wilson, and O'Haire, 1960) and on maps and in a report by Cooley (1960a; 1960b; 1963b).

The authors gratefully acknowledge the assistance given to them by Flagstaff officials, who supplied information concerning the development and use of water by the city. Special mention should include C. T. Pulliam, Herman Dunnam, and J. D. Beard. Thanks are given to the drillers who collected samples of new wells and made available many logs of old wells; also, to residents who furnished information concerning their wells and springs. E. L. Gillespie of the Survey assisted in the hydrologic fieldwork.

GEOLOGY AND OCCURRENCE OF GROUND WATER

The main aquifers (water-yielding rocks) on the San Francisco Plateau are the Coconino Sandstone, the uppermost 100 to 200 feet of the Supai Formation, the alluvium, and volcanic rocks and associated sediments. The Coconino Sandstone, however, is by far the most important aquifer in the area. Nearly all the other rocks yield water only locally, generally to small springs. Sedimentary rocks older than the Supai Formation are deeply buried except for a small exposure on Elden Mountain; the deep burial of these rocks, therefore, precludes their development at this time.

Supai Formation

The Supai Formation of Pennsylvanian and Permian age crops out only in Oak Creek Canyon, but it is in the subsurface throughout the plateau. It is about 1,500 feet thick and consists of flat, somewhat lenticularly bedded units of light-brown, reddish-brown, and orangish-red siltstone, silty sandstone, and sandstone. A few thin beds of sandy limestone are present in the formation; one bed near the top of the unit can be traced throughout Oak Creek Canyon. Exposures in Oak Creek Canyon and drill cuttings from wells in the Flagstaff area show that the uppermost 100 to 200 feet of the Supai Formation consists mostly of fine- to medium-grained sandstone, which is similar in lithology to the

overlying Coconino Sandstone. The Supai-Coconino contact is difficult to detect in well outcrops; however, sandstone in the upper 100 feet of the Supai Formation usually is brick red in contrast to the gray or cream-colored Coconino Sandstone. The Supai-Coconino contact is recognized more easily in exposures because crossbeds in the upper part of the Supai were deposited at lower angles than were the ones in the Coconino Sandstone.

The sandy upper 100 to 200 feet of the Supai Formation contains water and combines hydraulically with the overlying Coconino Sandstone. The Supai furnishes most of the water to wells in the Doney Park area, near Bellemont, and in areas near the eastern and southern edge of Flagstaff. Other wells receive water from both the Supai Formation and the Coconino Sandstone. The sandstone in the upper part of the Supai has a low permeability (capacity for transmitting water) and therefore yields only small amounts of water. In a few areas, however, the sandstone units of the Supai are fractured and may yield as much as 100 gpm (gallons per minute) to wells.

The chemical quality of the water in the upper part of the Supai Formation is excellent—containing less than 200 ppm (parts per million) dissolved solids. The quality probably becomes progressively poorer toward the north, as it does in the overlying Coconino Sandstone.

Coconino Sandstone

The Coconino Sandstone of Early Permian age is composed of white to very pale orange, very fine to medium-sized, well-sorted quartz grains cemented by calcareous and (or) siliceous cement. Where it crops out it characteristically displays large sweeping crossbeds typical of those in modern sand dunes, and therefore it is considered to have been deposited by wind.

The Coconino is exposed in the north end of Oak Creek Canyon and in an isolated outcrop in Walnut Canyon National Monument, and it occurs in the subsurface in the rest of the San Francisco Plateau. It is from 300 to 900 feet thick near Flagstaff and thins northward across the area. The uppermost 200 feet of the sandstone in the area near Flagstaff is probably a lateral equivalent of the Toroweap Formation.

The Toroweap is similar lithologically to the Coconino on the San Francisco Plateau and is not discussed separately in this report.

The Coconino Sandstone, in combination with the uppermost part of the Supai Formation, is the main aquifer in most of the area between the Little Colorado River and the Mogollon Rim. It is a source of water for municipal, industrial, irrigation, domestic, and stock uses. The water in the aquifer near Flagstaff is under water-table conditions, and depths to water range from 300 to 1,000 feet below the land surface. The water is generally in the lower part of the Coconino and

(or) in the upper part of the Supai Formation.

Water is not present everywhere in the Coconino Sandstone and the upper part of the Supai Formation, notably on the upthrown blocks of faults and in places where the rocks are so intensively fractured that the water drains downward into the underlying rocks. Deep wells drilled in Fort Valley, at a locality 15 miles east-southeast of Flagstaff, and in Deadman Flat penetrated the Coconino and the upper part of the Supai and failed to obtain enough water from these formations to warrant development. Another well, drilled to a depth of 1,200 feet in Flagstaff near the Arizona Highway Department headquarters, also penetrated the Coconino and the upper part of the Supai without obtaining water. This well, however, might have obtained water from the Supai had it been drilled 100 feet deeper.

The Coconino Sandstone and the upper part of the Supai Formation where undisturbed have a relatively low permeability and do not yield large quantities of water to wells or springs. In many places, fracturing due to faulting and folding has increased greatly their effective permeability (Akers, 1962). The maximum well yield in the Flagstaff area is 4.5 gpm per foot of drawdown. This yield is from a well in the Woody Mountain well field, which was drilled in a fractured zone close to the Oak Creek fault. The fractured sandstone allows relatively free movement of water. The Coconino Sandstone has

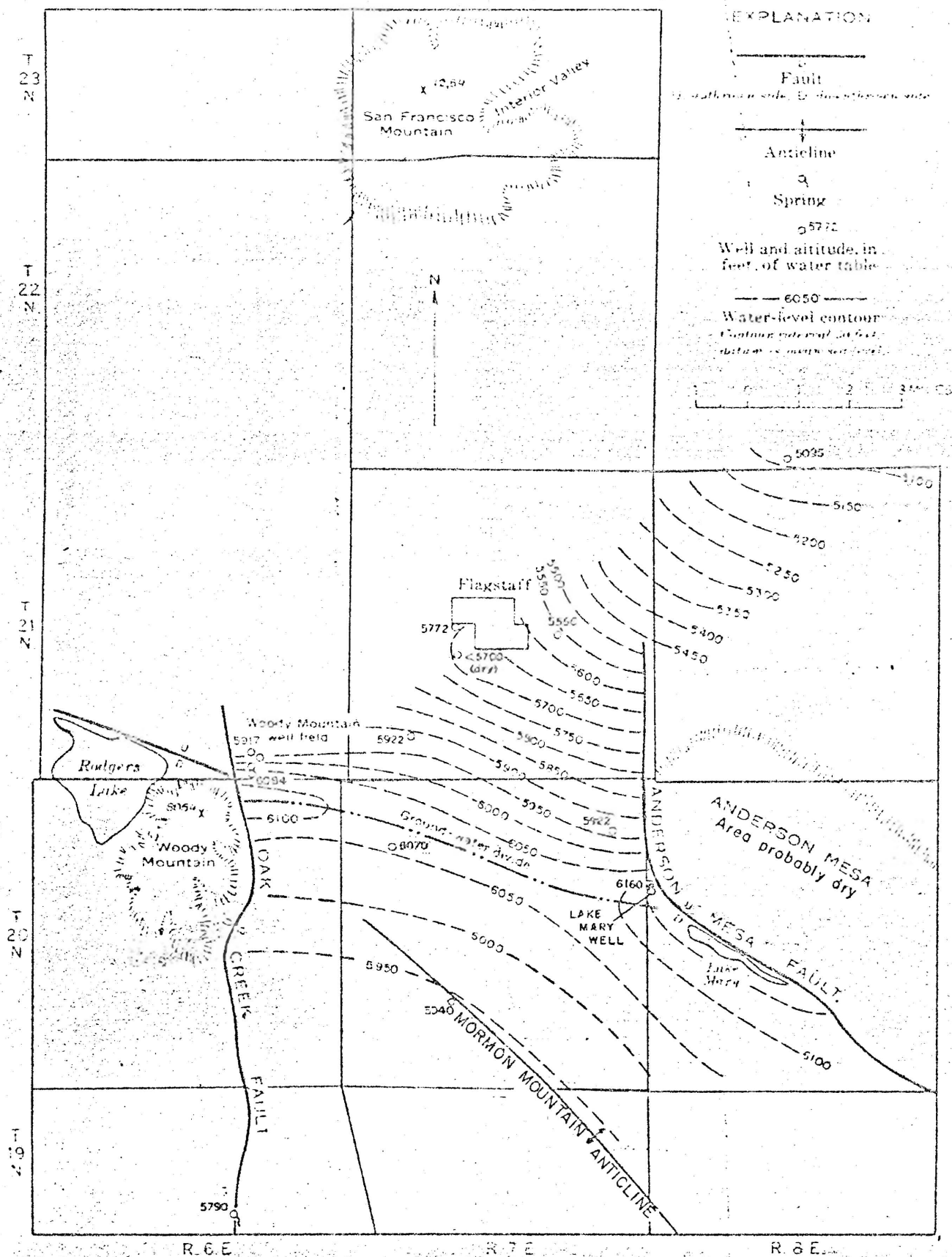
been so fractured in some areas that it consists of uncemented sandstone fragments and loose sand and makes drilling and well development difficult; to prevent "sanding" some wells must be sand packed and screened.

The general direction of ground-water movement in the Cocconino Sandstone and the upper sandy part of the Supai Formation is shown by water-level contours on figure 2. The contours show that water moves northeastward and southward from the Woody Mountain-Lake Mary area. They also show two principal areas of recharge, indicated by ground-water mounds near Lake Mary and Woody Mountain. The mounds are connected by a ground-water "ridge," which is also a ground-water divide. This ridge or divide coincides with an intensely jointed belt extending along a line connecting the Anderson Mesa fault near Lake Mary with the Oak Creek fault near Woody Mountain.

The chemical quality of water in the Cocconino Sandstone is excellent. The concentration of dissolved solids is about 150 ppm. The quality becomes progressively worse toward the north, and in the Wupatki National Monument area it is marginal—containing a concentration of more than 1,000 ppm, of which 360 ppm is chloride.

Kaibab Limestone

The Kaibab Limestone of Early Permian age is exposed on



Water level contours from Akers, 1962.

Figure 2. --Contour map of the San Francisco Plateau, showing regional water levels in the Coconino Sandstone and uppermost part of the Supai Formation.

much of the San Francisco Plateau near Flagstaff. It is composed of silty to sandy dolomitic limestone, which is yellowish gray on a fresh surface and light gray on a weathered surface. Near the top it commonly contains chert nodules and thin beds of chert. In some areas it includes thin lenticular beds of marly material that may be mostly siltstone. Quartz and calcite geodes are abundant in places. Beds of the Kaibab are from a few inches to a few feet thick, and where the formation has been incised by streams it forms a blocky cliff; in other areas it weathers to a knobby and pitted surface.

The Kaibab is not uniform in thickness because it has been subjected to several periods of erosion since it was deposited. The Kaibab ranges in thickness from 300 to 450 feet and has an average thickness of 300 feet.

The Kaibab is a brittle formation and is strongly jointed and fractured. In some places the fractures have been widened by solution. The fractures permit the movement of water through the limestone and thus facilitate recharge to the underlying Coconino Sandstone. Wells are not completed in the Kaibab Limestone because it is above the regional water table, although in a few places the Kaibab may contain small bodies of perched water.

Moenkopi Formation

The Moenkopi Formation of Middle(?) and Late Triassic age

crops out in isolated exposures, because most of it was removed by erosion prior to the time when lava flowed over the area. In several places the Moenkopi was preserved because it was lowered by faults and protected from erosion.

The Moenkopi is composed of reddish-brown, dark-red, and orange-red siltstone and sandstone. In some areas where it filled depressions eroded into the underlying Kaibab Limestone it contains at its base yellowish-gray conglomerate composed of silt, sand, and pebbles of chert and limestone, which are derived in part from the Kaibab Limestone. The bedding ranges in thickness from a fraction of an inch to several feet. Ripple marks are numerous in the Moenkopi Formation. It weathers to a ledgy slope that is strewn with pieces of sandstone and siltstone.

Because of its spotty occurrence in the Flagstaff area, the thickness of the Moenkopi Formation varies considerably from place to place. It is about 90 feet thick in well 4 in the Woody Mountain well field, more than 200 feet thick in the northern part of Switzer Mesa, and 300 feet thick on Anderson Mesa.

The Moenkopi Formation is not an aquifer; it functions mainly as a confining bed for water moving downward through the overlying sediments and volcanic rocks. In a few places it underlies bodies of perched water in the overlying rocks. Locally, sandstone beds in the

Moenkopi yield some water to springs, and two springs near Wapathi Ruin have been developed for domestic use (Cosner, 1932).

Sediments Underlying the Volcanic Rocks

Silty and gravelly sediments of probable Pliocene age underlying the volcanic rocks crop out in several places on the San Francisco Plateau. Most of these sediments were correlated by Cooley (1933b) with the lower member of the Bidahochi Formation of Pliocene age. An outcrop in an escarpment south of Cedar Ranch, about 25 miles north of Flagstaff, consists, in ascending order, of grayish-orange conglomerate 17 feet thick; a sequence of greenish-gray claystone, mudstone, and silty sandstone 88 feet thick; yellowish-gray conglomeratic sandstone and siltstone 81 feet thick; and grayish and pale-red mudstone 96 feet thick. An exposure 60 feet thick on the northeastern tip of Anderson Mesa is similar in composition, bedding, and general appearance to the strata near Cedar Ranch. A well drilled in 1960 northwest of Mormon Lake penetrated about 300 feet of pink mudstone and claystone, also believed to be correlative with the lower member of the Bidahochi Formation. The sediments usually do not contain water and form a barrier to the downward movement of ground water; they hold up small bodies of perched water near Cedar Ranch and at several places on Anderson Mesa. A few small springs, however, issue from gravelly sediments (Price, 1950) lying below the volcanic rocks in Sycamore Canyon.

Alluvial Deposits

Alluvial deposits of Quaternary age form a series of coalescing fans around San Francisco Mountain. They also underlie the grass-covered valleys and parks and occur along the larger washes as channel deposits. The deposits forming the fans are composed of angular to subangular, pebble- to boulder-size fragments of dacite, latite, andesite, rhyolite, and basalt in a matrix of gravelly sand and silt. The alluvium underlying the parks and along the washes usually is finer grained than the fan material and consists principally of sand and silt and subordinaately of gravel.

Ground water is held temporarily in the alluvial deposits near the mountains. The general coarse nature of the alluvium aids infiltration and transmission of water from precipitation into the underlying aquifers. Transitory perched-water bodies form above silty zones in these deposits during the rainy season and in the early spring when the snow melts. A few temporary springs or seeps issue where the silty zones intersect the land surface.

Water at shallow depth underlies numerous valleys and parks on the San Francisco Plateau, such as Antelope and Fort Valleys and Munds Park. The amount of water in storage in these valleys and parks depends largely on seasonal precipitation and, therefore, they are not everywhere dependable sources of water.

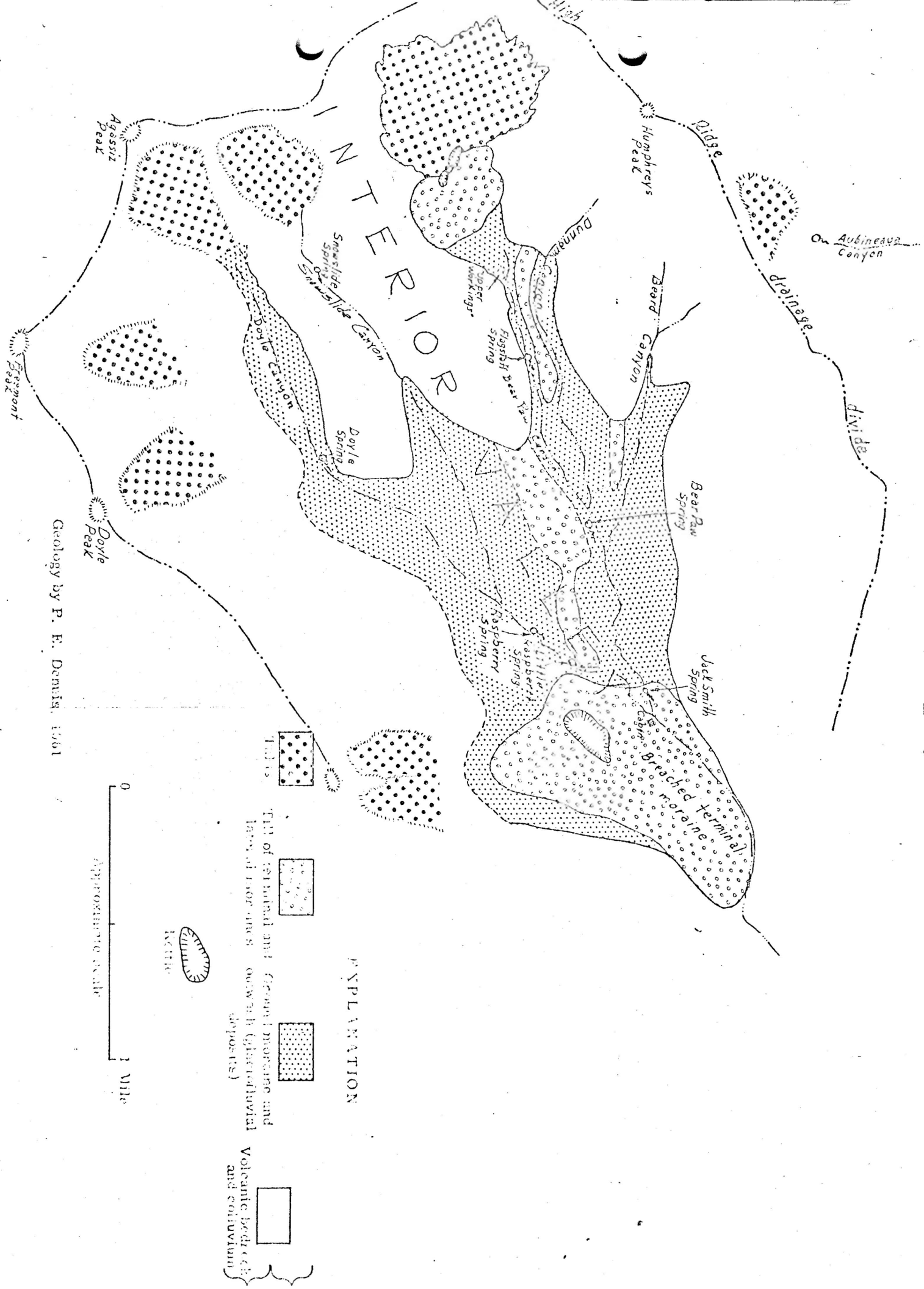
The alluvium along Schultz Creek in and just north of Flagstaff contains water at shallow depth. Wells in the alluvium yield as much as 50 gpm for short periods, but the amount of water in storage is limited because the alluvium is thin—generally less than 50 feet thick—and not extensive. Therefore, sustained yields throughout the year may be only a few gallons per minute.

Glaciocluvial Deposits on San Francisco Mountain

Glacial and glaciocluvial deposits of Pleistocene age in the Interior Valley on San Francisco Mountain are of particular interest in Arizona because they are the only such deposits in which ground water has been developed extensively in the State. Three stages of glaciation are recognized, and these were described in a report by Sharp (1942). The glaciation took place atop San Francisco Mountain in a depression that probably was a volcanic crater, which had been enlarged by erosion before it was partly filled with snow and ice. Drainage from the crater was established through a breach in the northeast periphery of the crater wall.

The glaciocluvial materials were deposited in the lower parts of the Interior Valley, and they extend up Doyle and Bear Paw Canyons for a considerable distance (fig. 2). They also are in the lower part of Beard and Snowflake Canyons. A few isolated outcrops of glaciocluvial

Figure 3.-Sketch map showing geologic and hydrologic features in the Interior Valley of San Francisco Mountain north of Flagstaff, Ariz.



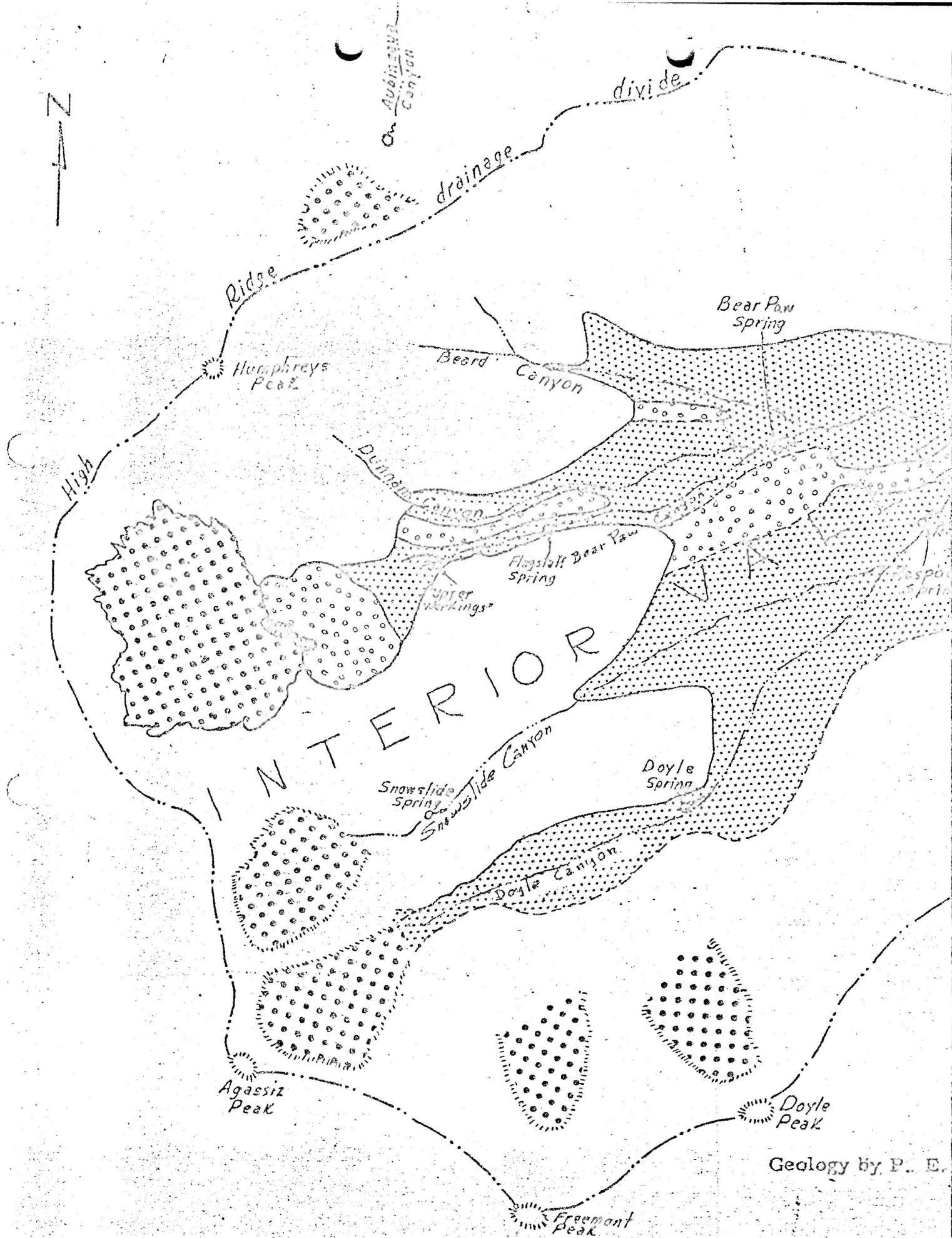
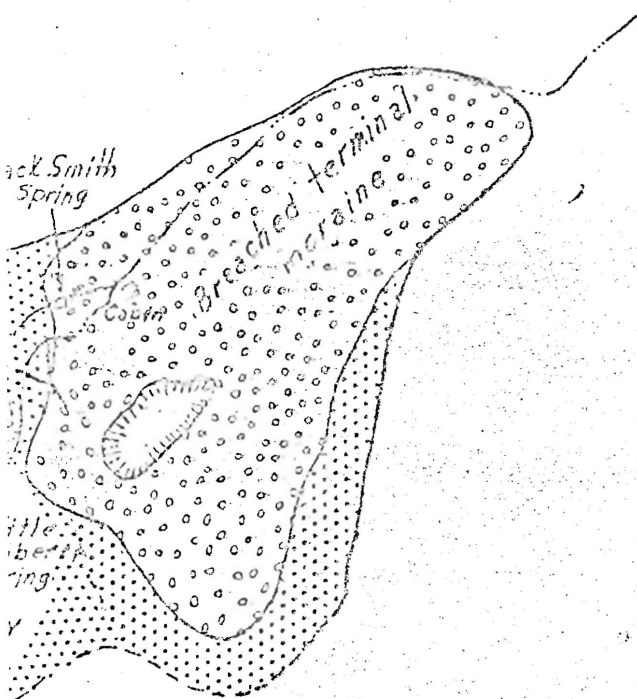


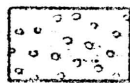
Figure 3.--Sketch map showing geologic and hydrologic features in the Interior



EXPLANATION



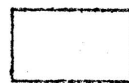
Talus



Till of terminal and lateral moraines



Ground moraine and outwash (glaciofluvial deposits)

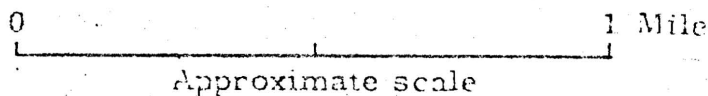


Volcanic bedrock and colluvium



Kettle

TERTIARY QUATERNARY



Approximate scale

Smith, 1961

Valley of San Francisco Mountain north of Flagstaff, Ariz.

deposits occur in canyons outside the crater on the north side of the mountain. The deposits in the Interior Valley cover an area of about 1-1/2 square miles. The main body of the glaciofluvial material is about a mile wide and 1-1/2 miles long. Four fingerlike projections extend southeast of the main body and terminate in poorly formed cirques at altitudes between 10,500 and 11,000 feet. The lowest deposits in the Interior Valley occur at an altitude of slightly more than 9,000 feet. Gravelly deposits, however, probably outwash, extend from the Interior Valley to the north and east and underlie much of Bonito Park and Deadman Flat. These deposits are interbedded with some of the lava flows on the northeast margin of San Francisco Mountain.

The deposits in the Interior Valley include till deposited as terminal, lateral, and medial moraines and outwash. The moraines consist of material eroded from the crater walls and carried along by the glaciers until dropped as the ice melted and the glacier receded. As the names imply, the till dropped at the terminus of the glacier is terminal moraine and that dropped along the sides is lateral moraine. The till is not stratified, is poorly sorted, and contains considerable amounts of clay and silt. As a result, the till has a low permeability and does not readily absorb and transmit water. In contrast, the glacial outwash is composed of silt, sand, and gravel, which are stratified and fairly well sorted so that they are relatively permeable.

The city of Flagstaff has developed water in the glaciofluvial deposits by the construction of collection galleries. The galleries supply about 175 million gallons annually, although the amount of water available each year is variable and is dependent on the precipitation, principally snowfall.

Talus, formed as a result of intensive frost action, has accumulated in the cirques at the periphery of, and overlies, the glaciofluvial deposits. It is composed of angular blocks of material, which permit the rapid infiltration of rainfall and snowmelt, and it aids in recharging the ground-water reservoir in the glaciofluvial deposits.

The Interior Valley resembles a large funnel in which the ground water flows northeastward through the glaciofluvial material. The moraines restrict ground-water movement, thus forming dams in places that may help impound water in the permeable outwash and confining the ground water in other places to relatively narrow channels partly filled by the outwash (Fig. 3). Springs represent points of overflow of the ground-water body across or around moraines.

Volcanic Rocks

Most of the San Francisco Plateau is covered by volcanic rocks that belong to several periods of eruption beginning in Pliocene time and lasting into Recent time. These rocks include cinders and lava flows

of basaltic, intermediate, and silicic composition. Volcanic rocks of basaltic composition cap Anderson Mesa and cover most of the plateau.

Rocks of intermediate and silicic composition form Elden, Mormon, and San Francisco Mountains and O'Leary and Kendrick Peaks.

The lava flows commonly overlap, and at any particular place there may be as many as five or six flows exposed in a vertical section, which may be more than 800 feet thick. Many flows are interbedded with cinders, gravel, and soil or residual material; the detrital material ranges in thickness from a few inches to more than 100 feet. These zones are important to the occurrence of ground water, as some are relatively impermeable and act as barriers to the downward movement of water and thus give rise to temporary or in some places permanent bodies of perched water. Others are highly permeable and yield water to wells. Most of the water in the volcanic rocks, however, occurs in fractures. In areas where the volcanic rocks are underlain by impermeable formations—such as the Moenichi Formation or the silty sediments correlated with the Bidahochi Formation—they may contain some water; if they are underlain by the permeable Kaibab Limestone, the water will move on downward through the Kaibab Limestone and into the underlying Coconino Sandstone.

Cinders of Pliocene and Quaternary age forming cones, marking centers of volcanism, and in dunes are common in the Flagstaff

area; some of the cinder deposits are buried by volcanic flows and alluvium. All the cinder deposits are permeable and rapidly absorb and transmit rainwater and snowmelt to underlying formations, thereby greatly facilitating ground-water recharge.

Structure

Folds. --The San Francisco Plateau is along the crest and on the northeastern flank of a broad gentle anticlinal highland that extends from Anderson Mesa northward to beyond the Grand Canyon. The strata dip away from the crest at angles generally less than 2° . On Anderson Mesa the Mormon Mountain anticline forms part of the anticlinal highland (fig. 2). Dips on the southwest limb are steeper than those on the northeast limb. The regional movement of water in the Coconino Sandstone, except in the Lake Mary area, is from its crest generally northeastward toward the Little Colorado River and southwestward toward the Verde Valley and Oak Creek Canyon (fig. 2).

The Black Point segment of the East Kaibab monocline (Eabenroth and Strahler, 1945) may extend almost to the southeast flank of San Francisco Mountain. The monocline dips southeastward between 10° and 15° in the area near Wupatki Ruin. The exact location and the amount of structural relief cannot be determined south of Wupatki Ruin because the folded rocks are buried beneath the volcanic rocks

and alluvium. In this area the monocline probably limits the occurrence of ground water in the Coconino Sandstone to the area southeast of the structure; evidence that the Coconino may be dry in the area to the northwest of the monocline is from the deep well reported to be dry that was drilled in Deadman Flat.

Faults and joints. --Several large and many small faults have fractured the rocks in the Flagstaff area. Most of them trend northward or northwestward and a few trend eastward. Several of the faults are parallel, relatively close together, and form boundaries of grabens. Joints are numerous and are parallel to the trends of the faults.

The Oak Creek fault is the largest in the area, and Oak Creek Canyon has formed along it. This fault trends northwestward in its southern part and northward in its northern part. It is downthrown on the east end and has a maximum displacement of about 500 feet. The fault extends from near Fort Valley to southeast of Sedona—a distance of more than 30 miles. The Anderson Mesa fault also trends northward and northwestward. It is downthrown about 400 feet on the west side. Lake Mary is in a graben, which is formed by the Anderson Mesa fault and a small parallel fault that is downthrown on the northeast side.

Most of the small faults are parallel to the large faults, although some intersect the large faults and trend almost west. The displacement along the small faults is usually less than 50 feet.

The faults are important factors in the occurrence and movement of water. The fracturing and shattering along the fault zones have increased greatly the effective permeability of the rocks, which normally have low permeabilities. The wells completed in the Coconino Sandstone and the upper sandy part of the Supai Formation near Lake Mary and Woody Mountain were located in fractured zones on the down-thrown sides of the faults to take advantage of this increased permeability. Ground water moves in the more permeable fractured zone parallel to the faults, northward along the Anderson Mesa fault, and in both directions (north and south) from the ground-water divide along the Oak Creek Canyon fault (Fig. 2).

The Kaibab Limestone and underlying rocks between the Anderson Mesa and Oak Creek faults are fractured extensively. In places the fractures have been widened by solution and provide open conduits that divert water from the surface into the subsurface, thereby aiding recharge to the Coconino Sandstone and other rocks. Several fractures near the northwest end of Lake Mary had to be plugged because large quantities of water were lost through them. At "Bottomless Pits" east of Flagstaff, fractures near the junction of the Anderson Mesa fault and several small transverse faults have been widened into a hole several yards in diameter. According to reports of local residents there are several rather large caverns branching in several directions

from the "Bottomless Pits." Many other solution caverns, pits, and large cracks along joints and faults occur in the Kaibab Limestone on the San Francisco Plateau.

PROBABLE AREAS OF FUTURE DEVELOPMENT

The most favorable prospects for ground-water development are along large faults and in fractured zones in the Coconino Sandstone and the glacioluvial deposits in the Interior Valley of San Francisco Mountain.

Favorable conditions for the drilling of deep wells completed in the Coconino Sandstone and Supai Formation are along the downthrown sides of the Oak Creek and Anderson Mesa faults. The development of ground water along these faults has led to the establishment of the Woody Mountain well field near the Oak Creek fault and the well drilled near Lake Mary along the Anderson Mesa fault (Fig. 2).

The fractured zone along the Oak Creek fault at the Woody Mountain well field is about 2,000 feet wide. In the well field and to the south numerous small transverse faults are along the Oak Creek fault. These small faults serve to increase the permeability in the fault zone and, therefore, the yield to wells.

Another favorable area for development of ground water is in the fractured zone along the downthrown side of the Anderson Mesa fault. The area near the northwestern part of Lake Mary is the most favorable because it is more intensively fractured than elsewhere and because water is diverted into the area by the fault.

Other fractured areas are near the "Bottomless Pits" east of

Flagstaff and near Munds Park (Fig. 1). To date, no wells have been completed in the Coconino Sandstone in these areas; therefore, the hydrologic characteristics of the aquifer near the faults are unknown.

Before the drilling of any deep well, a geologic study should be made of the proposed site. The large and small faults in the site area should be located and the amount of fracturing and the width of the fractured zone, if present, should be determined.

The glaciofluvial deposits in the Interior Valley on San Francisco Mountain probably will supply considerably more water than is now obtained from them. Most of the ground water in the Interior Valley is funneled through the restriction in the lower part of the valley near the cabin by Jack Smith Spring (Fig. 3), and it would seem that considerably more water could be obtained from the deposits near the cabin. To determine how much ground water passes through the restriction it would be necessary to determine the slope of the water table and the transmissibility and width of the saturated material, which could be done by test drilling, coring, and test pumping. A series of holes completely penetrating the glaciofluvial deposits and drilled in a line perpendicular to the main drainage would indicate the thickness of the saturated material, and several holes drilled parallel to the drainage would indicate the slope of the water table. The holes also would show the configuration of the preglacial valley carved in the volcanic rocks.

The lowest part of the preglacial valley would be a favorable site for ground-water development.

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