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UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Water Resources Division

TEST DRILLING FOR WATER IN CRYSTALLINE BEDROCK

PLEASANT VALLEY AREA

JOSHUA TREE NATIONAL MONUMENT

CALIFORNIA

Prepared in cooperation with the
National Park Service

ADMINISTRATIVE REPORT
For U.S. Government use only

Menlo Park, California
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TEST DRILLING FOR WATER IN CRYSTALLINE BEDROCK, PLEASANT VALLEY AREA JOSHUA TREE NATIONAL MONUMENT, CALIFORNIA

By G. A. Miller

ABSTRACT

A test well 1,004 feet deep drilled in a fault zone in Pleasant Valley, Joshua Tree National Monument, Calif., penetrated, from top to bottom, about 10 feet of sandy and gravelly alluvium of Holocene age, 250 feet of clayey, silty, carbonate-bearing lacustrine deposits of Pleistocene age, 380 feet of highly fractured gneissic bedrock, and 364 feet of moderately fractured to massive gneissic bedrock. The most permeable zones in the bedrock are above the water table and were dry. After completion the static water level was approximately 827 feet below land surface. The borehole was cased with 1¼-inch diameter pipe and was pumped by use of an airlift at a rate of about 0.25 gallon per minute. This pumping rate probably is only a fraction of the potential yield because the small diameter casing did not allow full development of the well. The quality of water probably is suitable for most local uses. Several other sites in the monument, including sites near Old Dale Junction, Lost Horse Valley, and Covington Flat are in faulted areas and are worthy of further exploration for small supplies of fresh water in fractured bedrock.

INTRODUCTION

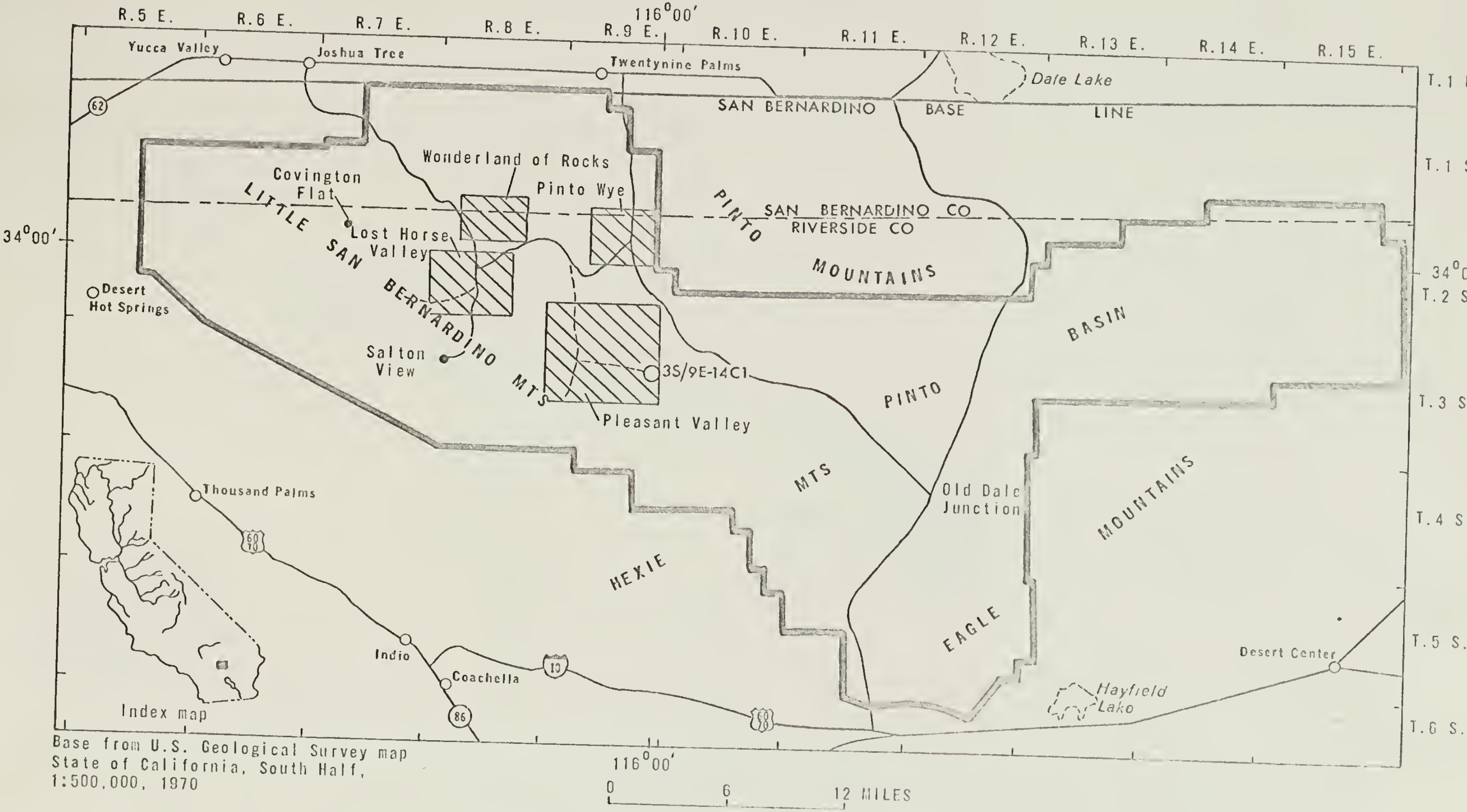
Purpose and Scope

During 1968-69 the U.S. Geological Survey, at the request of the U.S. National Park Service, investigated the water-bearing characteristics of fractured crystalline bedrock in the water-deficient western part of Joshua Tree National Monument.

The scope of the work included (1) the selection by use of geologic, photogeologic, and geophysical methods of a test-drilling site in intensely and deeply fractured, and thus permeable, bedrock; (2) general supervision of the drilling; and (3) evaluation of the results.

Location

Pleasant Valley is in the west-central part of Joshua Tree National Monument, Riverside County, Calif. (fig. 1). The area is shown on the Geological Survey's Lost Horse Mountain 15-minute quadrangle. The test-well site is about 16 airline miles south of the town of Twentynine Palms, in the NW¼ sec. 14, T. 3 S., R. 9 E., San Bernardino base line and meridian, at an altitude of about 3,190 feet above mean sea level (fig. 2). Access to the site is by 5.5 miles of semi-improved dirt road from the paved road in Queen Valley (not shown), and then by 3.8 miles of sandy, partly improved road across the north edge of Pleasant Valley (fig. 2). The area is in the higher part of the Mojave Desert region. The average annual precipitation at the site probably does not exceed 5 inches.



Base from U.S. Geological Survey map
State of California, South Half,
1:500,000, 1970

FIGURE 1.--Joshua Tree National Monument showing location of test well and location of areas studied.

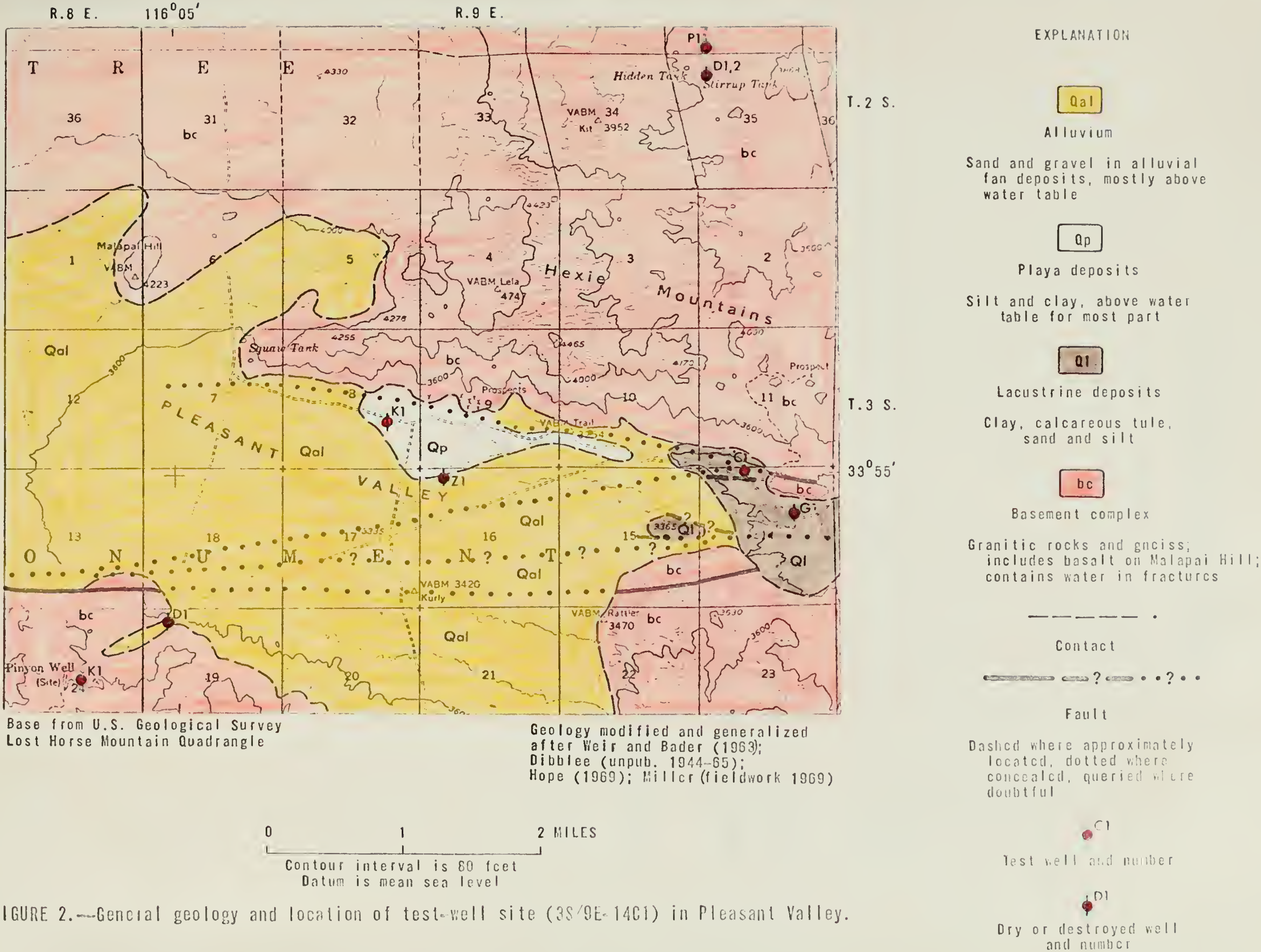


FIGURE 2.—General geology and location of test-well site (3S/9E-14C1) in Pleasant Valley.

Previous Work and Acknowledgments

The geology of the project area was included in a larger area mapped by Dibblee (1967, 1968), Hope (1969), and Rogers (1961). Additional unpublished geological mapping was done by T. W. Dibblee, Jr., (1944-65) and T. H. Rogers (1963-64). As part of a general study of ground water and related geology of the entire monument, Weir and Bader (1963, p. 51-52) studied the ground-water geology and hydrology in the Pleasant Valley area. Miller (1968) reported on test drilling and pumping tests in the area.

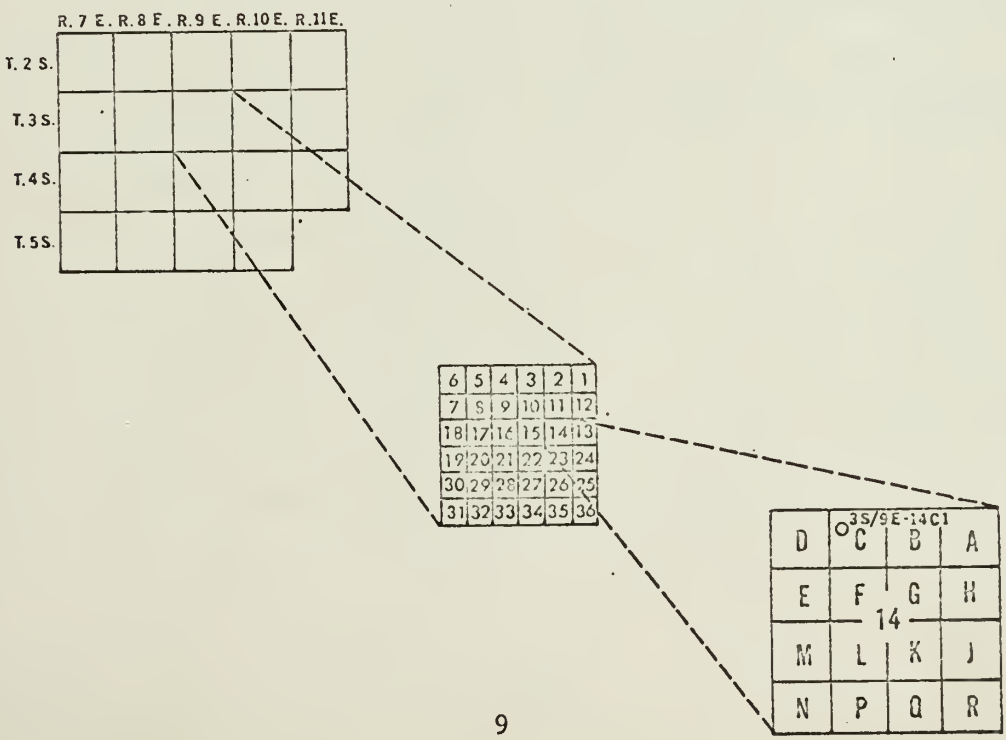
The author wishes to thank Mr. W. R. Supernaugh, superintendent of Joshua Tree National Monument at the time of the study, and his staff for their cooperation and assistance during the work.

The work was done under the general direction of L. R. Peterson, district chief in charge of water-resources investigations in California, and the immediate direction of R. E. Miller, successive chiefs of the Garden Grove subdistrict.

Well-Numbering System

Water wells in California are numbered according to their location in the rectangular system of townships and ranges for subdivision of public land. That part of the number preceding the slash (as in 3S/9E-14C1) indicates the township (T. 3 S.); the number following the slash indicates the range (R. 9 E.); the number following the hyphen indicates the section (sec. 14); the letter following the section number indicates the 40-acre subdivision of the section according to the lettered diagram below. The final digit is a serial number for wells in each 40-acre subdivision. The area covered by this report lies entirely in the southeast quadrant of the San Bernardino base line and meridian.

The letter Z, substituted for the letter designating the 40-acre tract, indicates the well was plotted from unverified descriptions; the described locations of such wells were visited, but no evidence of a well could be found.



SELECTION OF DRILLING SITE

Preliminary Site Selection

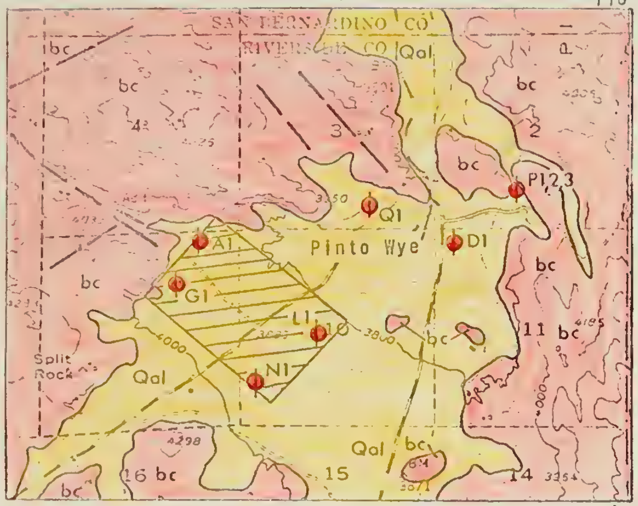
The selection of a drilling site was aimed at locating an area of deeply fractured and thus permeable bedrock where (1) the estimated depth to water was less than 1,000 feet and (2) the site was easily accessible to drilling equipment. Preliminary study of geologic maps and aerial photographs suggested four areas suitable for more detailed investigation. These areas, shown in figures 1-3, are:

1. An alluvial slope southwest of the road intersection known as Pinto Wye, including the eastern part of sec. 9 and the western part of sec. 10, T. 2 S., R. 9 E. The traces of several prominent fractures in bedrock nearby project into this area.

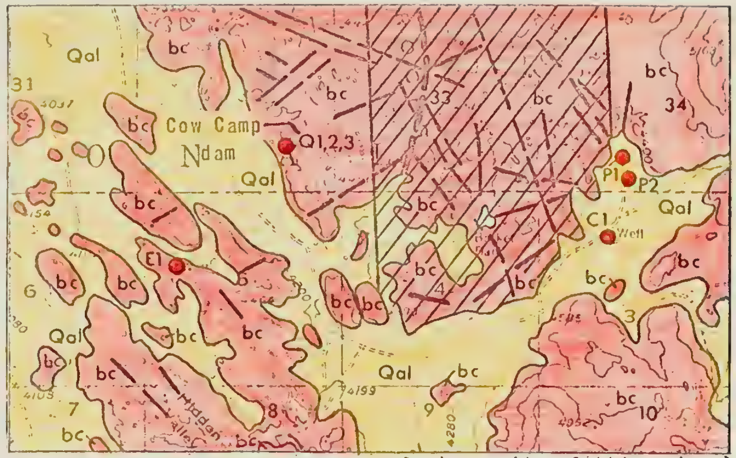
2. The southern part of the Wonderland of Rocks, including parts of secs. 3 and 4, T. 2 S., R. 8 E., and parts of secs. 33 and 34, T. 1 S., R. 8 E. Prominent fractures in the bedrock occur here.

3. The southern part of Lost Horse Valley, including the eastern part of sec. 30, T. 2 S., R. 8 E., and the western part of sec. 29, T. 2 S., R. 8 E. A concealed fault (Weir and Bader, 1963) trends northward across an alluvial slope in this area.

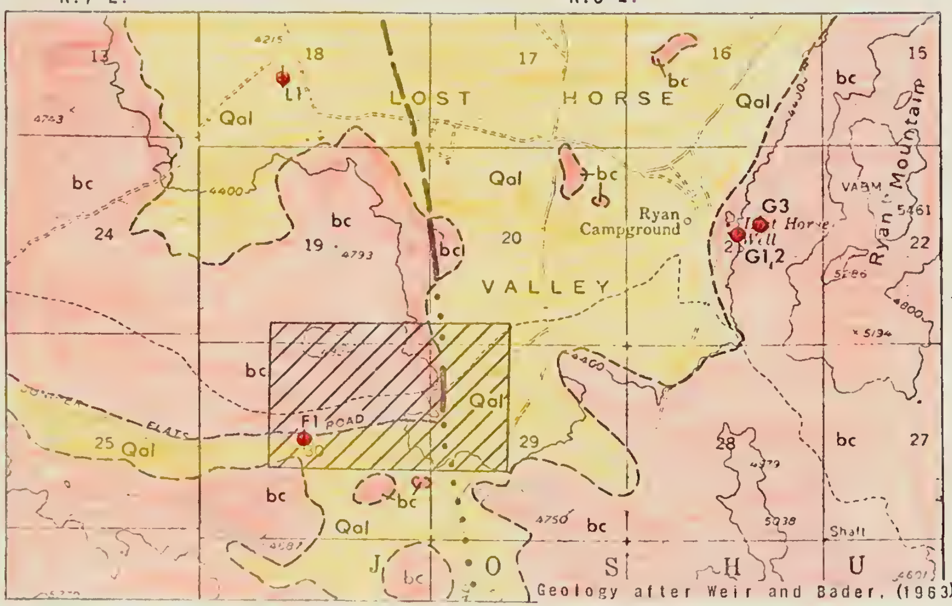
4. The Pleasant Valley area, near Squaw Tank, in sec. 7, T. 3 S., R. 9 E., and the east end of the valley in secs. 14 and 15, T. 3 S., R. 9 E. A prominent fault trends about N. 80° W. across the north side of Pleasant Valley. This fault is part of an extensive east-west fault zone (Hope, 1969) that can be traced for about 50 miles.



Area 1. Southwest of Pinto Wye
(part of Twentynine Palms quadrangle)



Area 2. Wonderland of Rocks
(part of Twentynine Palms quadrangle)



Area 3. Southern part of Lost Horse Valley
(part of Lost Horse Mountain quadrangle)

EXPLANATION

See figure 2 for explanation of rock types

Contact

Dashed where approximately located

Fault

Dashed where approximately located, dotted where concealed

Fractures or joints

Area of detailed investigation

C1 Well and number

Q1 Dry or destroyed well and number

0 1 2 Miles

Contour interval is 40 and 80 feet
Datum is mean sea level

FIGURE 3.—Three areas investigated as possible test-well sites.

Detailed Site Examination

Geologic and hydrologic features of the four areas were examined in more detail in the field. The results of these studies are summarized briefly below.

Pinto Wye area.--In area 1 (fig. 3), southwest of Pinto Wye, studies using magnetic and seismic-refraction techniques suggested that most of the fractures in the quartz monzonite bedrock (Dibblee, 1968) may not extend to significant depths as openwork structures and thus probably are not promising aquifers. A shallow shothole (L1) augered for the seismic-refraction study near the center of sec. 10 in this area encountered very moist, fine- to medium-grained, arkosic alluvial fan deposits at a depth of about 30 feet. This material appeared to be almost saturated, which suggests that the area would be worthy of further exploration for shallow ground water in such deposits.

Wonderland of Rocks.--In area 2 (fig. 3), a field examination of the hydrologic character of the quartz monzonite bedrock indicated that most of the prominent fractures are slightly weathered and tightly cemented. The marked physiographic features that give this area its name have been formed by erosion along these fracture zones. The zones seem to be similar in hydrologic character to the fresh, unfractured rock. Limited data collected by the Geological Survey from the lake behind Cow Camp dam (fig. 3) suggest that downward leakage from the reservoir along the fracture zones is small, probably less than the losses by evaporation. The lake behind Cow Camp dam is one of three small reservoirs in the area that occupy three of many small valleys cut along the fractured zones. Water was standing in small pools in narrow stream courses along the floors of several of these fracture-controlled valleys in the area a week or more after a rain during the winter of 1968-69. The above evidence, plus the small yield of wells in the area reported by Weir and Bader (1963) and Miller (1968), led to the tentative conclusion that the known fractures in bedrock here are of low permeability and would yield only very small quantities of water to wells.

Lost Horse Valley.--Area 3 (fig. 3), in the southern part of Lost Horse Valley, is crossed by a north-trending fault that is concealed beneath alluvial cover (Weir and Bader, 1963, fig. 3). The hydrologic character of the fractured gneissic bedrock here is not known. A reconnaissance investigation using seismic-refraction techniques yielded inconclusive but unpromising data as to the presence of fractured bedrock, and thus a productive aquifer, at depth. As shown by Weir and Bader (1963, fig. 3) this fault zone trends northwest across Lost Horse Valley, where it is concealed by alluvium. The alluvial fill is estimated to be 100 feet thick or less beneath much of the valley; thus the fault zone could be readily explored by seismic-refraction and other geophysical techniques. Limited data on ground water in this general area (Weir and Bader, 1963, table 5) suggest that it is of good to excellent chemical quality. The depth to water in fractured bedrock may be less than 500 feet.

Pleasant Valley.--The location and nature of a covered fault zone in quartz monzonite and gneissic bedrock in the western part of area 4 (fig. 2), Pleasant Valley, was investigated using seismic-refraction, gravimetric, and magnetic techniques. The fault trace immediately south and east of Squaw Tank (fig. 2) is locally apparent only from gross topographic features, and little can be deduced about its width and hydrologic character from a surface examination. A seismic-refraction study of the alluvial area near the road southwest of Squaw Tank suggested that the fault zone in bedrock beneath the alluvium may be from several tens of feet to about 100 feet in width. This zone is of lower seismic velocity and seems to attenuate seismic signals much more readily than the surrounding bedrock, which suggests that it may be highly fractured or weathered or both.

Measurements of the total magnetic field and the gravity field at the same points as the seismic study (at stations 50 feet apart) showed broad, poorly defined anomalies at about the same location where the fault zone was indicated by seismic studies. The magnetic anomaly is about 60 gammas in amplitude; the gravity anomaly is about 2 milligals in amplitude.

Limited data on wells in Pleasant Valley from Weir and Bader (1963, table 2) and from Miller (1968, table 1) suggested that the depth to water in this area may be in excess of 500 feet, and might be greater than 1,000 feet.

A drilling site was selected at the more remote eastern end of Pleasant Valley where the fault zone described above is better exposed and is about 200 feet wide. The gneissic bedrock in the fault zone east of the drilling site is fractured and locally seems to be highly permeable. The drilling site (fig. 2) was near an unimproved, sandy road in the NW1/4 sec. 14, T. 9 N., R. 3 E., in an area where a thin cover of alluvium, of Holocene age, overlies lacustrine deposits, of Pleistocene age (Weir and Bader, 1963, fig. 3). The lacustrine deposits, which have been deformed along the fault zone, overlie the crystalline bedrock that consists of gneissic rocks intruded by quartz monzonite. The site is about in the center of the fault zone, as judged by projection of the zone on aerial photographs from bedrock areas to the east and by nearby fault scarps in the lacustrine beds.

The test well was drilled during June-October 1969 using cable tools, down-hole-hammer type air-percussion tools, and hydraulic rotary methods. Original plans were to complete the well using air tools to avoid plugging the aquifer with drilling mud, but drilling conditions did not permit this.

The hole was drilled with cable tools to a depth of 250 feet and cased with 8-inch ID (inside diameter) steel casing. The material below this point was firm enough to allow the use of air-percussion tools. From 250 to about 600 feet, the air-percussion tools worked satisfactorily. Drilling rates of several tens of feet per hour were attained at times in this interval. On several occasions the string of drilling tools would appear to almost free-fall from several inches to about a foot or more in the loose, fractured, dry material. Loose, dry, caving material from the drill cuttings and probably from loose gouge in the fault zone caused great difficulty during drilling at depths from about 610 to 640 feet.

At a depth of about 640 feet, the drilling method was changed to hydraulic rotary. Revert[1] drilling mud, an organic-base material that decreases greatly in viscosity after a few days under normal physical and chemical conditions, was used in an effort to prevent the permanent plugging of open fractures by the invasion of drilling fluid under high head. However, the drilling fluid rapidly migrated into the highly permeable fault zone at rates estimated to exceed 100 gallons per minute at times. After several unsuccessful attempts to maintain circulation of the drilling fluid, the organic-base mud was replaced with bentonite-base mud. A large quantity of wood sawdust was added to the drilling fluid in order to adequately seal off highly permeable zones and to maintain enough circulation to allow drilling to continue.

On October 3, 1969, the hole was completed to a depth of 1,004 feet below land surface, and several geophysical logs (fig. 4) were run. The hole later was cased with 1¼-inch ID pipe, and about 2,000 gallons of clear water was pumped through the pipe to partly flush out the drilling mud. Gravel was placed in the lower part of the annulus between the pipe and the walls of the hole. The static water level in the 1¼-inch pipe stood at approximately 827 feet below land surface.

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[1]Brand name is used as identification only and does not imply endorsement by the U.S. Geological Survey.

The lithologic log of well 3S/9E-14C1 follows:

Test well 3S/9E-14C1. Drilled by Belknap Drilling Co. Completed October 3, 1969. Casing 0-10 feet—cemented sanitary seal; 0-250 feet—8-inch, black, 12-gage with drive shoe; 0-1,002 feet—1¼-inch ID galvanized pipe, perforated 983-1,002 feet with 1/8-inch by 3-inch slots, 2 cuts around, 2 rows per foot. Gravel placed in annulus of lower part of hole. About 2,000 gallons of clear water circulated through 1¼-inch pipe to clear the lower part of borehole of drilling fluid. Static water level approximately 827 feet below land surface.

Lithologic description	Thickness (feet)	Depth (feet)
Alluvial deposits of Holocene age		
Sand and gravel, loose, dry	10	10
Lacustrine deposits of Pleistocene and Holocene age (Weir and Bader, 1963)		
Clay, grayish-brown	25	35
Clay, silty and sandy, greenish-brown, calcareous	30	65
Clay, silty, reddish-brown	20	85
Silt, sandy and clayey, olive-green	10	95
Sand, coarse, pebbly	10	105
Sand, silty and clayey, calcareous, grayish-brown	20	125
Sand, pebbly, 2- to 3-inch maximum size, some calcareous silty material	20	145
Clay, silty, sandy, calcareous, brown to greenish-brown	20	165
Clay, silty, sandy, very calcareous, greenish-brown	35	200
Sand, silty, medium-coarse, slightly calcareous, gray, dry	20	220
Silt, sandy and clayey, calcareous, pale-greenish-brown, dry	25	245
Sand and gravel, poorly sorted, gray, dry	15	260
Fractured-to-massive crystalline rock		
Fractured rock, mostly gneiss, weathered near top and locally throughout, dry	330	590
Breccia zone, loose sand and rocks, difficult drilling because of caving, dry	50	640
Fractured rock, mostly gneiss	30	670
Fractured rock, with blue-clay zones, mostly gneiss	50	720
Fractured rock, mostly gneiss	60	780
Hard, black rock, gneiss(?)	215	995
Fractured rock with clay	9	1,004

The thin alluvium and the lacustrine deposits (fig. 4) penetrated by the test well were not saturated, although records of water wells in the area (Weir and Bader, 1963) suggest that at times a perched water-saturated zone or zones may exist locally in the lacustrine beds in the Pleasant Valley area.

Much of the total thickness of fractured bedrock seemed to be highly permeable, judging from the drilling characteristics and from geophysical logs. This high permeability was indicated, as mentioned earlier, by rapid drilling rates in some zones and by the loss of circulation of drilling fluid at extreme rates. The geophysical logs, in particular the seismic log and the caliper log, suggest that several highly permeable zones exist in the material penetrated by the borehole.

The seismic log is a continuous refraction log of the borehole. The refracted signal is recorded to show the sonic velocity as a function of arrival time (for example, early arrival indicates fast velocity), and the intensity of the signal is an indication, in this case, of the degree of fracturing in the material.

Mr. R. K. Ault of the Birdwell Division of Seismograph Service Corp. analyzed the geophysical logs (written commun., 1969). His calulations of the parameters of the rock and his associated pertinent remarks are listed below:

Depth interval (feet)	Average true resistivity ohms M^2/M	Average velocity (feet per second)	Average porosity (percent)	Assumed matrix velocity	Remarks
550-600	150	8,500	45	17,500	Air filled porosity.
600-645	50	10,400	27	17,500	Low permeability, clayey.
645-690	250	10,000	34	18,500	Highly fractured porosity.
690-765	80	12,600	20	19,500	Low permeability.
765-795	55	11,400	26	19,500	Fractured.
795-815	200	7,800	55	19,500	Highly fractured.
815-835	30	7,800	15	17,500	High clay content.
835-1,004	50	13,800	15	19,500	Low permeability, competent rock.

Mr. Ault's comments on the logs seem to correlate well with the drilling characteristics. The most obvious permeable zones are above the water table. The logs suggest that the most permeable zones below the water table (depth, 827 feet) are at 827-830, 850-853, 900-910, 940-960, and 995-1,004 feet. No clear-cut evidence of the top of the saturated zone was apparent during the drilling or from the geophysical logs.

The caliper log (fig. 4) gave a graphic representation of the diameter of the borehole, and reflected to a large degree the physical competence of the crystalline rock in response to the drilling process. This competence, in turn, reflected the degree of fracturing and weathering of the rock. Therefore, for lithologic conditions encountered in this borehole, a large diameter hole in relation to the bit size (6-5/8 inches) suggests that the rock is fractured and weathered and thus more permeable.

The caliper log indicated that the borehole between depths of 251-660 feet was significantly larger in diameter than the drill bit. For about 20-25 percent of its length in this interval, the borehole exceeded 8 inches in diameter, and at several places exceeded 10 inches. For about 40-50 percent of its length between 800-1,004 feet, the borehole had a diameter that significantly exceeded the diameter of the bit. These features of the caliper log correlate closely with the seismic and driller's logs.

The general character of the electrical logs showed a large-scale correlation with the seismic, caliper, and driller's logs. A correlation of many details between the electrical and other logs was not readily apparent. Probably the major cause is that most of the ordinary techniques that have been developed for interpreting electrical logs are based on logs in layered, saturated, sedimentary rocks. All of the electrical log (fig. 4) for this well was in crystalline rocks and about 75 percent of the log was above the zone of saturation.

A temperature log of the borehole made October 3, 1969, shortly after completion of the drilling (fig. 4), showed a steady increase in temperature with depth at a rate of about 0.3°F per 100 feet of depth. This rate probably was greatly affected by the heat generated during drilling and by the circulation of the drilling fluid. On June 4, 1971, T. L. Henyey (University of Southern California) logged the temperature in the lower part of the hole (fig. 4) for purposes of studying heat flow in the earth's crust. His measurement, which probably was not affected by the drilling processes, indicated a fairly even gradient of about 0.1°F per 100 feet of depth. Little can be deduced from these temperature logs about the hydrology of the area. However, minor variations in the temperature log (oral commun., T. L. Henyey, 1971) correlate reasonably well with permeable zones below the water table inferred from other logs.

The well was pumped by use of an airlift for several hours, and a sample of water was collected for chemical analysis. Periodic water-level measurements after pumping indicate that no significant change in water level has occurred (table 1).

The sample taken for chemical analysis (table 2) is mixed, to an unknown degree, with (1) breakdown products from Revert drilling fluid, (2) sodium hydroxide added to the Revert drilling fluid during drilling to prolong its life, (3) detergent added to the 1¼-inch pipe to aid insertion of a ½-inch plastic hose to a depth of about 980 feet in order to airlift the sample, (4) bentonite-based drilling fluid with its makeup water, and soluble products from the sawdust mixed with the drilling fluid to reduce losses, and (5) the water used to flush out the lower part of the hole. Thus, the chemical analysis may or may not reflect the chemical nature of the native ground water. The chemical quality of ground water is good at other sources in similar geohydrological environments in the monument. However, the overlying lacustrine beds in this vicinity may contain easily soluble material and thus could influence the quality of ground-water recharge moving through these deposits into the fractured bedrock.

TABLE 1.--Water levels, test well 3S/9E-14C1

Date	Hour (PST)	Depth to water below land surface datum, in feet	Remarks
Oct. 25, 1969	--	826.5	Measured with copper wire electrical sounder subject to stretch of about 1 foot per 1,000 feet; field measurement was 825.7 feet.
Nov. 7, 1969	1415	827.4	Same sounder as above.
Feb. 12, 1970	1300	825.2	Measured with steel tape, smeared water-level cut on tape. Result probably too high.
Feb. 12, 1970	1400	826.5	Measured with steel-line electrical sounder.
Feb. 13, 1970	0958	874.0	Recovery after air-lifting well intermittently for 8 hours at about 0.25 gallon per minute; electrical sounder malfunctioned; remaining recovery not measured.
Feb. 13, 1970	1002	872.0	
Feb. 13, 1970	1005	871.0	
Feb. 13, 1970	1010	870.0	
Feb. 27, 1970	0715	826.1	Measured with steel-line electrical sounder.
Dec. 15, 1970	1515	826.6	Do.
June 4, 1971	1615	826.0	Do.

TABLE 2.--Chemical analysis of water[1] from test well 3S/9E-14C1

Constituents in milligrams per liter	
Silica (SiO_2)	0.8
Iron (Fe)	1.6
Calcium (Ca)	20
Magnesium (Mg)	1.4
Sodium (Na)	414
Potassium (K)	28
Carbonate (CO_3)	2
Bicarbonate (HCO_3)	728
Sulfate (SO_4)	260
Chloride (Cl)	90
Nitrate (NO_3)	3.6
Fluoride (F)	.3
Boron (B)	--
Phosphate (PO_4)	18
ABS	56
Dissolved solids calculated (Sum of determined constituents)	1,180
Hardness calculated as calcium carbonate	56
Percent sodium	91
Specific conductance (micromhos at 25°C)	1,590
Temperature	57°F
Point of collection	Airlift discharge
Analyzing laboratory	U.S. Geological Survey
Date collected	Feb. 13, 1970
Laboratory number	60083
Depth of well, in feet	1,004

[1]Sample consists of native ground water mixed with other material, see text, p. 23.

The yield of the test well during pumping by airlift for sampling was about 0.25 gpm (gallon per minute). Inflow to the well during part of the recovery period after pumping was about 0.15 gpm. These low yields probably are not representative of the yield characteristics of the aquifer. They are reduced for two reasons: (1) the small percentage of submergence of the airlift system restricted the pumping rate; and (2) more importantly, the native permeability of the fractures in the crystalline rock in the fault zone was reduced significantly by the invasion of drilling fluid.

The estimated differential static pressure between the borehole and the aquifer, which would tend to drive the drilling fluid away from the borehole and into permeable zones, would be about 410 psi (pounds per square inch) at a depth of 1,000 feet, assuming that (1) the water table is at a depth of 827 feet, and (2) the density of the drilling fluid including cuttings is 70 pounds per cubic foot. The static pressure during drilling at the water table (depth, 827 feet), where a permeable zone occurs, would be about 400 psi. These pressures are adequate to cause pervasive invasion of any significantly permeable fractured zones intercepted by the borehole. Because there was no way to effectively reverse more than a small percentage of these pressure gradients during the development of the well, most of the drilling fluid remained in the aquifer materials surrounding the well, plugging the permeable fractures leading to the borehole, and hereby greatly reducing the yield.

Because of this reduction in permeability caused by the invasion of drilling fluid, no firm estimate of the potential yield of the well can be made.

RECOMMENDATIONS

Test Well

The potential yield of the test well and the chemical quality of the water cannot be evaluated from the information presently available. Determination of the water-yielding characteristics of the aquifer is among the most important original objectives of the project. To obtain adequate information about these parameters, the following modifications of the test well are recommended:

1. Remove the 1¼-inch pipe from the hole.

2. Clean the total depth of the hole of the gravel pack and any other loose material.

3. Install 7-inch ID casing from about 240 feet to about 800 feet; some reaming may be required, and the casing should be landed on firm material. The hole below this depth probably will stand open.

4. Bail the well for about 4 hours and record the yield, drawdown, and recovery.

5. Draw down the water level in the well by bailing immediately prior to adding a solution of about 100 pounds of a polyphosphate and about 3 pounds of calcium hypochlorite dissolved in 300 gallons of water (Johnson, 1966, p. 329-330). This will loosen and help remove the drilling fluid. Surge the mixture thoroughly. Slowly add about 200-300 gallons of clear water after surging to aid in forcing the solution into fractured areas. Let stand for at least 24 hours and clean with a bailer.

6. Bail the well in a manner similar to step 4 above. If the yield increases significantly, repeat step 5 (Johnson, 1966, p. 329).

7. If little or no increase in yield occurs, deepen the well about 100 feet with cable tools or with air-rotary or air-percussion tools until fractured material that is free from drilling mud is penetrated. Test the yield and drawdown by bailing or by test pumping for at least 8 hours. Take a sample of water at the end of each hour of pumping to help determine when nonnative fluids, previously added to the hole, have been removed. Measure water-level recovery for 24 hours after the end of the bailing test.

Additional Test Sites

Several other areas of faulted and fractured rock in the monument are accessible by drilling equipment and are in areas of scant water supply. Some of these areas that are potentially productive drilling sites for water are described briefly below.

1. The fault zone in Pleasant Valley extends into Pinto basin, crossing several roads, and is easily accessible about 15 miles to the east, near Old Dale Junction (fig. 1) (Weir and Bader, 1963, fig. 2). The depth to water is estimated to be less than 1,000 feet, and the water-yielding characteristics of the fault zone may be similar to that in Pleasant Valley. Information about the exact location, width, and perhaps the intensity of fractures in the zone could be obtained by a geophysical investigation of the area. Such data would allow an evaluation of the fault zone as a suitable site for a test well.

2. The fault zone that trends northwestward across Lost Horse Valley (fig. 3), part of which has been investigated (area 3 in this report), seems to be worthy of further investigation as a source of water for this area. The projected trace of the fault is largely covered by alluvium from a few feet to several tens of feet thick so that geophysical methods of study would be required to locate and evaluate the zone as a potential test-well site. The depth to water here probably would be in excess of 500 feet.

3. Lower Covington Flat near Covington Spring, which is dry, is probably bounded on the north by a northwest-trending fault zone (Dibblee, 1967). This fault zone is several miles long and is covered by a thin layer of alluvium. Near Covington Spring, in sec. 25, T. 1 S., R. 7 E., the fault zone is easily accessible, and the depth to water probably is less than 1,000 feet. The location, width, and nature of the fault should be investigated by geophysical methods to determine its suitability as a drilling site.

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FIGURE 4