GEOLOGICAL SURVEY CIRCULAR 233

A GEOLOGIC AND GEOPHYSICAL RECONNAISSANCE OF THE DONEY PARK-BLACK BILL PARK AREA, ARIZONA WITH REFERENCE TO GROUND WATER

By J. H. Feth

With a section on geophysics

By C. B. Yost, Jr.

UNITED STATES DEPARTMENT OF THE INTERIOR
Douglas McKay, Secretary

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INTRODUCTION

Purpose and cooperation

Doney and Black Bill Parks, near Flagstaff, Ariz., are inhabited by a number of families whose domestic water supply is derived almost entirely from precipitation caught on the roofs of farm buildings and stored in cisterns. During dry months in a year of normal precipitation, and throughout much longer periods in years of subnormal precipitation, the residents of the area haul water from Flagstaff.

In 1950 only one of the wells in the area yielded water. Officers of the Doney Park Farm Bureau and of the San Francisco Peaks Soil Conservation District requested that investigation be made in the area to determine whether it would be possible to develop additional domestic water supplies from wells.

The Ground Water Branch of the U. S. Geological Survey, in cooperation with the Arizona State Land Department, made a reconnaissance investigation in the fall of 1950 and the spring of 1951. Field work was under the direction of S. F. Turner, district engineer of the Ground Water Branch. The geology of the area was mapped by J. H. Feth, who was assisted for part of the time by L. R. Moore; the geophysical investigation was made by C. B. Yost, Jr., and J. P. Mooseau, Jr. Residents of the area contributed assistance during the geophysical work and furnished information regarding old wells in the area.

Location

Doney and Black Bill Parks are unforested areas east of the San Francisco Mountains and Elden Mountain on the San Francisco Plateau subdivision of the Colorado Plateaus. The area mapped comprises about 125 square miles. It is bounded on the south by Walnut Canyon, on the west by Elden Mountain and the San Francisco Mountains, on the north by the topographic divide between Black Bill Park and Deadman Flat, and on the east by an irregular range of cinder hills including Sunset Crater and O'Neill Crater (New Caves Hill).

Flagstaff, the county seat of Coconino County, Ariz., is about 15 miles southwest of the center of the area mapped. U. S. Highway 66 and the main line of the Atchison, Topeka and Santa Fe Railway cross the southern part of the area. U. S. Highway 89 extents north from Flagstaff through the western part of the area. County, Federal, and private roads provide access to all parts of the area.

Climate

U. S. Weather Bureau records have been kept at Flagstaff for more than 50 years. These records show that the mean annual temperature at Flagstaff is about 45° F. The mean temperature during December and January is about 20° F. and during July and August, about 65° F. The mean annual precipitation is about 22 inches, much of which occurs as snowfall. The altitude of Flagstaff is 6,900 feet above sea level. The farm lands in Doney and Black Bill Parks lie 6,500 to 7,000 feet above sea level. The average growing season at Flagstaff is about 125 days a year; this would be about the average for Doney and Black Bill Parks.

Agriculture and industry

The dry-land raising of pinto beans and small grains is the principal industry in the area considered in this report. Lack of water prevents development of any appreciable livestock industry although small herds of beef cattle are raised in a few localities where surface water is stored in earth tanks, and where range conditions permit.

Logging operations are carried on intermittently in forested areas, principally on the flanks of Elden Mountain and the San Francisco Mountains, and a small sawmill was in operation in Black Bill Park during 1950-51.

Previous investigations

The most comprehensive previous geologic investigation of the Black Bill-Doney Park area is reported by Robinson (1913). [1] None of the papers cited in this report have dealt specifically with the geology in relation to the occurrence of ground water. It is believed that the present report is the first to attempt an analysis of ground-water conditions in the parks.

Maps and field work

About 4 man-months was spent in the field during the investigation, a little more than 75 percent of the time being devoted to geologic mapping and to compiling and analyzing data on springs and wells.

Geologic mapping was done on contact prints of aerial photographs made originally for the U. S. Forest Service. Data so recorded were transferred to an uncontrolled aerial mosaic. Land lines were taken from a U. S. Forest Service topographic map and adjusted to section corners recovered in the field. The resulting geologic map appears as plate 1 in this report.

Geophysical probes were made with electrical-resistivity apparatus. The results are discussed in the section on geophysics (p. 5).

[1] See p. 9 for list of literature cited.

LAND FORMS

Three types of land forms predominate in the Doney-Black Bill Parks area. The San Francisco Mountains, composed of numerous volcanic peaks, dominate the landscape. Elden Mountain, an outlier of the volcanic mass, is an important unit on the southwest boundary of the area. Although of volcanic origin, Elden Mountain has been described (Robinson, 1913, pp. 74-84) as a laccolith rather than a volcanic cone. The interpretation of Elden Mountain as a laccolith was based upon the presence of about 2,000 feet of sedimentary strata on the east flank of the mountain, dipping east at angles as much as 50° from the horizontal, and on about 700 feet of sedimentary rocks on the north flank of the mountain, dipping north about 12°. The summit of Elden Mountain is 9,280 feet above sea level, or about 2,500 feet higher than Doney Park. The summits of six of the San Francisco peaks exceed 11,000 feet in altitude.

Numerous cinder cones rise about 100 feet to 1,000 feet above the general level of the country in and adjacent to Doney and Black Bill Parks. Most of these cinder cones have been colored red by oxidation of the originally black cinders. Locally, parts of the cones consist of black or gray basalt ("malpais"). The northeast and east boundaries of the area consist in large part of cinder cones and cinder ridges.

The cultivated parts of Doney and Black Bill Parks are gently rolling unforested areas among the cinder cones. Doney Park is about 3 miles by 4 miles at its maximum, and Black Bill Park is about $2\frac{1}{2}$ miles by 4 miles. Alluvial fans extend eastward from the foot of the mountains to the parks, forming long smooth thinly forested slopes.

In the southern part of the area the presence at or near the surface of horizontal limestone and sandstone strata has led to development of a topography characterized by approximately parallel ridges separated by shallow swales. Walnut Canyon, a gorge cut in the limestone and sandstone beds, is the southern limit of the area.

GEOLOGY AND ITS RELATION TO GROUND WATER

The following paragraphs give in brief what is known about the various rock formations identified in Doney and Black Bill Parks with respect to their geologic age, rock types, and water-bearing properties. The rock units are discussed in order of age, the oldest being presented first.

Rock units

Sedimentary rocks

Devonian. --Sandy limestone and limy sandstone of Devonian age crop out on the east side of Elden Mountain and are the oldest rocks exposed in the area mapped. The limy sandstones grade upward into quartzitic sandstone. The aggregate thickness of Devonian strata is about 125 feet (Brady, 1934, p. 10). These rocks are not known to be water bearing in Doney and Black Bill Parks.

Carboniferous (Mississippian). --About 200 feet of the Redwall limestone of Mississippian age overlies the Devonian rocks (Gutschick, R. C., personal communication, November 1950). The Mississippian strata consist in large part of beds of coarsely crystalline limestone containing many poorly preserved marine fossils. Shaly sandstones and mudstones are locally interbedded. The Redwall limestone is not known to be water bearing in the area.

Carboniferous (Pennsylvanian) and Permian. --Rocks assigned to the Supai formation are about 750 feet thick (Brady, 1934, p. 10) on the east slopes of Elden Mountain. This formation was considered of Pennsylvanian age by Robinson (1913, p. 23). Other investigators have assigned a large part of the Supai formation to the Permian period. Current practice is to consider most of the Supai formation as Permian but to assign some of the lower strata to the Pennsylvanian.

The Supai formation consists mostly of fine-grained sandstone and siltstone. Red is the predominant color. Thin beds of the limestone also occur in the sequence.

About 12 miles west of Flagstaff a well at the Navajo Ordinance Depot obtains water from beds of the Supai formation 1,300 feet below the surface. A spring flowing a few gallons per minute emerges from beds of the Supai formation in sec. 31, T. 22 N., R. 8 E., west of the south end of Doney Park.

The Coconino sandstone overlies the Supai formation on the slopes of Elden Mountain. Brady (1934, p. 10) states that these sandstone beds are about 600 feet thick. Part of the stratigraphic thickness thought to be occupied by the Coconino sandstone at the foot of Elden Mountain is masked at the surface by an overwash of sand and soil from higher slopes. In typical exposures, as in Oak Creek Canyon 15 miles south of Flagstaff, a prominent characteristic of the formation is its large-scale cross bedding.

At various points 50 to 100 miles east of Flagstaff the Coconino sandstone is known to be a good aquifer. In the deep well at the Depot, the Coconino sandstone lies above the water table and does not yield water to the well. In Doney and Black Bill Parks its water-bearing properties have not been tested. There is an intermittent seep, which was dry when visited, in sec. 30, T. 22 N., R. 8 E., at or near the contact between the Coconino and Supai formations.

McKee (1938, pp. 12-27) proposed the name Toroweap formation for a series of beds overlying the Coconino sandstone and underlying the Kaibab limestone in Grand Canyon and elsewhere on the Colorado Plateaus. In Walnut Canyon, beds assigned to the Toroweap formation (McKee, 1938, p. 26) show large-scale cross bedding normally considered typical of the Coconino sandstone. In this report, the Toroweap formation of McKee, if present, is included with the Coconino sandstone.

The Kaibab limestone in the region of the Colorado Plateaus consists of alternating strata of limestone, sandy limestone, sandstone, and locally shaly sandstone and siltstone. In the Flagstaff area the Kaibab limestone is generally sandier than in the Grand Canyon, where the term was first applied. The deep well at the Depot penetrated 525 feet of strata assigned to the Kaibab limestone. Brady (1934, p. 10) recognized 300 feet of beds on the east side of Elden Mountain as Kaibab.

So far as is known, the Kaibab limestone is not water bearing in the area around Flagstaff. The formation is fractured in most places where exposed, and solution of the limestone and lime-cemented sandstone has created channels and sinkholes that readily conduct water downward. The Bottomless Pits in sec. 17, T. 21 N., R. 8 E., are an example of sinkhole development in thoroughly jointed Kaibab strata.

Triassic. --Red sandstone and siltstone of the Triassic Moenkopi formation are prominent on hills between Flagstaff and Doney Park. Outcrops of Moenkopi strata are present in the southern part of the area but are too small to be shown on plate 1.

According to Price, [2] the Moenkopi formation on the rim of Sycamore Canyon, about 15 miles southwest of Flagstaff, averages about 250 feet in thickness and attains a maximum thickness of 370 feet. In Doney and Black Bill Parks, exposures of the Moenkopi formation consist only of a basal conglomerate a foot or a few feet thick, or of the conglomerate and less than 10 feet of overlying sandstone and siltstone. No wells or springs in Doney and Black Bill Parks are known to derive water from the Moenkopi formation.

Quaternary. --Quaternary deposits, mostly of sedimentary origin, occur in both parks--in Doney Park in thicknesses up to about 300 feet. The logs of test bores on the Raymond A. Smith farm in sec. 33, T. 22 N., R. 8 E. (see well logs, pp. 10-11), show 285 to 293 feet of sand, gravel, clay, and tuff from the land surface to the top of the Kaibab limestone. It is not known whether the tuff penetrated in drilling the Smith prospect was dust deposited directly from the air, or whether it settled into water and was deposited as a series of water-laid beds.

The presence of temporary lakes in Quaternary time is indicated in at least two places in the region. Valley fill materials exposed in a gully near the Bottomless Pits in sec. 17, T. 21 N., R. 8 E., contain ripple-marked sands and silts and cross-bedded strata overlying the Kaibab limestone. The appearance of the sand and silt suggests deposition in a shallow body of water.

The presence in Recent time of a temporary lake in the Walnut Creek valley north of U. S. Highway 66 near Winona, 13 miles east of Flagstaff and east of the area mapped, has been reported (Colton, 1929, pp. 93-94). In that locality, Colton found shells of species of mollusks known to inhabit freshwater ponds and lakes.

An area west of Bonito Park at the north boundary of Black Bill Park is underlain by sand and gravel deposited by meltwater from glaciers that existed in Pleistocene time in the Interior Valley of the San Francisco Mountains (Sharp, 1942, pp. 488-489). The thickness of these deposits ranges from about 30 feet to 100 or 150 feet at places where

[2] Price, W. E., Jr., 1948, Rim rocks of Sycamore Canyon, Ariz., p. 37. [Unpublished Master of Science thesis in files of Univ. of Arizona Library.]

geophysical probes were run. The beds, where exposed in gravel pits, dip a few degrees to about 10° east toward Bonito Park. The water-bearing properties of the deposits have not been tested.

The Farrell well in the SW$\frac{1}{4}$ sec. 26, T. 22 N., R. 8 E., yields a small amount of water at a depth of about 30 feet from Quaternary valley-fill materials overlying volcanic rock. The water-bearing properties of the Quaternary deposits otherwise are not definitely known in the area of the two parks.

Igneous rocks

Basaltic flows and basaltic cinders are the predominant rocks in the area and are thought to belong to what Robinson (1913, pp. 87-90) has called the Third Period of eruption. The volcanic activity of the third period took place mostly, or entirely, in Pleistocene and Recent time. Rocks of almost identical composition and appearance were extruded during what Robinson called the First Period of eruption. First Period basalts have not been recognized in the two parks and are thought to be covered by younger lavas and sediments.

The rocks comprising Elden Mountain, Little Elden Mountain, and the foothills of the San Francisco Mountains have been assigned by Robinson (1913, pp. 41-42, 70, 77, 78) to an intermediate stage (the Second Period) of volcanic activity that occurred probably in Pliocene time.

The eruption of Sunset Crater near the northeast corner of the parks (pl. 1) is the most recent event in the volcanic history of the area. This eruption is considered by Colton (1945, p. 7) to have occurred between 1046 and 1071 A. D. Cinders falling from that eruption covered a large part of the Doney and Black Bill Parks and adjacent areas.

The only areas of intrusive igneous rock observed, other than those forming parts of Elden Mountain and the San Francisco Mountains, were the volcanic neck of O'Neill Crater in sec. 29, T. 22 N., R. 9 E., and a small ring dike or plug in the NE$\frac{1}{4}$ sec. 21, T. 21 N., R. 8 E.

Many springs in the Flagstaff area issue from basalt, and seeps at the bases of cinder cones are found west of Flagstaff. In Doney and Black Bill Parks, Little Elden Spring emerges from the dacite of Little Elden Mountain. Basalt flows are thought to form a partial barrier to the downward percolation of water thus creating perched water bodies in places, such as the one that supplies water to the Farrell well in sec. 26, T. 22 N., R. 8 E.

Laboratory tests of a sample of Recent cinder deposits obtained at a depth of about 25 feet below the surface in an auger hole on the Crisp farm, sec. 29, T. 22 N., R. 9 E., show that 44 percent of the volume of the sample consists of pore spaces. The water drained by gravity occupies 23 percent of the volume of the sample, and the water retained by capillary attraction, 21 percent. It is common experience in the two parks to find that, at depths of a few inches to a few feet below the surface, the Recent cinder deposits are wet and seem to be nearly saturated. However, holes drilled to depths of 20 or 30 feet in cinders have, so far as known, failed to yield water.

Structure

In general, sedimentary rocks exposed in the area shown on the geologic map (pl. 1) dip at angles of less than 10°. In many places the Kaibab limestone is horizontal. The glacial outwash gravels dip from 5° to 10° E. The dip of the outwash gravels is considered to be initial, for it is probably the result of deposition on a sloping surface and not indicative of structural deformation after deposition.

The principal area of steep dips in sedimentary rocks is that of the Paleozoic strata on Elden Mountain, where the dip is from 30° to 50° E. This area lies mainly in secs. 30 and 31, T. 22 N., R. 8 E. Robinson (1913, pp. 70-78) interprets the structure of Elden Mountain as that of a laccolith. By this explanation, the dacite that comprises the core of Elden Mountain was forced toward the surface as a mass sufficiently viscous as to drag upward Paleozoic strata more than 2,000 feet thick. The Paleozoic strata exposed on the flanks of Elden Mountain are the remnants of the original mass of rock dragged toward the surface. In the hills at the east base of Elden Mountain the Kaibab limestone dips about 50° SE. Two miles southeast of the hills, in the NS$\frac{1}{4}$ sec. 33, T. 22 N., R. 8 E., a test well on the Smith farm penetrated the Kaibab limestone at a depth of about 300 feet. In an outcrop about 1 mile farther southeast the limestone dips about 4° N. Horizontal strata of the Kaibab limestone crop out in the canyon of Rio de Flag 5 miles east of Elden Mountain. It is obvious that the steep dip observed in the hills does not continue southeastward. Therefore, it is assumed that a fault or a sharp fold exists between the base of Elden Mountain and the Smith farm. No other major structural deformation of the rocks in Doney and Black Bill Parks has been demonstrated in the present investigation.

Minor drag of the Kaibab limestone occurred adjacent to the dike or plug in the NE$\frac{1}{4}$ sec. 21, T. 21 N., R. 8 E. It is probable that comparable drag occurred during intrusion of other small bodies of igneous rock at the cores of cinder cones in the area.

Sets of joints in Kaibab strata have been observed at many places in the area. The jointing is especially well displayed at the Bottomless Pits in sec. 17, T. 21 N., R. 8 E. The more prominent set of joints at Bottomless Pits strikes northeast and dips about 70° SE. Sinkholes have developed there along three of these joints. The other set of joints strikes northwest and is approximately vertical.

At Little Elden Spring, sec. 19, T. 22 N., R. 8 E., joints strike N. 40° E., dipping 75° SE.; and N. 70° W., dipping 70° SW. The joints are believed to provide channels through which water moves to the spring.

OCCURRENCE OF WATER

Surface water

Doney and Black Bill Parks are in the drainage basin of Rio de Flag. Most of the moisture that falls as rain or snow is evaporated or absorbed by the soil. Runoff from the parks occurs only during times of abnormal precipitation. Small stream channels cross the parks from mountain canyons toward Rio de Flag. These channels disappear either in grass-covered meadows or at the edges of cultivated fields.

A few earth tanks have been constructed to catch and store local surface runoff. The largest of these tanks is in Schultz Pass; it is the principal source of water for the Doney Park Water Co. From the pass, the pipeline extends to a small concrete-lined reservoir in Doney Park. From the reservoir, water is distributed to the homes of members of the water company. In some years there is no water in the system, and in many years the supply is insufficient to provide adequate pressure in the water lines. Other earth tanks are used for stock watering.

Ground water

Springs

The occurrence of springs in Doney and Black Bill Parks was previously described under "Rock units." Yields of all springs observed were small, ranging from a trickle to a few gallons per minute. Two springs emerge from Paleozoic sedimentary rocks on the east slope of Elden Mountain. Other springs issue from volcanic rocks at the contact with relatively impermeable underlying materials. A few small seeps in Bonito Park emerge from soil, probably near the contact of glacial outwash gravels with underlying lava.

Wells

Colton (1932, pl. 10) published a map showing seven wells in Doney and Black Bill Parks. He commented (1918, pp. 42-44) that, although three wells in the area were known to contain water part of each year, only one provided water for more than a few months of each year. The most successful well reported by Colton is the only well presently in use in the two parks. This well was dug on the Farrell farm in the SW$\frac{1}{4}$ sec. 26, T. 22 N., R. 8 E., and is 50 feet deep. It provides sufficient water for domestic use even in years of average precipitation, and the yield is increased when runoff occurs in Rio de Flag.

At one time there were two wells on the Richardson ranch in Bonito Park (see well logs, pp. 10-11) in the NE$\frac{1}{4}$ sec. 20, T. 23 N., R. 8 E. According to oral information one well was dug originally to a depth of 30 feet. At that depth, the well yielded water at least part of the year. Later the well was deepened to 60 feet and all water was lost. The second well was drilled to a total depth of 42 feet. It is reported that when the well was drilled the water level was 32 feet beneath the surface. The well was never utilized because it became partly filled with trash, and a pump was not installed.

Colton's map (1932, pl. 10) shows two wells, each 80 feet deep, one in sec. 27, T. 22 N., R. 8 E., the other in sec. 3, T. 21 N., R. 8 E. He reports these wells to have held water during part of the year. No other details are available about these wells. It is probable, however, that the well in sec. 27, T. 22 N., R. 8 E., is the one commonly referred to as the Butler well by present residents of Doney Park. It is reported that the Butler well supplied the needs of several families for a number of years, but an attempt to increase the yield by dynamiting destroyed its usefulness. No effort was made to reopen the well.

The well now known as the Piper well may be the same as that shown by Colton in sec. 3, T. 21 N., R. 8 E. Some years ago, while the property was leased to tenants, the well was partly filled with scrap iron and other debris. To date, no attempt has been made to redeem the well.

Colton's map shows dry holes ranging in depth from 40 to 70 feet in secs. 23, 26, and 35, T. 22 N., R. 8 E. Only one of these, the hole in sec. 23, could be found during the present investigation. When visited, the hole seemed to have been partly filled, and it contained no water.

A hole dug through 12 feet of cinders to an underlying clay layer is in the NE$\frac{1}{4}$ sec. 28, T. 22 N., R. 8 E. The well is curbed with concrete and roofed with wood. The owner reported that at times water in considerable quantity seeped into the hole through the cinders. At some time in the past, during a period in which the well was dry, it was partly filled with cinders slumping from the walls and was therefore abandoned.

On the Crisp Ranch, sec. 28, T. 22 N., R. 9 E., there is evidence of the existence of a truly ancient well. A round depression about 4 feet deep and 40 feet in diameter having a distinct surrounding ridge and containing a heavy concentration of fragments of Indian pottery was first recognized by S. F. Turner as a partly obliterated Indian "walk-in" well. (See fig. 1.) This was later confirmed by archeologists from the Museum of Northern Arizona. Mr. Crisp dug a shaft 32 feet deep at the center of the depression, uncovering Indian artifacts in the upper 10 feet of cinder and clay fill. From 10 feet to 28 feet the shaft (see well logs) penetrated cinders tightly held in a matrix of ice. Below the 18 feet of ice the cinders were loose and wet but not saturated to the point of yielding water. The bottom of the shaft was on basalt boulders.

An attempt was made to deepen the hole with cable-tool drilling equipment. A few additional feet were drilled with cable tools and the driller reported a small amount of water. It was not possible with the available equipment to go farther at that site, and a new hole was started from the surface not far from the collar of the dug shaft. At time of this writing the outcome of drilling the new hole was not known.

GEOPHYSICAL INVESTIGATIONS

By C. B. Yost, Jr.

To determine the thickness and lithology of the various subsurface materials in Doney and Black Bill Parks, 13 electrical-resistivity probes were made in 4 areas. The locations of the probes (pl. 1) were determined after completion of the geologic mapping. Probe sites were selected in areas where the surface geology suggested the possibility that subsurface structures or cinder-clay relations might retard downward percolation of water, or at places where information was desired regarding thickness of weakly consolidated materials overlying bedrock.

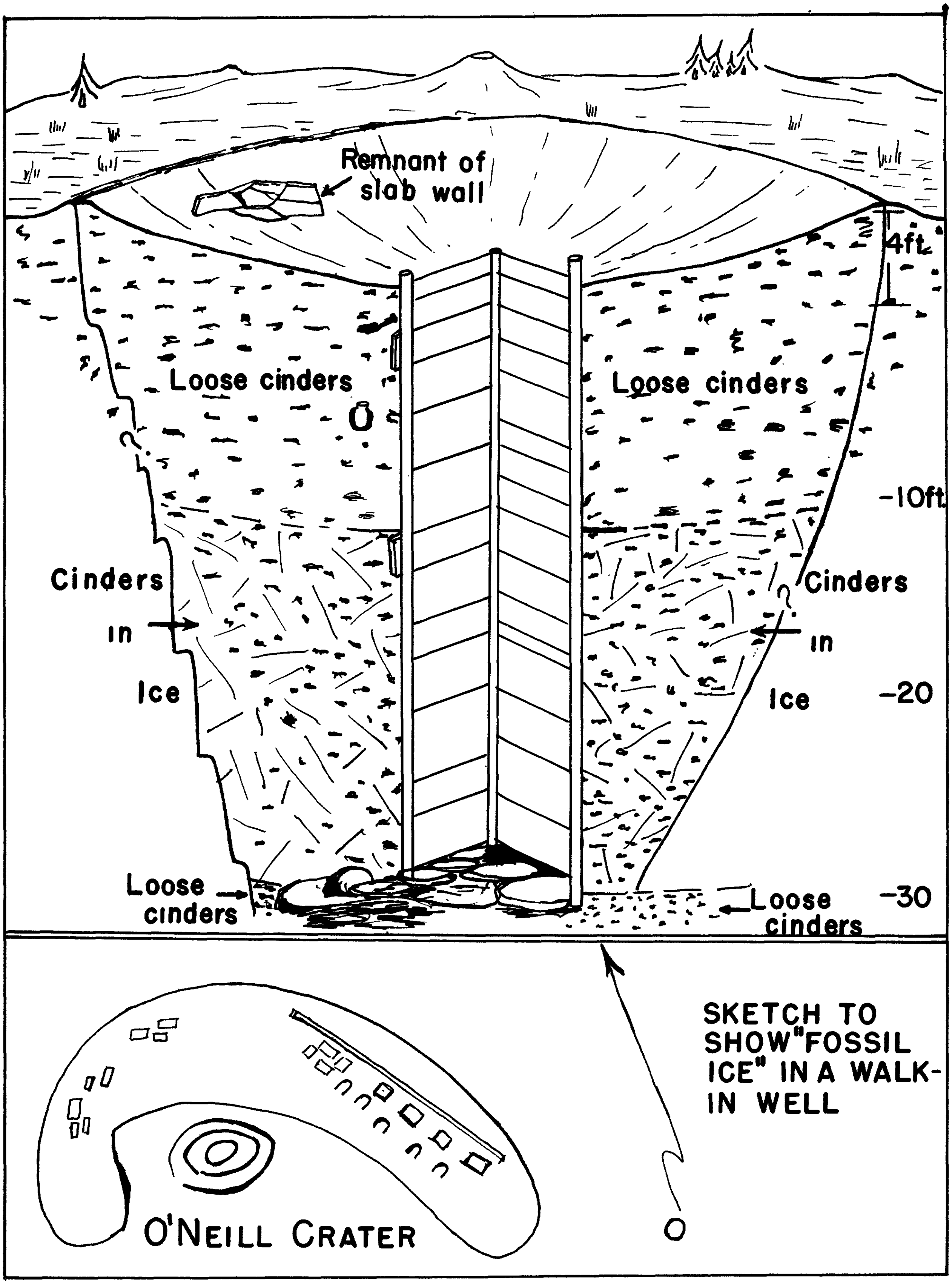

Figure 1.--Sketch showing "fossil ice" in Indian "walk-in" well on Crisp Ranch.

The field work was done from June 13 to 19, 1951. Assistance in placing the electrodes was given by several residents of the area. A modified Gish-Rooney electrical-resistivity apparatus was used. Interpretation of the graphs that resulted from the 13 probes was made by comparing the graphs with theoretical three-layer curves (Wetzel and McMurray, 1937) in the light of knowledge of the geology of the area. In general, for equivalent moisture content, fine-grained materials, such as clay or silt, have a low resistivity; coarser materials, such as gravel, have a higher resistivity; and igneous rocks commonly have a high to very high resistivity. The following discussion describes the investigations and presents an interpretation of results for each of the four areas where work was done.

Doney Park area

Alluvium underlies most of the central part of this irregular topographic basin. The small bordering hills are composed mostly of volcanic cinders and basalt.

Probes were made at five points along a $3\frac{1}{2}$-mile traverse through the central part of the park area. Probe 1 (pl. 1) was on the Smith farm in sec. 33, T. 22 N., R. 8 E., near the site of a drilled hole 410 feet deep. From probe 1 the traverse extended northeast through probe 2 to probe 13, then trended north through probe 4 to probe 3, in sec. 23, T. 22 N., R. 8 E. To avoid side effects, all probes were located as far as practicable from cinder-basalt outcrops.

The maximum stake separation for the five probes ranged from 600 to 3,000 feet, depending upon the depth to which information was desired and upon the space available for extending the two outer electrodes in a straight line without electrical or physical interference.

Interpretation of the graphs of measured resistivity indicates that the area in the vicinity of the traverse is underlain by several layers of material of differing resistivities. The uppermost layer, consisting of alluvium, is of low to medium resistivity and ranges from 20 feet to 200 feet in thickness. The next layer is of high to very high resistivity and is 100 to more than 400 feet thick. The third layer is of low to medium resistivity (pl. 1). Correlation of probe 1 with the log of the 410-foot test hole nearby (pl. 1) shows that at the site of probe 1 the three resistivity layers correspond respectively with alluvium, tuff, and Kaibab limestone.

All the probes indicate that the alluvium is underlain by a second layer consisting of various combinations of tuff, basalt, and cinders.

Probes 1, 2, and 3 are fairly definite in indicating the presence and depth of the third layer of low to medium resistivity.

The probes at sites 13 and 4 showed, at a depth of less than 50 feet, a second layer of material so highly resistive that the current density within it was too low to allow measurement of surface potential differences, and it was therefore impossible to define the lower limit of this layer. It is certain to be at some depth greater than 100 feet. The low to medium resistivity of the third layer is of the magnitude that would be expected for Paleozoic sedimentary rocks or more recent alluvial material. At probe 1 this resistivity layer is known to correspond to the Kaibab limestone.

The resistivity cross section, plate 1, shows material of high to very high resistivity forming an apparent trough with its deepest determined part near probe 2. The profile of the upper surface of the layer of high resistivity between probe 13 and probe 3 rises to a peak near the site of probe 4. It is probable that this peak reflects a shallow subsurface connection between outcrops of igneous rocks east and west of probe 4. (See pl. 1.)

The trough indicated by the resistivity cross section (pl. 1) may be part of a subsurface basin. The basin may, or may not, be sealed at the bottom by material of low permeability. If such a basin exists and is sealed at the bottom, a test hole may reasonably be expected to yield water, at least in small quantities, at a depth of not more than 350 feet. The record of the Farrell well, 1,000 feet southeast of probe 2, indicates that the basin may be at least partially sealed. The well has water at a depth of about 25 feet below the surface, and the water level rises when runoff is carried in Rio de Flag.

Crisp farm

The Crisp farm, sec. 29, T. 21 N., R. 9 E., is in a topographic basin having an area of about 1 square mile. The basin is underlain by cinders and the surrounding hills are composed of cinders and basalt. Two auger holes, bored through the surface cinders, penetrated clay at depths of 22 and 32 feet. Neither hole was deep enough to disclose the thickness of the clay or the identity of the underlying material.

Probes 5 to 9, inclusive (pl. 1), were made on the Crisp farm. Graphs of the probes show a surface layer of medium resistivity, 5 to 20 feet thick. The layer is interpreted as being composed of cinders and alluvium. A second layer of very high resistivity, 10 to 70 feet thick, is interpreted as volcanic cinders. Beneath this is a third layer, of medium resistivity, which could be an older less resistive type of volcanic material or sedimentary rock.

The five probes do not indicate conclusively the presence or absence of an extensive clay layer that might retard downward movement of ground water. The fact that no clay layer was indicated may be due to one or more of the following conditions: The layer is so thin that it has little effect on the flow of electricity; the layer is of limited areal extent; the more resistant overlying layer masks the effect of the clay layer.

According to probes 6 and 8, which were run near the two auger holes, the clay that was penetrated is near the contact between the second and third resistivity layers. Direct delineation of a clay layer does not seem possible with electrical-resistivity methods in this locality. However, if it were determined by drilling that clay occurs everywhere at the top of the third layer, it might be possible to obtain indirect information about the clay by using resistivity methods to trace the position of the third layer.

In the vicinity of probes 8 and 9 the top of the third layer is 10 to 20 feet below the surface; southward, in the vicinity of probes 5, 6, and 7, the depth is 50 to 85 feet.

Although additional resistivity probing in coordination with exploratory drilling might yield information of value, it is probable that augering or drilling would be quicker and would yield more positive results than would resistivity methods. Deeper exploratory drilling would establish the character of the third layer. If the material in this layer is less permeable than that in the overlying layers, or if it is permeable but everywhere separated from the second layer by clay, perched ground water may be present.

Glacial-outwash area

Probes 10 and 11 (pl. 1) were made in the area of glacial outwash gravel in the western part of T. 23 N., R. 8 E.

Both probes show an upper layer of medium to high resistivity which represents the surface gravel. Below this is a second layer of moderately low resistivity interpreted as gravel having a higher proportion of sand and silt. The third layer is highly resistant and probably is volcanic rock. At probe 10, near a gravel pit, the surface of the highly resistant third layer is at a depth of approximately 100 to 150 feet. At probe 11, farther from the mountain front, the top of the highly resistant layer is about 30 to 36 feet below the surface. The probes indicate that the gravel is thicker near the mountain front.

Schultz Pass area

A single probe, no. 12 (pl. 1), was made in the NE¼ sec. 24, T. 22 N., R. 7 E., to determine the thickness of alluvium overlying bedrock. The probe shows a layer of medium resistivity from the bottom of the soil to a depth of 150 to 200 feet. This layer probably corresponds to a mixture of gravel and fine-grained material because the resistivity of the layer is intermediate between that generally found for either material occurring alone.

Below the layer of medium resistivity a layer of medium-high resistivity was found. This layer extends at least to 600 feet, the total depth of the probe. Although the resistivity seems too low for solid igneous material, it could be igneous rock in which fractures or other openings contain moisture.

CONCLUSIONS AND RECOMMENDATIONS

The geologic and geophysical investigation in the Doney Park-Black Bill Park area, supplemented by information obtained in the investigation of other areas near Flagstaff, suggests the following conclusions regarding the occurrence of ground water in the two parks:

1. The supply of ground water that can be developed at depths of a few feet to a few hundred feet is small.
2. There are various localities where ground water has been available to residents of the area, including several springs and six wells, five of which have been abandoned.
3. Ground water at relatively shallow depths occurs only in those formations overlying the Kaibab limestone, at places where impermeable layers retard the downward movement of water. A possible exception exists in an area at the base of Elden Mountain. There it is possible that a fault or fold may retard downward movement of water and thus make water available at depths of a few hundred feet in strata underlying the Kaibab limestone. Elsewhere, water moves readily downward through the limestone and the underlying Coconino sandstone.
4. The places where ground water is stored in beds overlying the Kaibab limestone seem to be few.
5. Ground water is probably available in Recent cinder deposits at several places in Doney and Black Bill Parks, during at least part of each year of average precipitation. Development will depend on finding underlying clay layers or other local impervious bodies that will trap small supplies of water.
6. Recharge to local bodies of perched water depends largely upon direct precipitation. This recharge is supplemented by runoff in Rio de Flag and from the canyons on the east slopes of the San Francisco Mountains.
7. An area of glacial outwash at the mouth of a major canyon at the north end of Black Bill Park presumably conducts water from the San Francisco Mountains toward Bonito Park.

In light of these conclusions, the following possible courses of action are suggested for developing ground water in the area.

Spring development

Little Elden Spring, sec. 19, T. 22 N., R. 8 E., might be developed by means of a shaft extended below the present point of emergence of the spring. Crosscutting from the base of the shaft might develop additional water. No other springs in the area investigated seem to warrant extensive development.

Well development

The dug well in sec. 13, T. 22 N., R. 7 E., adjacent to the pipe line of the Doney Park Water Co. in Schultz Pass, could be cleaned out and equipped to siphon or pump water into the pipe line.

Geophysical exploration in the Schultz Pass area indicates the presence of 150 to 200 feet of talus and alluvial material in the reentrant valley north of Little Elden Mountain. This area appears to warrant experimental drilling to bedrock.

An area in the SE¼ sec. 30, T. 22 N., R. 8 E., lies between Elden Mountain and a line of foothills of the Kaibab limestone. Beds of the Supai formation are exposed on the slopes of Elden Mountain adjacent to this area. Beds in both the Supai formation and the Kaibab limestone in that locality dip steeply southeast.

A major structure may be concealed by fanglomerate east of the foothills. Beds of the Coconino sandstone presumably underlie the area between the foothills and the strata of the Supai formation on Elden Mountain. The writer believes that exploratory drilling to a depth of several hundred feet in the pocket lying between the foothills and the base of Elden Mountain would be warranted. A seep in the SE$\frac{1}{4}$ sec. 30, T. 22 N., R. 8 E., indicated the presence of ground water in the area.

The area of glacial outwash at the north end of Black Bill Park is considered worthy of exploratory drilling to bedrock. At probe 10 a thickness of 100 to 150 feet of gravel and sand was indicated. Of the two places at which probes were made, the more favorable site for test drilling seems to be that in the vicinity of probe 10.

The area in the vicinity of probe 2 seems to be underlain by a basin that may contain ground water. This conclusion is based on an interpretation discussed in the section on geophysics. It is possible that a well drilled to a depth of 250 to 350 feet in the area might develop a supply of water sufficient for one or more families. Previous test holes were only 70 to 80 feet deep and were unsuccessful.

The history of wells along Rio de Flag, notably those presently referred to as the Farrell well, the Butler well, and Piper well, suggests that properly constructed wells in alluvium adjacent to the channel of Rio de Flag would provide water during at least a part of each year. Care is essential in order to prevent (1) sealing off the aquifer during construction or (2) piercing the impermeable underlying layer.

Basalt is exposed in the stream bed of Rio de Flag in sec. 34, T. 22 N., R. 8 E. The presence of dense vegetation suggests that a permanent supply of water may be present. A test well near the trees seems warranted.

Further exploration in the vicinity of the ancient Indian walk-in well on the Crisp farm seems justified.

The presence of groves of walnut trees in the two parks suggested to S. F. Turner (oral communication, 1951) the possibility that ground water is present at depths within reach of the tree roots. It is possible, therefore, that digging in the immediate vicinity of the walnut groves would develop small water supplies. However, the high water-retaining capacity of the cinders may create a unique condition in which the walnut trees extract their supply from capillary water retained in the cinders. Under these conditions, the presence of walnut trees would not necessarily indicate the existence of a water table within reach of the tree roots.

Infiltration galleries in cinder hills

The cinder hills in Doney and Black Bill Parks may offer a source of domestic water. Cinders from the eruption of Sunset Crater were deposited over the entire area considered in this report. Subsequent wind action has created dunes of black cinders derived from the Recent deposits on the windward side of older reddish cinder hills.

In places near Flagstaff, layers of clay soil, or of partly decomposed cinders in a clay matrix, have been observed at or near the surface in the older reddish cinders. If dunes of black cinders overlie depressions on the surface of the older cinders, and if the older deposits are sufficiently clayey, small amounts of water may occur near the bases of the black cinder dunes that occupy such depressions. Exploration of favorable cinder-dune localities by digging tunnels may develop small perched water supplies.

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Logs of wells in Doney Park-Black Bill Park area, Coconino County, Ariz.

	Thickness (feet)	Depth (feet)
Farrell well (dug). M. F. Farrell, owner. Sec. 26, T. 22 N., R. 8 E.		
Soil, some clay and cinders	22	22
Clay, gravelly	28	50
Bore on Lander Ranch (drilled). A. E. Lander, owner and driller. Sec. 33, T. 22 N., R. 8 E.		
Soil, cindery	5	5
Cinders, black	75	80
Lava, black, very hard ("drilled up like flour of emery")	15	95
Hole lost water all the way; hit crevice at 95 feet		
Smith Ranch well 1 (drilled). R. A. Smith, owner and driller. Sec. 33, T. 22 N., R. 8 E.		
Soil, loose rock, and a little clay	29	29
Boulder	5	34
Soil and loose rock	84	118
Sandstone, red	23	141
Soil and loose rock	56	197
Soft tuff or lava; a small strip of coarse gravel at 217 feet	96	293
Kaibab limestone	117	410
Smith Ranch well 2 (drilled). R. A. Smith, owner and driller. Sec. 33, T. 22 N., R. 8 E. (100 feet northwest of well 1)		
Missing	15	15
Soil, dark yellowish-brown	5	20
Clay and fine sand, light-tan	10	30
Sand, light reddish-brown, fine- to medium-grained, mostly quartz	5	35
Sand and pebbles of red cinders	5	40
Sand, light reddish-brown, medium-grained; a few pebbles of purple and gray volcanic rock and white chert	10	50
Sand, darker-brown	10	60
Clay, pink, and chert pebbles	10	70
Sand, brown, coarse; some pebbles	5	75
Sand, brown, fine-grained	5	80
Sand and clay, light-tan	15	95
Sand and silt, brown to light reddish-brown; coarser at top and bottom	50	145
As above but coarser-grained; pebbles common in lower 10 feet	40	185
Sand, silt, and granules, probably largely tuffaceous, light grayish-brown; woody fragments and one small twig in samples between 225 and 260 feet	85	270
Silt, light yellowish-tan, very limy	15	285
Kaibab limestone, tan, silty	8	293
Shaft at Indian "walk-in" well (dug). U. S. Forest Service, owner. U. S. Crisp, lessee. Sec. 28, T. 22 N., R. 9 E.		
Cinders, black	1	1
Clay, few to no cinders	9	10
Cinders, black, tightly frozen in ice matrix	18	28
Cinders, black, loose, very wet	1	29
Soil	1	30
Boulders, black lava	2	32

	Thickness (feet)	Depth (feet)
Richardson Homestead well (dug). S. I. Richardson, owner. Sec. 20, T. 23 N., R. 8 E.		
Cinders	3	3
Coarse sand and gravel	57	60

Note: Reported that well was used for a time at depth of 30 feet, then deepened to increase yield. All water was lost during deepening and none was recovered.