GEOLOGIC RECONNAISSANCE AND TEST-WELL DRILLING PROGRAM, MARINE CORPS TRAINING CENTER, TWENTYNINE PALMS, CALIFORNIA

By F.S. Riley *and* G.F. Worts, Jr.

U.S. GEOLOGICAL SURVEY
Open-File Report 98-166

Prepared in cooperation with the
U.S. DEPARTMENT OF THE NAVY

Long Beach, California
October 1952
[Retyped 2001]

U.S. DEPARTMENT OF THE INTERIOR
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FOREWORD

This report originally was completed in 1952 by the U.S. Geological Survey (USGS) in cooperation with the U.S. Marine Corps, Department of the Navy, as an Administrative Report. The purpose of the report was to present to the Department of the Navy results of a geological reconnaissance and a test-well drilling program that were undertaken to assess the availability of a ground-water supply at a Marine Corps Training Center that was under construction. This training center has evolved into the Marine Corps Air Ground Combat Center (MCAGCC), Twentynine Palms, California.

Administrative reports may not be cited or quoted or released to the public. However, this report contains valuable information on the geology and hydrology of the area that has important implications on the availability, source, and movement of ground water. For these reasons, and because of the importance of ground water to the MCAGCC and surrounding area, this report has been retyped for public release at this time.

In some respects, this report does not conform to current USGS editorial standards and it uses technical terms that are no longer used by the USGS. Also, as is common in reports produced for other Federal agencies, direct recommendations are given by the author. To avoid confusion, however, the report has been largely reproduced as originally written. It is our belief that these deficiencies are outweighed by the advantages to the public of making the information in this report available to potential users.

Michael V. Shulters
District Chief

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Multiply	By	To obtain
foot (ft)	0.3048	meter
gallon (gal)	3.785	liter
gallon per minute (gal/min or gpm)	0.06309	liter per second
inch (in)	2.54	centimeter
inch (in)	25.4	millimeter
mile (mi)	1.609	kilometer
square mile (mi^2)	259.0	hectare
square mile (mi^2)	2.590	square kilometer
yard (yd)	0.9144	meter

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C = (°F - 32) / 1.8$$

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

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INTRODUCTION

Scope and Purpose of the Investigation

In December 1951 the Public Works Office, Eleventh Naval District, San Diego, requested the participation of the U.S. Geological Survey in a program of exploration for a ground-water supply at the Marine Corps Training Center under construction at Twentynine Palms, California. At that time the Navy was also considering the advisability of obtaining water from the Colorado aqueduct—a project which would have cost several million dollars more than development of a local ground-water supply, if such were found to be available.

In accordance with agreements made with the District Public Works Office, the Geological Survey was to make the geologic exploration, and Mr. W.O. Wagner, consulting engineer, who was retained by Neptune and Gregory, Architects and Engineers for the overall project, was to make the hydrologic study. Briefly, Mr. Wagner was to submit an initial report on the hydrology including the selection of test-well sites, to prepare the test-well specification, and to make a final report on the hydrology including the selection of supply-well sites.

The more detailed activities of the Geological Survey were outlined in a letter from the Director, U.S. Geological Survey, to the Director, Engineering and Technical Services Division, U.S. Navy, dated December 12, 1951. The scope of the investigation was outlined as follows: (1) To carry out the geologic phases of the test-drilling program; (2) to prepare a geologic reconnaissance map of the area; (3) to prepare a report of geologic and ground-water conditions; and (4) to act as technical advisor to the Navy in matters relating to the test-drilling program. The fourth phase of the Survey's activities was to include review of Mr. Wagner's reports and well specifications, advice to the Navy as to their adequacy, and advice to the Navy regarding geologic and hydrologic problems related to the test-drilling program.

Toward the accomplishment of these four main objectives, the Survey has completed the geologic phases of the test-drilling program, reviewed Mr. Wagner's initial report and test-well specifications, reviewed supply-well specifications prepared by Neptune and Gregory, and acted as technical advisor to the Navy throughout the course of the test-drilling program. The reconnaissance geologic map and report, including certain pertinent hydrologic data collected during the test-drilling program, make up the body of this report. Mr. Wagner's final report will be reviewed as soon as a copy is supplied for that purpose.

Because two of the ground-water basins explored during the test-drilling program contain relatively large quantities of potable, stored ground water that can be pumped readily from wells, the Navy has requested the Survey to investigate the ground-water conditions of the area in more detail during the 1952–53 fiscal year with special reference to the Deadman and Surprise Spring Basins. The program as outlined in a letter dated June 25, 1952, from the Acting Director, U.S. Geological Survey, to the Bureau of Yards and Docks, is as follows: (1) Estimate the ground-water storage capacity of Deadman and Surprise Spring Basins; (2) estimate, if possible, the amount of recharge to these basins; (3) report on chemical quality of water in these basins; (4) begin a water-level measuring program in these basins and in Mesquite Basin; and (5) provide consultation and advice on ground-water development and possible artificial recharge operations.

Location and General Description of the Area

The area discussed in this report is slightly west of the center and along the southern edge of San Bernardino County, California, in the southeastern part of the Mojave Desert. It constitutes about 85 percent of the area between 116°00′ and 116°30′ west longitude and between 34°5′ and 34°30′ north latitude, which is the area covered by plate 1.

Geographically it consists of a broad, moderately high, eastward sloping desert basin bounded on the east and northeast by the westernmost range of the Bullion Mountains; on the south by the Little San Bernardino Mountains; on the west by the eastern fringe of the San Bernardino Mountains; and on the north and northwest by an irregular mountain area from which three ridges extend southeastward into the basin for distances of 8 to 12 miles (pl. 1).

The maximum east-west dimension of the basin is along its southern edge and is about 24 miles. Along the northern edge the northwesterly trend of the Bullion Mountains reduces the width to about 18 miles. The north–south dimension averages about 25 miles. Thus, the basin area is approximately 500 square miles.

The town of Twentynine Palms, the largest community in the area, is at the extreme southeast corner of the basin and claims a population of about 3,500. The Twentynine Palms Highway runs due west from the town along the base of the Little San Bernardino Mountains for about 19 miles, then runs west–southwest out of the area toward Morongo Canyon, and eventually joins U.S Highway 60 about 16 miles east of the town of Banning. Several small but expanding communities are spread out along the Twentynine Palms Highway, the chief of which are Joshua Tree, 15 miles west of Twentynine Palms, and Yucca Valley, 7.5 miles farther west. Near the east edge of Yucca Valley a well-maintained gravel road runs northerly along the base of the San Bernardino Mountains for about 16 miles, then turns northwest and runs out of the area toward Old Woman Springs and Lucerne Valley. East of Twentynine Palms a road leads to Dale Dry Lake and thence north to Amboy on U.S. Highway 66.

The central part of the basin is very sparsely settled but is penetrated by a number of fair to good dirt roads. Giant Rock Airport, in the northwest part of the basin, is 27 miles from Twentynine Palms and is accessible over a fair gravel road. Surprise Spring, an important desert watering place for many years, is slightly northeast of the center of the basin, at the end of a northeast-trending road, 15 miles from its junction with the Twentynine Palms Highway east of Yucca Valley. The geologic map (pl. 1) shows only a few of the more important roads, drawn principally for purposes of reference. For detailed information the reader should consult the excellent road map of San Bernardino County published by the Automobile Club of Southern California.

The Test-Well Drilling Program

The contract for drilling the test wells in the basin was awarded to Mogle Brothers Drilling Co. in December 1951 (contract NOy-71062). Test drilling was started near Deadman Lake in January 1952 and was completed September 3. Ten test wells were drilled to depths ranging from 400 to 800 feet; the total footage drilled was 5,163 feet. The test wells were carefully logged by L.C. Dutcher, R.E. Evenson, R.S. Stone, and the authors, geologists, U.S. Geological Survey. In addition to the logging, the men collected samples of the deposits penetrated during drilling, supervised the bail tests, and collected water samples for chemical analyses. The detailed logs, chemical analyses, and bail test data are given in tables 4, 5, and 6 at the end of this report.

The cable-tool method of test-well construction enables the geologists to obtain accurate data on water levels and types of material, and to collect water samples for chemical analyses during the course of drilling. Because of the poor mechanical condition of the drilling rigs, the average rate of drilling was only 15 feet per working day per rig, so that completion of the drilling program required more time than had originally been anticipated.

The data obtained from the test-well drilling program and from the geologic reconnaissance indicate that a ground-water supply for the Marine Corps Training Center can be obtained from wells constructed in the area northwest of the camp site. Some of the test wells, which are 10 inches in diameter, could be used as standby wells for camp supply. The pertinent data obtained during the test-drilling program are presented in table 1.

Table 1. Summary of test-well data, Marine Corps Training Center, Twentynine Palms

[Altitudes in feet above sea level; depths in feet below land surface. Specific capacity in gallons per minute per foot of drawdown. °F, degrees Fahrenheit; ppm, parts per million]

Test well no.	Altitude[1] (feet)	Drilled depth (feet)	Depth to water (feet)	Altitude of water level (feet)	Saturated water-yielding material (percent)	Total lineal perforations (feet)	Specific capacity	Temper-ature[2] (°F)	Quality[2]: Fluoride (ppm)	Quality[2]: Total dissolved solids (ppm)
Mesquite Basin										
1	1,860	400	81	1,779	45	57	1.9	85	8.0	580
Deadman Basin										
2	1,850	526	43	1,807	55	115	21.7	72	4.0	830
3	1,860	512	48	1,812	45	74	1.6	83	4.0	980
8	1,900	800	88	1,812	50	99	8.6	85	1.4	860
10	2,010	501	189	1,821	65	96	11.3	83	1.6	640
Basin averages (where shown)					54		10.8		2.8	828
Surprise Spring Basin										
5	2,300	400	25	2,275	65	93	42.9	93	1.1	140
6	2,430	450	148	2,282	80	64	13.3	74	0.3	430
9	2,540	430	250	2,290	40	89	30.5	78	0.5	140
12	2,480	500	190	2,290	55	72	12.1	80	0.7	164
Basin averages:					60		24.7		0.6	218
South of Surprise Spring Basin										
11	2,540	644	334	2,206	60	93	1.4	96	1.1	154

[1]Based on barometric measurements. See unnumbered table in "The Test-Well Drilling Program" section for spirit-level altitudes for these wells.
[2]Sampled at end of 8-hour pump test.

Since the completion of this report the altitudes of the test wells have been determined by spirit leveling carried out by Neptune and Gregory, Architects and Engineers. These data are tabulated below:

Test well no.	Altitude		Test well no.	Altitude	
	Land surface (feet)	Top of casing (feet)		Land surface (feet)	Top of casing (feet)
1	1856.2	1858.87	8	1890.9	1893.13
2	1845.7	1846.39	9	2514.2	2516.02
3	1850.2	1851.35	10	2020.2	2021.23
5	2271.5	2274.31	11	2531.6	2534.06
6	2403.6	2404.70	12	2442.0	2444.77

These revised altitudes of land surface are shown for the test-well logs in table 4, but have not been used elsewhere in the report or to revise the altitudes shown on plate 2, which would require extensive revision. However, the revised altitudes do not change the concepts in this report.

Climate

Few quantitative climatic data are available for the area under consideration. Observations made by the U.S. National Park Service at their cooperative weather station in Twentynine Palms are briefly summarized in table 2. These data are probably roughly applicable to most of the basin floor, although mean temperatures decrease with altitude, whereas precipitation generally increases somewhat with altitude and proximity to mountain ranges.

Table 2. Climatological averages at Twentynine Palms, California, for the period January 1936 to December 1950

[°F, degrees Fahrenheit. Data from National Park Service, Twentynine Palms, California]

Average daily temperatures (°F)							
Month	Minimum	Maximum	Mean	Month	Minimum	Maximum	Mean
January	34.1	60.5	47.3	July	71.2	104.4	87.8
February	37.0	65.1	51.0	August	70.4	102.8	86.6
March	42.1	72.0	57.4	September	63.5	96.4	79.9
April	49.8	81.2	65.5	October	52.4	83.1	67.8
May	56.8	88.4	73.1	November	41.0	71.2	56.2
June	63.6	97.7	80.6	December	36.9	63.3	50.1
Average yearly temperature				66.9°F			

Average monthly precipitation (inches)			
January	0.62	July	0.37
February	0.37	August	0.60
March	0.40	September	0.37
April	0.11	October	0.60
May	0.01	November	0.39
June	0.003	December	0.70
Average yearly total		4.54 inches	

In summarizing and amplifying the statistics in table 2, it may be noted that the basin is arid in part because it lies in the "rain-shadow" of the San Bernardino Mountains. As is typical of other California desert areas, most of the meager precipitation occurs during the fall and winter months. However, during the summer and particularly during August, occasional rain falls in the form of scattered thundershowers. These rarely attain cloudburst proportions, but when they do they can cause flash floods of great erosive and destructive power.

The mountainous rim of the basin, particularly in the San Bernardino Mountains to the west, receives more precipitation than the basin floor. Most of the precipitation there occurs west of the drainage divide, however, and does not contribute to the water supply of the basin. Nevertheless, the eastern foothills of the San Bernardino Mountains are believed to be the source of most of the runoff and ground-water recharge entering the main part of the basin floor.

Temperatures range from moderately cold in winter, when early morning temperatures may be subfreezing, to exceedingly hot in summer, when mid-day temperatures are usually between 100° and 105°F.

Wind velocities are generally moderate. During the rather windy months of early spring the region is not swept by the frequent strong and persistent gales which are characteristic of some other parts of the Mojave Desert, notably Antelope Valley to the northwest.

RECONNAISSANCE GEOLOGY

The geologic discussion in this report is based on about six weeks of field mapping done during the period January to March 1952. The area covered during that time was about 600 square miles, and accordingly this work was of a reconnaissance nature only. In planning and carrying out the field work, chief emphasis was placed upon determining the physical character, areal extent, thickness, and geologic structure of known or potential water-bearing formations. For the most part the work was confined to the basin floor north of the Twentynine Palms Highway, and the greatest amount of time was devoted to the eastern half of the area, where the test wells are located. The western edge of the basin was examined only briefly.

Inasmuch as no U.S. Geological Survey topographic maps of the area have been made, the best base map available for the field work was the Twentynine Palms topographic map prepared by the Metropolitan Water District of Southern California for the 30′ quadrangle between latitudes 116°00′ and 116°30′ west and longitudes 34°00′ and 34°30′ north. The scale of the map used was about 1:120,000 and the contour interval was 100 feet. Cultural features such as roads and towns were lacking, and the location of the township and range grid proved to be rather inaccurate. In addition, as the field work progressed it was discovered that many of the topographic features were misplaced or incorrectly represented on the map.

However, it has been possible to make certain improvements. The Automobile Club of Southern California provided a field work-map of the area, on which most roads were accurately shown. The most important roads have been transferred to the geologic map (pl. 1). In addition, a set of excellent vertical aerial photographs (scale ca. 1:40,000), covering all but a narrow strip along the north edge of the area, was obtained from the Department of the Air Force. These, together with a set of oblique aerial photos provided by the Navy, were of great assistance in reducing some of the more serious errors in the base map, as well as in refining some of the geologic interpretations.

Landforms

The area considered in this report is a broad intermontane basin of the type characteristic of the Basin and Range Province. For the purposes of this report the basin as a structural unit is called the Twentynine Palms Basin. It may be divided into two units: (1) the eastward-dipping basin floor and (2) the rugged mountains that form the basin rim. Beneath much of the basin floor is a thick section of permeable sedimentary material which overlies the ancient bedrock and constitutes a large ground-water reservoir. In the surrounding mountains the consolidated bedrock has been elevated above the general basin surface by large-scale movement along extensive faults. The mantle of unconsolidated sediments has been stripped off by erosion so that the hard, impervious bedrock is exposed. The bedrock exposures are critical to the ground-water supply of the basin only insofar as they serve as catchment and runoff areas.

In referring to the geologic map (pl. 1), on which the topography is not shown, the reader may assume that any extensive area of Precambrian or Jurassic rocks is more or less mountainous, and that in general the amount of relief is roughly proportional to the areal extent of the outcrop.

The Basin Rim

To the west the basin is bounded by the complex and extensive mass of the San Bernardino Mountains, including San Gorgonio Mountain, whose summit altitude of 11,485 feet is the highest of any peak in southern California. East of the summit area the mountains descend toward the basin floor, through a series of foothills of diminishing altitude. About 21 miles east of San Gorgonio Mountain the edge of the mountainous area is sharply delimited by a group of basalt-capped mesas which rise steeply to heights 400 feet above the adjacent basin floor to the east. The eastern foothills of the San Bernardino Mountains, which receive a moderate amount of precipitation, contribute much of their runoff to the basin floor through Pipes Wash and its tributaries (pl. 1).

To the south, the Little San Bernardino Mountains rise abruptly along a very irregular east–west front to heights of 1,000 or more feet above the valley floor. A sizeable mountain mass known as Fortynine Palms Mountain, immediately south of Twentynine Palms has an altitude of about 5,700 feet[1], which is about 3,800 feet higher than the town.

To the east and northeast, the west range of the Bullion Mountains rises very abruptly along an irregular front which trends about N. 30° W. The range attains its greatest altitude, about 3,900 feet, near the middle and diminishes rapidly toward the south, terminating about 5 miles north of Twentynine Palms. The eastern slope is much gentler than the precipitous western face, suggesting that the range is an eastward-tilted block upthrown by a steeply dipping fault or series of faults along its westward edge.

North of the center of the basin a sharp, narrow ridge about 13 miles long extends S. 33° E. from its origin near the northwestern end of the Bullion Mountains. It is known variously as Pinto Mountain or Coffin Mountain and has a maximum altitude of about 4,400 feet. Between the southern tip of Coffin Mountain and the Bullion range to the east lies an unparched area of folded continental deposits which have been eroded into typical badlands topography. This area is known by local residents as the Mud Hills. The Mud Hills are within the drainage area of the Twentynine Palms Basin, but they form an effective structural boundary near the northeast edge of the basin floor.

Just west of the northern end of Coffin Mountain, and connected with it by a low saddle, is another mountain from which a low, discontinuous ridge of rugged hills extends 6.5 miles to the southeast. This mountain is connected by a saddle at its northern end to a third southeast-trending ridge, known as Deadeye Mountain, whose steep eastern scarp is 4.5 miles west of Coffin Mountain. Deadeye Mountain[2] is actually the easternmost ridge of a larger mountain mass which, 2 miles west of Deadeye Mountain, rises to its maximum altitude of about 4,100 feet. This western part of the mountain has apparently never been named. From its southwestern corner a saddle of moderate altitude, 2,940 feet, connects with the northeast corner of the San Bernardino Mountains and separates the main basin from Means Valley to the northwest.

It is apparent from the foregoing discussion that the basin floor is almost completely rimmed by mountainous or upland areas. The only breach in the rim is in the southeast corner of the area, about 3 miles northeast of Twentynine Palms. There a wash cuts through the low point on a nearly flat saddle between the southern tip of the Bullion Mountains and a row of hills. During infrequent periods of heavy runoff, surface drainage spills out of the basin through this wash and proceeds eastward down a long, gently sloping valley to Dale Lake, 18 miles distant.

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[1] Unless otherwise specified, all altitudes mentioned hereafter in this report are taken from the Metropolitan Water District map and must be regarded as very approximate.

[2] The crestline of mountains and interconnecting saddles that forms the basin's northern drainage divide lies slightly north of latitude 34°30′ and does not appear on plate 1. However, all of the southeastward-extending ridges are shown.

This large dry lake, or playa, 4 miles long and 3 miles wide, lies at an altitude of 1,184 feet and is the ultimate "sink," or low point, for the whole area under consideration.

The Basin Floor

The floor of the Twentynine Palms Basin is a broad, irregular, plain of detrital material, sloping eastward from a maximum altitude of about 3,600 feet along the foot of the San Bernardino Mountains to a minimum of about 1,800 feet in the low trough that contains Deadman and Mesquite Dry Lakes. The major topographic features of the basin floor are direct expressions of the underlying geologic structure; the details have been sculptured by erosion. Deposition has played a relatively minor role in developing the present surface; for the most part its effects are limited to piedmont slopes and playa areas. The basin floor has three prominent types of features: (1) The isolated bedrock hills and mountains which protrude through the basin floor; (2) the low, north-trending ridges composed of sedimentary material; (3) the playas and playa basins.

The Isolated Bedrock Hills

The largest of the bedrock hills is about 8.5 miles west of Twentynine Palms and is known as Copper Mountain. It is 6.5 miles long, about 3.25 miles wide at the widest point, and has a maximum altitude of about 2,900 feet. The ridge is asymmetrical in cross section, having a steep western face and a more gentle eastern slope. Several small bedrock hills crop out just east of the southern part of the mountain.

In the southwest corner of the area a prong of bedrock hills extends eastward from the San Bernardino Mountains and separates a long, narrow re-entrant trough, known as Yucca Valley, from the main basin floor. At the eastern end of the prong, the prominent hills known as the Bartlett Mountains rise 800 feet above the basin floor to a maximum altitude of about 3,700 feet. North and east of the Bartlett Mountains are the Coyote and Zeitz Mountains and several low, unnamed mounds of bedrock. To the north in the vicinity of the Giant Rock Airport are four sizeable bedrock hills, the highest of which, known both as Goat Mountain and Table Mountain, has an altitude of about 3,500 feet, more than 700 feet above the surrounding plain.

The North-Trending Ridges

The eastern half of the Twentynine Palms Basin is crossed by five low but persistent ridges which trend almost due north. Apparently, the sediments of the basin floor have been raised to form the ridges by a system of recent north-trending faults, subsidiary to the predominantly northwest-trending regional structure. (See pl. 1.) The fault origin is most strongly indicated for the three westernmost ridges, all of which have moderately steep western slopes which are well defined and nearly straight for considerable distances. These three ridges are also similar in that the greatest relief occurs near their southern ends. The two ridges near the eastern end of the basin are poorly defined and may represent folds in the sediments rather than faults. In either case, the structures are probably underlain at depth by faults in the bedrock.

The westernmost of the north-trending ridges extends 9 miles northward from Coyote Mountain and ranges in height from 20 to 100 feet, except where studded by Coyote Mountain and another bedrock hill which rise more than 200 feet above the terrain. This ridge is not only a drainage divide but also a physiographic boundary, for it divides the central basin floor into two quite dissimilar parts (pl. 2). West of the ridge is a smooth, evenly sloping surface broken only by the low Zeitz Mountains. The drainage pattern is diffuse, consisting of a great number of small washes which have not appreciably dissected the surface. East of the ridge the intermittent streams have developed a dendritic pattern of broadly convex-sided valleys whose relief may be 100 feet or more, although it is more commonly on the order of 30 to 60 feet. This moderately dissected area extends eastward to Surprise Spring Fault, beyond which the terrain slopes off gently with diminishing relief toward Deadman Lake. (See pls. 1 and 2.)

Immediately east of Copper Mountain are two parallel north-trending ridges of very similar appearance. Each ridge forms the eastern side of a fairly large trough and acts as a barrier that diverts surface drainages southward. The western ridge is only about 4 miles long and does not extend north of Surprise Spring Fault. The other ridge, 1.5 miles to the east, extends northward for about 11 miles. The northern half is only 20 to 40 feet high and is only locally effective as a barrier to surface runoff; it is breached by the Surprise Spring Wash and several others, all draining to Deadman Lake.

About 2.5 miles farther to the east a similar ridge extends almost 7 miles northward from just north of the Giant Rock Road. This low, discontinuous ridge is breached by washes in several places.The easternmost of the north-trending ridges, about 1.5 miles west of Mesquite Dry Lake, is low, irregular, and cut by many small washes draining eastward toward the dry lake.

The Playas and Playa Basins

The Twentynine Palms Basin is divided into seven subbasins which lack exterior surface drainage, so that during infrequent periods of heavy runoff, water accumulates in the bottoms of the subbasins to form ephemeral lakes. The clay and silt deposited in these temporary bodies of water produce the lake beds which, after the lakes have dried up, form the usually barren flats called playas, or dry lakes. The subbasins, termed playa basins in this report, are separated by relatively minor topographic divides on the main basin floor. The most prominent divide is a broad low arch that extends slightly south of west from the Bullion Mountains across the center of the basin floor to the Zeitz Mountains. Because this arch is oriented at nearly right angles to the trend of most topographic features in the area, it is referred to as the "transverse arch." Throughout its length it is effective as a drainage divide. The playas and playa basins are north and south of the arch in locations controlled by the positions of the isolated bedrock hills, the north-trending ridges, and parts of the basin rim.

Emerson Dry Lake, the largest of the playas, is 3 miles long and 2 miles wide and has an altitude of 2,294 feet. It lies near the northwest end of a shallow northwest-trending trough, which is about 18 miles long and 2 to 3 miles wide. The playa, however, receives drainage from only the northwestern two-thirds of the trough, for the remainder is separated from the Emerson playa basin by a low divide. Furthermore, the northern, eastern, and western extent of the basin is limited by the mountain ranges adjacent to the playa. However, the whole Pipes Wash drainage system is tributary to the Emerson playa basin (pl. 1), although in modern times the volume of discharge in Pipes Wash has seldom been sufficient to exceed seepage losses into the streambed, with the result that little surface flow has reached the playa.

Coyote Dry Lake, 3 miles long and as much as a mile wide, is in the south-central part of the area along the west flank of Copper Mountain. It lies at an altitude of about 2,370 feet in the bottom of a valley which was called Copper Mountain Valley by Thompson (1929, p. 645–646). The name Copper Mountain Valley is used in this report, although the term Sunfair Valley is more widely used by local inhabitants. The valley is bounded on the north by the crest of the transverse arch, on the east by Copper Mountain and associated upraised sediments at both ends, and on the south by the Little San Bernardino Mountains. The southwestern corner of Copper Mountain Valley adjoins the eastern end of Yucca Valley, which is, in fact, part of the same drainage system. To the west–northwest the drainage basin extends between the Zeitz and Bartlett Mountains as far as the foothills of the San Bernardino Mountains.

The trough along the western base of the Bullion range contains the two remaining major playas, Deadman and Mesquite Dry Lakes, as well as a smaller unnamed playa. Deadman Dry Lake, occupying the northern part of the trough (pl. 1), is about 4 miles long by half a mile wide, and has an altitude of 1,816 feet, determined by spirit levels. Deadman Dry Lake receives runoff from a large though very dry area. Its drainage basin is bounded on the northwest by Coffin Mountain, on the northeast and east by the Bullion Mountains, on the south by the crest of the transverse arch, and on the west largely by the westernmost of the north-trending ridges near test well 9. However, the basin extends westward along the upper reaches of Surprise Spring Wash, which has thus annexed to the Deadman Dry Lake drainage basin a long strip extending southwestward through the Zeitz Mountains almost to Pipes Wash. Other washes drain to Deadman Lake from the northern flank of the transverse arch and from the upland area east and southeast of Coffin Mountain.

Immediately south of Deadman Lake the floor of the trough is warped slightly upward by the easternmost expression of the transverse arch. Here the western side of the trough is sharply delineated by an east-facing scarp, 20 to 60 feet high and about 2.5 miles long, in which is exposed a cross section of the beds on the top of the arch.

South of the arch the bottom of the trough is occupied by Mesquite Dry Lake, which is about 2.5 miles long, 1 mile wide, and, at an altitude of about 1,760 feet, is the lowest point in the Twentynine Palms Basin. The former U.S. Naval Auxiliary Air Station is at the southeast corner of the playa, and the new Marine Corps Training Center is under construction along its east side. The Mesquite Dry Lake drainage area is bounded on the east by the southeasternmost ridge of the Bullion Mountains, on the north by the transverse arch, and on the west by the longest and most prominent of the north-trending ridges near Copper Mountain. The southern end of the playa is truncated by a very low fan, which extends across the bottom of the trough between Mesquite Dry Lake and the small unnamed playa to the south, which has an altitude of about 1,780 feet (pl. 1). The principal wash tributary to Mesquite Dry Lake rises south of Copper Mountain and has cut a deep canyon to bedrock through an elevated strip that extends northwestward about 6 miles from the base of the Little San Bernardino Mountains.

The southern half of the elevated strip forms a north–south divide between Indian Cove to the west, which drains ultimately to Mesquite Dry Lake, and the valley to the east which drains through Twentynine Palms to the small unnamed playa south of Mesquite Dry Lake and to the wash draining toward Dale Lake. Much of the drainage of the southern basin, which probably once was tributary to the small playa, has been captured by recent headward erosion in the wash that drains to Dale Lake. As a result the small playa has been encroached upon by vegetation and is now largely covered with sand dunes.

Two lesser playas are just east of Copper Mountain. Both lie near the southern ends of the north-south troughs whose eastern sides are formed by the parallel north-trending ridges previously described. Their drainage areas are small, being limited in both cases to the troughs alone. A low topographic divide, apparently caused by a rather recent uplift, crosses the southern end of the troughs and separates them from the low area to the south, which drains to Mesquite Dry Lake.

Geologic Formations

In the following description of the geologic formations in the area, the ages given for the various formations are chiefly after Miller (1938, fig. 1) and Jenkins (1938, sheet VI). The critical study that would be necessary to corroborate or revise these age determinations is beyond the scope of this report. However, on the basis of the author's field work in this area where little geologic mapping had previously been done, a number of additions and revisions have been made in the areal distribution and extent of the formations. These changes are based on the correlation of exposures studied by Miller and others with those in previously unmapped areas studied by the author. Fortunately, all of the formations and rocks in the area are present in the immediate vicinity of Twentynine Palms, where Miller's detailed geologic work was done. The correlation between these rocks and those in the previously unstudied areas is based on pronounced lithologic similarities and identical interrelations among associated formations.

For the purposes of this report the formations in the area are divided into two major types: consolidated rocks and unconsolidated deposits. The consolidated rocks are virtually non-water bearing, whereas the unconsolidated deposits are largely water bearing.

Consolidated Rocks

The consolidated bedrock that forms the mountainous rim of the basin and underlies the sediments of the basin floor consists of two main rock groups of vastly different geologic ages. The older is a series of igneous and metamorphic rocks of Precambrian age; the younger is a Jurassic granite which has invaded the older rocks. Both the Precambrian and Jurassic formations are exceedingly hard, nonporous, and hence impervious to water. Small amounts of water may, however, enter the formations through fractures and joints which then function as conduits and, to a very slight extent, as storage reservoirs. Minor quantities of water may thereby be conveyed to the main ground-water reservoirs in the basin sediments. Furthermore, mountain springs emerging from crevices in the crystalline rocks generally derive their flow from water stored in the fractures. Although such supplies may sometimes be of local value for domestic use, their economic importance is usually negligible. For this reason the Precambrian and Jurassic rocks are classed as non-water bearing.

A third type of consolidated rock, a basalt of Quaternary age, crops out in a small area in the easternmost foothills of the San Bernardino Mountains. Although scoriaceous in part, and therefore probably permeable, the basalt flows are above the zone of ground-water saturation and are therefore not water bearing.

Precambrian Igneous and Metamorphic Complex

The Precambrian complex mapped by Miller (1938, p. 418–438) in the vicinity of Twentynine Palms has been found to extend around much of the basin rim and to form nearly all of the isolated bedrock hills (pl. 1). As described by Miller the complex is made up of gabbro-diorite, gneiss, granite, and monzonitic porphyry. The porphyry and gneiss are apparently the most extensively distributed of the Precambrian rock types. Both are very distinctive in their appearance, the porphyry because of its remarkably large and well-formed orthoclase phenocrysts, and the gneiss because of its strongly banded structure. The Precambrian complex is shown on the accompanying geologic map (pl. 1) as a single unit, because no attempt was made to determine the limits of the porphyry, gneiss, or lesser subunits.

Jurassic Granite Rocks

The mountains of the western and southern parts of the basin rim are composed principally of a light-colored granite, coarse-textured but equigranular, and very readily distinguishable from the Precambrian series which it has intruded. The contact between the two rock masses is particularly well exposed just west and south of Fortynine Palms Mountain, and it was in this area that Miller (1938, p. 438–443) studied the younger formation and described it as the White Tank quartz monzonite of Jurassic age. Although the exposures to the west in the Little San Bernardino Mountains are almost continuous with those described by Miller and are nearly identical in appearance, the extension of the specific term, quartz monzonite, to the rocks of this large area does not seem justified without a detailed petrographic study. The Jurassic formation will, therefore, be referred to as a granite, the term being used in its broad sense. The author's observations support Miller's tentative correlation of the White Tank quartz monzonite with the Cactus granite of the San Bernardino Mountains (Vaughn, 1922, p. 365). The areal distribution of the Jurassic granite is shown on plate 1.

Quaternary Basalt

In the vicinity of Pipes Wash at the western edge of the Twentynine Palms Basin a series of basalt flows, aggregating 200 feet in thickness, caps mesas that rise 400 to 600 feet above the adjacent basin floor (pl. 1). According to Vaughn (1922, p. 384), the flows probably occurred in early Quaternary time. They rest on a nearly flat erosional surface cut in part on late Tertiary sediments and in part on Jurassic granite.

Unconsolidated Deposits

Unconsolidated or semiconsolidated sediments of considerable thickness underlie nearly all of the basin floor. The sedimentary materials have been derived from the rapid weathering and erosion of mountainous areas composed largely of consolidated crystalline bedrock. The eroded material has been carried by running water to adjacent piedmont slopes, valley floors, and lake bottoms. The materials deposited range in size from boulders to clay, with a liberal representation of all size grades. However, medium to coarse sand, containing intermixed gravel, probably makes up about half of the total sediment in the basin. Though generally rather poorly sorted, this coarse material, as revealed in surface exposures and in wells, is porous and usually moderately permeable. Hence, it is capable of storing and transmitting relatively large quantities of ground water.

The sediments beneath the basin floor represent two main periods of deposition separated by a long interval of erosion. The older sediments, assigned in this report to late Tertiary time are by far the thickest and most widespread of the unconsolidated materials. These deposits supply nearly all of the ground water developed by well in the basin area. A comparatively thin veneer of Quaternary sediments, probably of late Pleistocene and Recent age, locally mantles the erosional surface of both the late Tertiary sediments and the Precambrian and Jurassic crystalline rocks. For the most part the Quaternary deposits appear to lie above the zone of saturation and are therefore of little importance as aquifers (water-bearing beds). However, the coarse permeable Quaternary deposits forming alluvial fans and stream-channel deposits are of hydrologic significance insofar as they permit the infiltration and downward percolation of surface water to the aquifers.

Late Tertiary Continental Deposits

The age of the thick section of continental deposits underlying the floor of the Twentynine Palms Basin has not been accurately determined. Miller's geologic map (1938, fig. 1) designates certain exposures near Twentynine Palms as late Cenozoic in age, but the text of the report does not include a discussion of these deposits. Reed (1933, p. 25) and Jenkins (1938, pl. VI) suggest a Miocene age for the same exposures, but without conclusive evidence. Because of their relations to older rocks and to the younger Quaternary basalts, and because of their lithologic similarity to Miocene and Pliocene deposits in other parts of the Mojave Desert, these deposits are inferred to be of late Tertiary age.

The depositional relations of the late Tertiary deposits to the underlying rocks are only locally exposed. On the back slopes of several tilted fault blocks, notably the Zeitz Mountains, Copper Mountain, and the southeastern Bullion range, the sediments apparently rest unconformably upon the pre-existing bedrock surface. The low knobs and patches of bedrock that protrude through the sediments in some places suggest that this old erosional surface was probably quite irregular.

The exposures that Miller examined and mapped as late Cenozoic non-marine beds occur along the Twentynine Palms Highway for a few miles both east and west of Twentynine Palms. The materials exposed here and elsewhere in the area are described below.

The hill 0.7 miles west of Adobe Road on the Twentynine Palms Highway is composed largely of medium to coarse sand containing stringers of gravel and cobbles. The material is poorly sorted, subangular to subrounded, and has a light orange-tan hue. Quartz is the dominant mineral constituent, but unweathered grains of feldspar are abundant. Although the bedding is not well defined, low-angle cross bedding can be observed in many places. The sediments are largely unconsolidated, being neither compacted nor strongly cemented. As a result weathering is rapid and the products of weathering accumulate faster than the infrequent runoff can remove them. The true nature of the deposit is therefore masked except along the steep sides of fresh gullies.

A complete description and accurate measurement of the stratigraphic section exposed in the hill west of Adobe Road was not made. However, distortion of the sediments by movements on adjacent faults has caused the beds to dip northeasterly at angles up to 55°, thereby exposing in the hill a stratigraphic thickness of more than 500 feet of material.

The low, northwest-trending ridge 2 to 4 miles east of Twentynine Palms is also composed of the late Tertiary sediments. Flat-lying sand and gravel beds similar to those in the hill west of the town are well exposed in an aggregate pit near the southeastern end of the ridge. At the northwest end of the ridge the strata are tilted northerly about 35°, revealing about 1,200 feet of sediments, predominantly sand.

Rather massive beds of fine to medium sand compose an estimated 55 percent of the exposed section. The material is moderately to well-sorted, is generally light in color, and locally contains iron-stained beds. Quartz is predominant, feldspar is prominent, and mica (biotite) occurs in small to moderate quantities. Crudely stratified beds of poorly sorted medium to very coarse sand, containing stringers of gravel ranging from pebbles to large cobbles in size, make up 30 percent of the section. The color of these beds ranges from light to medium orange-tan according to the amount of iron stain present. Quartz and feldspar are the chief minerals. Differences in the hardness of the beds are controlled by the amount of calcareous cement present. Some beds are quite highly cemented and are correspondingly very hard. About 10 percent of the section is composed of very fine, silty, micaceous sand, pale green in color and quite soft. The remaining 5 percent consists of light colored silty, sandy clay, as well as a few thin bands of white sandy lime. For the most part, fine, medium, or coarse deposits occur in zones 5 to 50 feet thick, within which individual beds average 10 to 30 inches in thickness. In the upper part of the section, there appears to be a slight tendency toward a general coarsening of the material.

Between Mesquite and Deadman Dry Lakes, beds of similar appearance but containing a greater proportion of fine material are exposed in the east-facing scarp which transects the transverse arch.

Northwest of Deadman Lake in the Mud Hills are the best and most extensive exposures of the late Tertiary deposits. Uplift and deformation of the strata and extensive dissection by erosion have revealed a thick section of sediments almost identical to those described above. Structural complexities, which could not be worked out in the time available, prevented measurement of the total stratigraphic thickness exposed in this area; it probably amounts to at least 1,500 feet and may exceed 2,000 feet. However, along the southeastern edge of the Mud Hills where the beds dip gently to the south beneath the Deadman Lake basin, it was possible to measure and describe a representative stratigraphic section 860 feet thick. The description of this section is shown in table 3.

Table 3. Stratigraphic section in late Tertiary continental deposits exposed in the Mud Hills, about 4.5 miles northwest of Deadman Lake

[ft, foot; in, inch]

Material	Thickness (ft)
Silt, fine sandy, highly micaceous, pale olive-green; and sand very fine, micaceous, light-tan; interbedded in 6- to 24-in beds. Top not exposed	22
Clay, silty, pistachio-green	6
Sand, very fine, silty, biotitic, light yellow-tan	22
Sand, medium to coarse, angular to subangular, arkosic; and some gravel; light rusty-brown; cemented in thin beds (1–6 in)	90
Sand, mostly medium to coarse, angular to subangular, arkosic, light rusty-brown; fairly massive, somewhat cross-bedded, numerous 1- to 3-ft beds of cemented coarse sand and gravel; occasional beds of fine slightly silty sand, rather massive with very thin laminar biotite concentrations	220
Sand, very fine, silty; and silt; some silty clay; highly biotitic, pale buff, soft to punky, all interbedded, 1- to 3-ft beds	120
Silt; silty clay; highly biotitic, light tan-gray, soft; and sand, very fine, silty, highly biotitic, light yellow tan, punky; all interbedded in 6- to 20-in beds	135
Clay, mildly calcareous, light to dark tan, blocky, hard; contains thin stringers of fine sandy silt every 5 to 10 ft	55
Sand, very fine, silty, green-yellow with limonite streaks	3
Clay, non-calcareous, very dark chocolate-brown, very hard (ferruginous cement), blocky fracture	2
Clay, silty, highly calcareous and gypsiferous with large selenite crystals, olive-green, very hard, flocculent structure	6
Clay, somewhat silty, light chocolate-brown, moderately soft, blocky structure	17
Lime, fairly hard, white	2
Silt, sandy, light rosy-tan; and sand, fine to coarse, muddy, poorly sorted, angular to subangular, arkosic, light to dark tan; interbedded in 2- to 4-ft beds	100
Sand, mostly coarse, some medium, very muddy, very poorly sorted, angular to subangular, arkosic, obscurely bedded, light tan to dark chocolate-brown, rather hard; contains numerous stringers of fine to coarse gravel and a few boulders. Bottom not exposed	60
Total section	860

From table 3 it may be noted that 370 feet, or 43 percent of this section, is composed of coarse material (chiefly coarse sand and gravel); 405 feet, or 47 percent, of fine material (chiefly sandy silt and very fine silty sand); and 85 feet, or 10 percent, of very fine material (chiefly clay). Zones of clay and silt, which were probably deposited in perennial as well as intermittent lakes, may by traced for a mile or more without significant lateral variation. On the other hand, zones of coarse sand and gravel, probably laid down as ancient alluvial fans, differ in texture and bedding from place to place, although the general characteristics of the zone persist over considerable distances. The materials described in table 3 include nearly every type of sediment observed in the Mud Hills area, although the percentages of the various size fractions differ considerably from place to place.

A type of sediment not represented in the above section is a bed of light pumiceous tuff, at least 75 feet thick, which crops out about 2 miles southeast of Coffin Mountain. The deposit is crudely and irregularly stratified and is streaked with light brown and green clay, suggesting that it may have originated, at least in part, as a volcanic mudflow. Concentrations of chert fragments were found on the land surface underlain by this material, but the mode of occurrence within the bed was not observed. The relative position of this tuff bed in the whole stratigraphic section could not be readily ascertained. However, it was seen to underlie directly a relatively thin series of silts and fine sands, mostly light olive green and yellow tan in color. From structural evidence, it is inferred that the tuff lies considerably lower in the formation than the section described in table 3.

South and southwest of Coffin Mountain several washes draining into the Emerson Dry Lake trough have deeply dissected the upwarped surface, thereby revealing late Tertiary beds, which there consist chiefly of rather massive medium to coarse sands with some intercalated gravels. About 2 miles southwest of test well 6 similar sediments are well exposed in a hill approximately half a mile in diameter and about 200 feet high. Thus, a string of discontinuous but closely spaced exposures of highly similar continental deposits extends from the vicinity of Twentynine Palms, where Miller mapped them, up the east side of the basin and thence westerly across much of its northern part. An attempt will be made to correlate these exposures in more detail in a later report.

Most of the basin floor is an erosional surface on which the characteristic inability of desert erosion to keep pace with desert weathering is evidenced by the mantle of residuum which largely masks the lithology and structure of the underlying sediments from which the residuum was derived. However, at scattered localities, generally along the cut bank of a wash, it is possible to find small exposures of gently dipping beds composed of silts, sands, and gravels similar to those found in the extensive exposures already described. The conclusion that the materials are all part of the same formation is well supported by their apparent structural relations and by the subsurface samples obtained from the U.S. Navy test wells.

The identification of the material throughout most of the basin floor as part of the late Tertiary formation is of considerable geologic and hydrologic significance. It means, among other things, that characteristics observed in areas of extensive exposures, such as the Mud Hills, may with due reservation be extrapolated through the areas where test wells were constructed and thereby beneath much of the basin floor. For example, observations regarding the lateral extent and persistence of zones of fine, medium, and coarse material will be of considerable assistance in determining ground-water storage capacity.

The thickness of late Tertiary sediments underlying the basin floor cannot be stated with accuracy because no wells in the area are known to have penetrated to bedrock. The depths of the test wells (400 to 800 feet) constitute minimum figures for the thickness of the sediments in their respective localities (see table 4 and pls. 1 and 2). In view of structural considerations, however, a few general statements can be made. The stratigraphic section exposed in the Mud Hills, which is estimated to be 1,500 to 2,000 feet thick, seems to dip beneath the Deadman Lake area, indicating that an equivalent or greater thickness of late Tertiary sediments probably overlies the bedrock in that vicinity. The regional dip of the late Tertiary strata, as revealed in a few exposures scattered across the basin floor, is in an easterly direction and ranges from 1° to 4°. This inclination is greater than the easterly slope of the land surface. In general, therefore, the thickness of sediments diminishes progressively toward the west so that the underlying bedrock surface crops out in a number of buttes in the western part of the basin and ultimately rises to form the San Bernardino Mountains.

Over most of the basin floor the only material lying on top of the late Tertiary sediments is the thin mantle of sandy to gravelly residuum, consisting of the nearly structureless and largely untransported material produced by weathering of the late Tertiary sediments. An interesting specialized variety of this residuum mantles the tops of low hills and the crests of interfluvial ridges. These nearly flat surfaces are covered with a very thin veneer of lag gravel known as "desert pavement." This material is a concentrate of the coarsest fragments derived from late Tertiary sediments which once lay above the present surface but have been almost entirely removed by gradual erosion. On the nearly flat ridge crests both the quantity and velocity of surface runoff are so low that its carrying power is insufficient to remove the coarse material. Therefore, as gradual surface degradation uncovers pebbles, cobbles, and occasional boulders in the sediments being eroded, these fragments lag behind, perched on the surface, while the finer particles of the matrix are removed by wind and infrequent runoff. The surfaces of the lag gravels in places resemble a cobblestone pavement and are characteristically hard enough to support an automobile.

Quaternary Alluvium

A comparatively small part of the basin floor is mantled by Pleistocene and Recent alluvium deposited by ephemeral or intermittent streams. For the purpose of reconnaissance mapping, these deposits, which rest unconformably upon the Precambrian, Jurassic, and late Tertiary formations, have been grouped as undifferentiated Quaternary alluvium and are shown as such on plate 1.

Extensive deposits of Quaternary alluvium are largely confined to alluvial fans and slopes along the mountain fronts, stream-channel deposits in the major washes, and alluvial plains on the valley floors around the playas.

The most extensive alluvial slope is that built out from the base of the Little San Bernardino Mountains by a number of small coalescing fans. The fans are composed of fresh, rather angular debris, chiefly quartz and feldspar grains, derived from weathering of the Jurassic granite of the mountain front. The deposits consist chiefly of loose, light-colored, poorly sorted sand and very fine gravel, containing some silt and clay. Fragments coarser than fine gravel are uncommon even at the heads of the fans. This results from the tendency of the granite to break down on weathered surfaces into the individual crystalline grains of which it is composed, rather than to develop closely spaced fractures that would permit the detachment of cobble-sized fragments.

Although the Quaternary alluvium has been mapped as a single unit, material of two slightly different ages may be observed along most of the Little San Bernardino Mountain front. Older fans, which were deposited adjacent to the mountain scarp, have been incised by the present stream channels; younger alluvial material has been deposited farther down the slope.

Along the western front of the Bullion Mountains, depositional conditions are similar except that the proportion of older alluvium is greater. The sedimentary materials are also generally similar, quartz and feldspar grains being the chief constituents, but some differences are caused by the differences in source rocks. Fragments of dark iron-magnesium minerals, which are plentiful in the Precambrian rocks, darken the sediments directly and on weathering produce iron oxide, which in many places stains the deposits a dark red-brown and in part cements them. The Precambrian rocks readily break into cobbles and boulders, and these are an important part of the fan deposits, which are generally coarse and very poorly sorted. Large sharp fragments of an acid dike rock are commonly a major constituent. Several mudflows along the east side of Deadman Lake have carried much very coarse detritus, including many boulders, out onto the edge of the playa. A minor feature along the Bullion front is windblown sand deposited in several places high on the mountain slope. The areas of sand are small and scattered and are not shown on the geologic map (pl. 1).

Small areas along the eastern edge of the San Bernardino Mountains are covered by dissected older alluvium. In a few places, Recent alluvium covers older sediments and bedrock to depths of several feet.

The chief mappable deposits of Recent stream-channel alluvium are in Pipes Wash (which is as much as half a mile wide), in Surprise Spring Wash, and in the wash that empties into the southern end of Mesquite Dry Lake. The thickness of alluvium in not known; it probably is nowhere much greater than 100 feet, and probably averages 20 to 25 feet. As in the lesser washes, most of the material deposited is coarse sand and very fine gravel. Ideally, finer sand would be deposited at the lower ends of the washes near the centers of the undrained basins, and silt and clay would settle out after the water had ponded, thus forming playa deposits in the very bottoms of the basins.

However, the runoff of many storms is not sufficient to exceed the seepage losses into the streambeds, so that the flows commonly disappear long before they reach the playas. When this occurs all the finer suspended particles, including some silt and clay, are deposited in the streambeds. This material filters into the interstices of the coarser material and thereby somewhat reduces its permeability.

Where Pipes Wash enters the Emerson Dry Lake trough south of the playa, a considerable amount of sand has been spread, probably thinly, over a wide area. Reworking by the wind has further distributed the material, although dunes have not formed. Farther south the bottom of the trough has been alluviated by detritus from the uplifted sediments flanking the southwestern end of Coffin Mountain.

Much of the lower part of Copper Mountain Valley seems to be floored by alluvium, although in this area some of the so-called alluvium may be residuum that mantles the late Tertiary rocks.

Along the southwestern side of Deadman Lake two small but well-developed alluvial fans have spread out onto the playa from the mouths of fair-sized wash. Farther to the north the Surprise Spring Wash has covered a considerable area just west of the playa with medium and fine sand. Much of this material has been picked up by the wind and redeposited around the mesquite bushes that line the western side of the playa, forming an effective windbreak. Windblown sand falling in and around the bushes has formed dunes about 20 feet high. In many cases the growth of the mesquite has kept pace with the deposition of sand so that the bushes appear to grow from the tops of the dunes. On some of the larger dunes no trace of a bush may be visible, but in several instances slight shifting of an apparently normal dune has revealed a mesquite skeleton. Whether all the dunes were formed around bushes is not known, but most of them probably originated in this manner. Below the Surprise Spring Wash the dunes appear to have encroached some distance upon the playa. For almost a mile they form a continuous barrier along the present shore so that runoff from the wash is prevented from reaching the playa.

Along the western side of Mesquite Dry Lake several small washes have deposited a band of alluvium half a mile to a mile in width. Reworking by the wind has produced an extensive area of high dunes formed about the vegetation that flourishes near the bottom of the alluvial slope and on the eastern margins of the playa. To the south a band of sand dunes and mesquite extends along the west side of the Mesquite Fault to the small unnamed playa, which is largely covered with dunes and vegetation.

Quaternary Lake Deposits

The deposits that make up the beds of Emerson, Coyote, Deadman, and Mesquite Dry Lakes and the unnamed smaller playa are distinctive in their geologic features and their hydrologic properties. These sediments consist largely of clay and silt deposited from shallow bodies of standing water which cover the bottoms of the basins during periods of heavy runoff.

The lake deposits are believed to rest unconformably upon the late Tertiary sediments; laterally they interfinger with contemporaneous late Pleistocene and Recent alluvium. The thickness of the lake beds is known only in the case of Mesquite Dry Lake, where two bore holes revealed 45 and 49 feet of clay and silt overlying coarse sand. Probably, the deposits in the other major playas are of the same general order of thickness, whereas those in the smaller playas, which are probably younger, may be much thinner. The lower strata of the lake deposits were probably laid down during late Pleistocene time in perennial or intermittent lakes which were formed when movements of the earth's crust disrupted the pre-existing drainage system.

Deposition has continued to the present, though doubtless at a reduced rate because of the increased aridity of modern times. Recent sedimentation may have been largely counterbalanced by wind erosion, the capabilities of which are amply demonstrated by the towering dust clouds that often rise above the playas.

Lake deposits in general, being composed almost entirely of clay and silt, are dense and highly impermeable. They will neither yield water to wells nor permit surface water ponded on the playas to percolate downward to the ground-water body. The deposits of many playas are so impervious that they merely become "slick" on the surface, even when covered with water for a prolonged interval; others, slightly more permeable, become soft to depths of many inches. Lake deposits may act as confining layers, thus producing artesian pressure in underlying aquifers. Such pressure exists beneath the western half of Mesquite Dry Lake. Lake deposits that are slightly permeable give rise to "discharging" playa surfaces where the ground-water level is within about 10 feet of the surface. Continuous capillary rise of water renders the playa mushy, and evaporation leaves behind a "snowy" deposit of the water's dissolved salts.

The pressures exerted by salts crystallizing in the interstices of the uppermost lake deposits are believed to produce the buckled, hummocky surface typical of a discharging playa. The playa surfaces near the margins of Emerson Dry Lake and on much of the western half of Mesquite Dry Lake are of the discharging type. Where the lake deposits are apparently most impervious, as in the center of Emerson Dry Lake, or where the depth to water is more than about 10 feet, as on the eastern half of Mesquite Dry Lake, the playa surfaces are of the "dry" type. The dry surface areas of these two playas are usually as hard as pavement and very smooth. However, where the uppermost lake deposits of a dry (type) playa are apparently slightly coarser and more pervious, as in Deadman and Coyote Dry Lakes and the smaller playas, the surface develops a crumbly, flaky veneer, probably as a result of saturation by occasional storms, followed by desiccation during the long dry periods.

Geologic Structure

Regional Structure

The Twentynine Palms Basin is the broad middle part of a great structural trough that extends from Lucerne Valley To Dale Dry Lake. On the southwest the trough is bounded by a composite mountain mass—including the San Bernardino, Little San Bernardino, and Pinto Mountains—which has been raised between a series of eastward-trending faults.

The western and southwestern limits of the trough are determined in part by the series of intersecting faults along the northern flank of the San Bernardino Mountains. Farther to the southeast, the elevated land surface of the San Bernardino Mountains descends into the Twentynine Palms Basin, probably by a combination of step-faulting and crustal flexure. Along its southern edge the trough is limited by the eastward-trending Pinto Fault along which the irregular front of the Little San Bernardino and Pinto Mountains has been raised.

The northern and northwestern boundaries of the trough are formed by the Ord, Newberry, Bullion, and Sheep Hole Mountains. These are fault-block mountains of typical basin-and-range type whose major structural features are controlled by northwest-trending normal faults. Most of the northeastern boundary of the trough is formed by the fault zones along the eastern flanks of the Newberry and Bullion Mountains. At its southeastern end the trough is closed by the precipitous southwest-facing fault scarp of the Sheep Hole Mountains.

Structure in the Twentynine Palms Basin

In the Twentynine Palms Basin, as in the surrounding mountains, the geologic structure is dominated by faulting, although the magnitude of the movements is not as great. Folding of the sediments is of minor importance, although it is moderate to intense along faults and in localized areas. Beneath most of the basin floor the deposits are only gently warped.

The main fault system is similar to that in the surrounding mountains, and consists of apparently normal faults with a northwesterly trend. A secondary fault system trending almost due north is prominent, and in addition, there are two major east-west faults crossing the southern end of the basin. The pattern of surface drainage on the basin floor is largely fault controlled. In general, no effort was made to map the faults in the consolidated rocks unless they appeared to extend into the sediments.

A number of "probable or doubtful" faults are shown on plate 1. For the most part these have been determined by topographic features which, though well defined, cannot be definitely attributed to faulting. Nevertheless, because of the demonstrated hydrologic barrier effect of several known faults it seems desirable to locate on the map these features whose possible barrier effects might be of concern in a future program of test-well or supply-well drilling. Fortunately, the existence and location of the most important faults cutting the basin floor are unquestionably demonstrated not only by topography but by vegetation and hydrologic evidence as well.

Surprise Spring Fault

The Surprise Spring Fault, so named because the spring emerges along its trace, is probably the most pronounced fault in the basin floor. It strikes N. 26° W. and extends from Coffin Mountain southeastward along a rift zone that is well defined as far as the spring but gradually dies out to the south. Movement on the fault has raised the block to the west, as is shown by the dissection of its surface (pl. 2). The greatest displacement is along the northern part, where Coffin Mountain has been raised above the plain.

The irregular topography along the Surprise Spring Fault indicates that the feature might more accurately be termed a fault zone or rift—an irregularly fractured and sheared zone, a quarter of a mile or more in width. The numerous dikes that cut the crystalline rocks of Coffin Mountain more or less parallel to the fault suggest that the fault follows a rather ancient and deep-seated zone of weakness in the bedrock, along which fracture and slippage have apparently occurred on several slightly different planes. Also, west and south of Surprise Spring for a distance of several miles the country is considerably broken by a number of apparently related minor faults which are difficult to locate precisely.

The Surprise Spring Fault is an important barrier to the eastward movement of ground water. The barrier effect there, as along other major faults in the area, is probably caused by compaction and textural alteration of the water-bearing strata immediately adjacent to the fault, by the steep tilting and offsetting of alternating beds of low and high permeability, by the smearing of highly compressed clay and fault gouge across the sheared ends of the strata in the actual plane of the fault, and by cementation of the fault zone by deposition of calcium carbonate from mineralized ground water.

Natural evidence of the barrier is provided by Surprise Spring, which rises where the incised Surprise Spring Wash traverses the fault. The wash, being the lowest point along the fault, may be considered the spillway over the underground dam. Ground water rising to the spillway creates a discharging area 0.6 miles long and 0.4 miles wide that supports a considerable growth of mesquite, grasses, and other vegetation. About 30 to 35 years ago a well was drilled about 200 yards west of the fault to a reported depth of about 30 feet. Although the land surface at the well is about 10 or 20 feet above the springs, a natural flow was developed which caused the springs to dry up. In December 1951 the flow of the well was about 10 gpm.

Mesquite Fault

The Mesquite Fault extends along the bottom of the trough at the west side of the Bullion Mountains. It may be traced from near the foot of the Pinto Mountains on the south to the Mud Hills on the north. The chief topographic expression of the fault is near its southern end where several low ridges along the east side of the fault suggest rather recent movement of this segment. Farther to the north, where the fault crosses Mesquite Dry Lake the playa surface is flat, or nearly so, and virtually unaffected. Furthermore, the thickness of lake clays on either side of the fault is nearly the same (45 and 49 feet), indicating little movement on this part of the fault since the lake bed began to form, probably in late Pleistocene time.

However, at either end of Mesquite Dry Lake and across the smaller playa south of it, the fault is marked by a sharp line of demarcation between the area of dense mesquite and sand dunes on the west where ground water is at or near the surface, and the barren area on the east where the depth to water is more than 200 feet. In addition, across Mesquite Dry Lake itself the fault is roughly marked by a somewhat irregular line between a discharging surface on the west and a dry surface on the east. Thus, although the fault has not displaced the playa surfaces to a noticeable degree, its existence within the lake deposits is suggested by the ground-water barrier.

Northward from Mesquite Dry Lake the land surface rises above the water table until even the tap roots of mesquite, which may draw water from as deep as 45 or 50 feet, can no longer reach it. Hence, this useful natural indicator of shallow ground water is not present to locate the fault line. The position of the barrier is, however, closely controlled by differences in water level in several wells. Farther north, mesquite is found all along the western edge of Deadman Lake, suggesting that the fault continues northward through that playa, probably near its western edge. The fault apparently diminishes northward; it is not seen to cut the exposures in the Mud Hills and may be terminated by another fault which strikes N. 60° W. near the southern edge of the Mud Hills (pl. 1).

Inconclusive evidence indicates that uplift has occurred on the east side of the Mesquite Fault. Near its southern end low ridges have apparently been uplifted along the eastern side. Farther north the beds exposed in the scarp northwest of Mesquite Dry Lake dip westward with increasing steepness near the fault owing to upward drag exerted by the rising eastern side of the fault. The Mesquite Fault may be related to the uplift of the Bullion Mountains.

Oasis Fault

About 0.7 miles north of the mouth of Pinto Cove the Twentynine Palms Oasis extends for almost a mile along a fault trace trending N. 84° W. Recent movement along the fault has created a barrier which forces ground water moving northward out of Pinto Cove to rise to the surface along a line of springs and seeps. The prominent strip of dense vegetation along the spring line includes mesquite, arrow weed, and salt grass, as well as large willows, cottonwood trees, and the "twentynine" palms that give the locality its name.

The Oasis Fault extends eastward across the mouth of Pinto Cove, where it can be traced even across the recent fan deposits, to the foot of the Pinto Mountains, where uplift on the northern side has raised Precambrian bedrock against late Tertiary sediments. West of the oasis the fault can be traced through the southern side of the hill of late Tertiary sediments 0.7 miles west of Adobe Road.

Farther west the fault is concealed by alluvium, but it probably ties into the extensive east–west fault which can be traced, with occasional interruptions due to alluviation, from a point on the Twentynine Palms Highway 2 miles west of Adobe Road as far west as the upper end of Yucca Valley. Relative movement along this western part of the fault has also been up on the northern side, and it has caused at least a part of the uplift of the southeastern prong of the San Bernardino Mountains, the Bartlett Mountains, and the southern end of Copper Mountain. In the western part of Copper Mountain Valley and in parts of Yucca Valley, the fault is marked by a very fresh scarp some 25 or more feet high which offsets the stream-channel alluvium in the bottom of the trough, with the result that at the present time there is a two-level wash in the trough. The higher level on the upthrown side of the fault carries the runoff from the northern side of the valley in a deeply entrenched channel, whereas the lower wash which receives drainage from the fans along the southern slope is only slightly entrenched.

Other Faults

Many other faults of considerable size occur in the area, several of which are briefly described. The Pinto Fault is shown on the geologic map of California (edition of 1938) and other maps as running eastward along the northern front of the Little San Bernardino and Pinto Mountains, accounting for the uplift of this front. Yucca Valley is a graben or down-dropped block, lying between the Pinto Fault on the south and the western extension of the Oasis Fault on the north. The Pinto Fault cannot be located with accuracy except perhaps at the western end of Yucca Valley because along most of the front it is covered by alluvial fans which postdate any movement on the fault.

The probable fault origin of the north-trending ridges that cross the center of the basin floor was noted in the discussion of landforms. The westernmost fault, near test well 9, has probably undergone the greatest movement. Uplift on the eastern side of the fault has been greatest along the southern part where Coyote Mountain and another large bedrock hill have been raised. Diminishing uplift along the northern part of the fault has combined with the movement on the Surprise Spring Fault to the east to elevate the whole intervening area as a block. Data obtained from nearby wells indicate that the northern half of this fault does not form a hydrologic barrier.

The faults along the other two major north-trending ridges, those immediately east of Copper Mountain, are also uplifted on their eastern sides. Again the movement has been greatest at the southern end and diminished gradually toward the north. The eastern and larger of these two faults may be traced north almost to the Mud Hills, although the topographic expression, and probably the movement, are relatively slight along most of the northern part. Comparison of water levels in test wells 10 and 8 indicates that the northern end of the fault does not form an appreciable barrier to ground-water movement.

Another large fault is the Emerson Fault along which the northeast-facing scarp of the Deadeye Mountains has been raised. This fault extends southeastward from the southern end of Deadeye Mountain for about 8 miles, crossing the broad area alluviated by Pipes Wash and raising a 200-foot hill of late Tertiary sediments near its southern end. As it dies out it appears to be striking nearly into another fault which, though striking in almost the same direction, shows uplift on its eastern side. This southern fault is probably a slightly different surface expression of the same deep-seated shear that produced the Emerson Fault. The water level in test well 9 indicates that the southern fault does not form a barrier to ground-water movement, but on the basis of reported water levels in wells south of Emerson Dry Lake, it is believed that the Emerson Fault may form a partial barrier for several miles south of Deadeye Mountain.

Farther up Pipes Wash the elongate butte immediately southwest of Spy Mountain has been raised by faulting along its northeastern side. This fault continues southeastward past the end of the butte, across Pipes Wash, and may extend as far as the Zeitz Mountains. Just south of the butte on the west side of the fault are several wells in which the depths to water are shallow (reportedly between 40 and 60 feet), demonstrating that this fault effectively dams some of the recharge moving eastward from the foothills of the San Bernardino Mountains.

Still farther west a major arcuate fault skirts the base of the San Bernardino Mountains and extends northwestward beyond the limits of the geological map (p. 1). Movement on this fault has been greatest toward its northern end where uplift on the western side has raised a series of large bedrock ridges. Near the southern end the most recent uplift has been on the eastern side, and it has apparently raised the granite barrier through which Pipes Wash has cut a narrow throat just after emerging from the foothills.

Folds in the Basin Sediments

Folding of the late Tertiary deposits is only a minor structural feature of the basin. Strong folding has been found only in the Mud Hills, where localized compressive forces, apparently from the northeast, have developed a series of relatively tight, southeast-trending and plunging anticlines and synclines.

In the east-facing scarp forming the western side of the trough between Mesquite Dry Lake and Deadman Lake a cross section of the eastern end of the transverse arch is exposed. The exposures in the scarp reveal that this west-trending topographic arch is also, at least at its eastern end, a structural arch or a broad low anticline. The bedrock high which would be expected to underlie the anticline, apparently crops out in the Zeitz Mountains, which form the western end of the arch.

Probably the broad, shallow, southern part of the Emerson Dry Lake trough is a synclinal structure, although the northern part is largely of fault origin.

The drag folds associated with the major faults probably have the most hydrologic significance. Inasmuch as the unconsolidated and semiconsolidated sediments are very weak and incompetent, they are readily dragged into sharp folds by the shearing action along the fault planes. Vertical or even slightly overturned beds have been observed in several places immediately adjacent to the fault plane; whereas, 20 feet away from the fault the bedding may be only slightly affected. Such extreme short-radius folding requires a great deal of squeezing, stretching, and slipping in the sedimentary strata and thereby alters the texture of the deposits so that their permeability is greatly reduced. Clayey, fine-grained beds, which are common throughout much of the stratigraphic section, react plastically, being squeezed thin and smeared along the fault plane. Thus, the effects of drag folding may account for much of the pronounced barrier effect encountered along faults that cut the late Tertiary sediments.

OCCURRENCE OF GROUND WATER

Ground-Water Basins

In the discussion of landforms it was pointed out that the Twentynine Palms Basin is divided into a number of subbasins by relatively minor drainage divides. Similarly, the ground-water body, which is contained in the sediments beneath the basin floor, is divided into a number of ground-water basins, primarily by several major faults which impede the flow of ground water. Three relatively large ground-water basins, which are of potential importance in the development of a water supply for the Marine Corps Training Center, have been defined and explored by the geologic reconnaissance and the test drilling. In this report, these basins are designated Mesquite Basin, Deadman Basin, and Surprise Spring Basin, after salient features within their respective confines. Because many local residents depend on the Mesquite Basin for their water supply, the Navy desired to avoid additional heavy withdrawals from this basin. Therefore, the exploration has been concentrated in Deadman and Surprise Spring Basins.

Mesquite Basin

Mesquite Basin lies immediately north of the town of Twentynine Palms and west of the site of the Marine Corps Training Center. It is bounded on the east by the Mesquite Fault, on the south by a fault in the town of Twentynine Palms, on the north by the transverse arch, and on the west by the faults east of Copper Mountain or by the mountain itself.

The relative watertightness of the various boundaries has not been investigated. However, the Mesquite Fault is highly impervious; a water-level differential across the fault of more than 200 feet is known to exist within a distance of less than 100 yards.

The ground water in Mesquite Basin has been moderately developed by residents of the northern part of Twentynine Palms. The old U.S. Navy supply wells 1 and 2 also tap this basin. In addition a considerable quantity of water is discharged annually by evapotranspiration from the heavily vegetated area of shallow ground water along the western sides of Mesquite Dry Lake and the small playa just south of it.

Test well 1 was drilled in the northern part of Mesquite Basin just south of the transverse arch (table 4). The well was drilled to a depth of 400 feet through late Tertiary deposits. The depth to water in the well is 81 feet. A rather high proportion of the saturated material encountered consisted of clay, silt, and fine sand; only 45 percent of the material was considered to be water yielding. Results of the bail tests were largely inconclusive because sand heaved up into the well 30 to 40 feet. However, during test pumping the well yielded only 180 gpm with a 97-foot drawdown, demonstrating that good yields cannot be obtained from fine-grained sections of the late Tertiary deposits.

The altitude of the water table in the eastern part of the basin, where most of the development has occurred, is about 1,760 feet, and the depth to water ranges from about 5 to 50 feet. The quality of the water in this basin varies from place to place but generally is poor, chiefly because of the presence of fluoride in very objectionable quantities (up to 15 parts per million). The concentration of fluoride is particularly high near Mesquite Dry Lake. The fluoride content in old Navy supply wells 1 and 2 is 7.5 and 11 ppm, respectively; content in well 1 is 8 ppm.

Deadman Basin

Areal Extent

Deadman Basin is immediately north of Mesquite Basin and about 6 to 8 miles north of the new camp site. It is bounded on the east by Mesquite Fault, on the south by the transverse arch, on the west by the Surprise Spring Fault, and on the north by the faults and folds of the Mud Hills. As so limited, Deadman Basin averages about 5 miles in width and 10 miles in length, thus including an area of about 50 square miles.

Up to the time of the test-drilling program, the basin contained only two active but little-used wells—a windmill well in the southeast corner of the basin and old Navy supply well 3 at the western edge of Deadman Dry Lake. Test wells 2, 3, 8, and 10 were drilled in the central part of the basin to explore the water-bearing deposits, the depth to water, the quality of the water, and the yields of the deposits.

Water-Bearing Deposits

Test wells 2, 3, 8, and 10 (pl. 1) were drilled to depths of 526, 512, 800, and 501 feet, respectively. The water-bearing materials penetrated are the late Tertiary continental deposits. Approximately 50 percent of the saturated material encountered was water-yielding sand and gravel. Test well 8, drilled to a depth of 800 feet, probably penetrated the same water-bearing deposits encountered in the other three test wells, but below a depth of 686 feet the materials were fine grained. Because of the thick section of water-bearing materials above 686 feet, it was not considered necessary to explore deeper.[3]

Owing to the large quantity of loose, running sand encountered in these wells, it was not possible to perforate the full water-yielding section in any of the wells. The Mills knife used for perforating the test wells cut a slot in the casing 3 in long and at least 0.25 in wide. Consequently, to avoid risk of having the well fill with sand when pumped, the casing could be perforated only opposite materials having at least a moderate content of gravel. Even with the care exercised in selecting perforated intervals, test well 10 sanded up partially during development.

In the deeper parts of test wells 2 and 8, many thin cemented zones of sand and gravel occur. These zones have not been classed as water bearing even though it is known that fair yields can be obtained from them. Most of the material tested in test well 8 was slightly cemented to cemented; nevertheless, the yield was good.

Quality of Water

From the standpoint of human use, the average quality of water in Deadman Basin is better than in Mesquite Basin, but considerably poorer than in Surprise Spring Basin. In Deadman Basin the total dissolved solids are higher but the fluoride content is lower than in Mesquite Basin.

In Deadman Basin the fluoride content in the test wells decreased westward from Deadman Dry Lake and slightly with depth. In test well 3, the fluoride concentration decreased from 7.5 ppm at 236 feet to 2.5 ppm at 470 feet, and was 4 ppm after an 8-hour pump test. Similarly, the fluoride concentration in test well 8 decreased from 4 to 5 ppm at about 200 feet to 3 ppm at 653 feet. However, it increased to 4 ppm at 800 feet. Surprisingly, when the well was pumped, the fluoride content dropped to only 1.5 ppm. A recheck analysis of a second sample gave a value of 1.4 ppm. The reason for the reduction in fluoride after pumping is not known.

The concentration of total dissolved solids in the Deadman Basin test wells is only slightly greater than that of Colorado River water and averages about 800 ppm. Unlike the fluoride content, the total dissolved solids remain about constant from well to well. However, in test well 10 the concentration is somewhat less, averaging about 640 ppm.

Yields of Test Wells

An evaluation of the yields of the test wells is being made by Neptune and Gregory, Architects and Engineers, under the supervision of Mr. Warren O. Wagner, consulting engineer, and will be presented by them in a separate report. In general, the pump tests made in Deadman Basin show that old Navy well 3 and all the test wells except no. 3 have good yields. The poor results obtained for test well 3 may be due to some structural defect in the well, possibly faulty perforations.

The bail tests made during well construction (table 6) show that, in general, the coarser materials are moderately permeable and would be capable of yielding large quantities of water to properly constructed supply wells.

Water Levels in Wells

The depth to water in wells in Deadman Basin ranges from 25 feet in old Navy well 3 to 189 feet in test well 10. The depth to water is almost a measure of the differential in surface altitude from well to well because the water-level gradient is nearly flat. Plate 2 shows the water-level profile across the area where known or controlled.

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[3] For detailed records of the test wells see tables 4, 5, and 6 at end of report.

On the basis of crudely determined barometric levels, the altitude of the water surface is approximately 1,820 feet above sea level at test well 10 and about 1,800 feet at old Navy well 3. Thus, it appears that water is moving eastward to southeastward through the basin.

Surprise Spring Basin

Areal Extent

The Surprise Spring Basin is about 12 miles northeast of the new camp site. The best defined boundary of the basin is formed on the east by the Surprise Spring Fault, which separates the basin from adjacent Deadman Basin to the east. The southern boundary apparently consists of a structural complex involving the gentle folding of the transverse arch and faulting of a somewhat indeterminate nature. However, the deep water level in test well 11 indicates that this well lies south of the basin. The basin probably extends westward as far as Zeitz, Goat, and Deadeye Mountains, and may extend between the Zeitz Mountains and Goat Mountain as far as the fault that crosses Pipes Wash. Emerson Fault may form a partial ground-water barrier across the lower end of Pipes Wash. To the north the basin may extend as far as the bedrock hills north of Emerson Dry Lake.

Thus, the width of Surprise Spring Basin reaches a maximum of approximately 9 miles at its southern end, narrows northward to about 2 miles, and averages about 5 miles. Its maximum length is about 20 miles, but the average is about 15 miles. The area of the basin is roughly 100 square miles. It should be pointed out that maximum limits for both Deadman and Surprise Spring Basins have been given here. It is expected that the more detailed studies to be undertaken during the 1952–53 fiscal year will define these limits and areas more accurately.

Ground-Water Development

There are about 10 wells in Surprise Spring Basin: 6 are domestic and 4 are irrigation wells which are about 2 to 3 miles southeast of Emerson Dry Lake. The area of irrigation development is relatively new and currently expanding. It may have a pronounced effect on the proposed development of a Navy supply from the same ground-water basin. Furthermore, in Pipes Wash area adjacent to Surprise Spring Basin there are about six domestic wells in which depths to water are reportedly 40 to 60 feet. Conceivably this area could be placed under irrigation, further restricting the amount of water available for Navy use. Thus, it is suggested that the Navy consider withdrawal from Public Domain of all lands in townships 2, 3, and 4 north and ranges 5 and 6 east until such time as the source, movement, and recharge to Surprise Spring Basin are defined.

Water-Bearing Deposits

Test wells 5, 6, 9, and 12 (pl. 1) were drilled in Surprise Spring Basin to depths of 400, 450, 430, and 500 feet, respectively. The water-bearing materials penetrated are the late Tertiary continental deposits. The tops and bottoms of discontinuously perforated intervals are 149–377, 240–390, 300–401, and 300–420 feet, respectively. The percentage of water-yielding sand and gravel in the saturated deposits penetrated by the test wells ranged from 40 percent along the southern and eastern part of the basin to as much as 80 percent in the northern part, and averaged about 55 percent (table 1). This percentage is slightly higher than that for Deadman Basin.

In test well 11, which is 644 feet deep, the depth to water is about 70 feet lower than the discharge level at Surprise Spring, indicating that a ground-water barrier or divide, possibly a fault, lies between the two. Thus, test well 11, which was drilled to ascertain the character and yield of materials at the southern end of Surprise Spring Basin, actually lies somewhat south of the basin.

Beds of loose, running sand made perforating the test-well casings opposite the full water-bearing section impossible. On the other hand, the casing in test well 9 was perforated opposite many cemented zones, and pump-test results indicate, as they did for test well 8 in Deadman Basin, that good yields can be obtained from such zones.

Quality of Water

The quality of water in Surprise Spring Basin is by far the best of that in the three basins, as is shown by the analyses in table 5 for test wells 5, 6, 9, 11, and 12. Samples collected during pump tests show that the fluoride content ranges from 0.3 ppm in test well 6 to 1.1 ppm in test well 5; and that the total dissolved solids content ranges from 140 ppm in test well 5 to 430 ppm in test well 6. In Surprise Spring Basin neither the fluoride content nor the total dissolved solids showed marked change with depth.

Water bailed from test wells 5, 11, and 12 during drilling contained large quantities of colloidal clay, probably bentonite, which did not settle out in a week. Water discharged from test wells 5 and 11 cleared during the pump tests, but water from test well 12 remained somewhat cloudy after 8 hours of pumping. A longer period of pumping would probably eliminate the colloidal material from test well 12.

Yields of Test Wells

An evaluation of the yields of wells in Surprise Spring Basin is being made by Neptune and Gregory, Architects and Engineers, under the supervision of Mr. Warren O. Wagner, consulting engineer, and will be presented by them in a separate report. In general, the pump tests show that all test wells in Surprise Spring Basin have good yields. Test wells 5 and 9 had the largest yields.

The bail tests made during well construction (table 6), show that, in general, the coarser water-bearing materials are moderately permeable and would be capable of yielding large quantities of water to properly constructed supply wells.

Water Levels in Wells

The water levels in wells in Surprise Spring Basin range from above land surface at an old well at Surprise Spring to 250 feet below land surface in test well 9. A well in sec. 35, T. 3 N., R. 6 E. had a reported water level of 420 feet. Depths to water are almost a measure of the differential in altitude from well to well because of a flat water-level gradient across the area (pl. 2). On the basis of approximate barometric levels, the altitudes of the water levels range from 2,270 feet in the old well at Surprise Spring to 2,290 feet in test well 9. Thus it appears that ground water is moving eastward to southeastward through the southern part of the basin.

Temperature of Ground Water

The range in temperature in wells differed considerably throughout all three basins, but for individual wells increased gradually with depth. For Mesquite Basin, old Navy wells 1 and 2 discharged water at 77° and 73°F, respectively, and test well 1 discharged water at 85°. In Deadman Basin the temperature during test-pumping ranged from 72°F in test well 2 to 85°F in test well 8. In Surprise Spring Basin the temperature during test-pumping ranged from 74°F in test well 6 to 93°F in test well 5.

The increase in temperature with depth, or geothermal gradient, is a normal physical phenomenon and differs from one locality to another. However, the wide range in temperature from place to place within the same area may be due to the proximity of some of the test wells to active faults.

SUMMARY AND CONCLUSIONS

The results of the geologic reconnaissance and the data obtained from logging the test wells are briefly summarized in the following paragraphs. In addition certain conclusions with respect to the geology of the water-bearing materials, quality of water, and proposed ground-water development in Mesquite, Deadman, and Surprise Spring Basins are presented:

1. The area covered by the geologic and hydrologic reconnaissance was the large basin area of about 50 square miles north and west of Twentynine Palms, California. This basin has been termed the Twentynine Palms Basin. It contains as much as 1,500 to 2,000 feet of late Tertiary continental deposits which are overlain by

thin veneers of Quaternary alluvium and playa deposits in seven dry lakes. The bounding ranges are the San Bernardino, Little San Bernardino, and Bullion Mountains, and several unnamed mountains, which are composed principally of Precambrian granitic and metamorphic rocks and Jurassic granite. These crystalline rocks form the sides and bottom of the basin.

2. The late Tertiary continental deposits are saturated with ground water below the water level, which ranges from land surface to depths of several hundred feet. A series of northwest- and north-trending faults cutting these deposits has created barriers to ground-water movement, thereby forming a number of large ground-water subbasins in the area. The five major barrier faults are the Oasis, Mesquite, Surprise Spring, and Emerson Faults, and an unnamed fault crossing Pipes Wash. In addition, an east-trending transverse arch of structural origin, which crosses the basin about 9 miles north of Twentynine Palms, also forms a ground-water barrier. On the basis of the reconnaissance work two ground-water basins, namely Deadman and Surprise Spring Basins, were selected for exploratory test-well drilling. A third, Mesquite Basin, although nearest the camp site, was not considered because local residents depend on it for their supply and because the quality is inferior.

3. In order to determine the water-bearing properties and yield of the late Tertiary continental deposits, the chemical quality of the contained ground water, and in part the extent of Deadman and Surprise Spring Basins, a test-well drilling program was started in January 1952 and was concluded in September 1952. Altogether, 10 test wells of 10 in diameter were drilled to depths ranging from 400 to 800 feet. The aggregate footage drilled was 5,163 feet. Pertinent data obtained for the two basins are presented in numbered paragraphs 4 and 5 that follow.

4. ***Deadman Basin.***—Deadman Basin is roughly 6 miles north of the camp site in the northeast part of the area. It is bounded on the east by Mesquite Fault, on the south by the transverse arch, on the west by Surprise Spring Fault, and on the north by folds and faults in the sediments. As defined, the basin covers about 50 square miles.

Data collected during the drilling and test-pumping of four test wells between 500 and 800 feet deep in Deadman Basin indicate that: (1) The depth to water ranges from 25 to 189 feet below land surface; (2) the altitude of the water table is about 1,800 to 1,820 feet above sea level (about 40 feet higher than that in Mesquite Basin to the south); (3) the water-yielding materials are chiefly sand and some gravel and compose about 55 percent of the saturated section; (4) the permeability of the sand and gravel as determined by bail tests is good; (5) the yield of the deposits is high; and (6) the fluoride content is lower in wells near the center of the basin (1.5–2.5 ppm), and the total dissolved solids average about 800 ppm.

It is concluded that properly constructed supply wells drilled to depths of 400 to 600 feet in the central part of Deadman Basin near test well 8 (about 8 miles from the camp site) would yield water of fair quality at rates of 1,000 to 1,500 gpm with moderate drawdown. To obtain yields of this magnitude without pumping sand, wells of gravel-packed construction would be required, and unless the samples obtained during supply-well construction indicate otherwise, the suggested gravel size for use in such wells would be: 100 percent passing a 0.50-inch screen and 50 percent retained on a 0.25-inch screen, and the remaining 50 percent passing a 0.25-inch screen and retained on a number 4 screen.

5. ***Surprise Spring Basin.***—Surprise Spring Basin is immediately west of Deadman Basin and about 12 miles northwest of the camp site. It is bounded on the east by Surprise Spring Fault, on the south by barrier features associated with the transverse arch, on the west by Zeitz, Goat, and Deadeye Mountains, and on the north by bedrock north of Emerson Dry Lake. The included area is approximately 100 square miles—about twice the size of Deadman Basin.

Data collected during the drilling and test-pumping of four test wells between 400 and 500 feet deep in Surprise Spring Basin indicate that: (1) The depth to water ranges from above land surface in an old well at Surprise Spring to 250 feet in test well 9 and is reportedly deeper farther west; (2) the altitude of the water table is about 2,270 to 2,300 feet above sea level (over 400 feet higher than in Deadman Basin); (3) the water-yielding materials are largely sand and some gravel and compose about 60 percent of the saturated section; (4) the permeability of the sands and gravels as determined by bail tests is good to very good, and the yield of the deposits is good to very good; (5) the fluoride content is low (0.3–1.1 ppm), and the total dissolved solids are relatively low

(140–430 ppm); and (6) the colloidal clay in test well 12 would probably clear up if test-pumped for a longer period.

It is concluded that properly constructed supply wells drilled to depths of 400 to 600 feet in Surprise Spring Wash near test well 5 (about 12 miles from the camp site) would yield water of very good quality at rates of 1,000 to 1,500 gpm with moderate drawdown. To obtain yields of this magnitude without pumping sand, wells of gravel-packed construction would be required and, unless the samples obtained during supply-well construction indicate otherwise, the suggested gravel size for use in such wells would be: 100 percent passing a 0.50-inch screen and 50 percent retained on a 0.25-inch screen, and the remaining 50 percent passing a 0.25-inch screen and retained on a no. 4 screen.

6. Deadman and Surprise Spring Basins are both relatively large ground-water reservoirs, whose stored water should, under proper development, be sufficient to supply the needs of the camp for many years.

7. Supply wells drilled in both Deadman and Surprise Spring Basins would utilize the available ground-water supply of the area most effectively. Pumping from both basins simultaneously would permit mixing water to obtain a satisfactory blend which would be somewhat better than the fair-quality water in Deadman Basin but somewhat poorer than the very good water in Surprise Spring Basin. Furthermore, because Surprise Spring Basin is about twice the size of Deadman Basin, withdrawals in the corresponding ratio of two to one would result in nearly equal utilization of the two basins.

8. Test wells 2, 5, and 8, and on old Navy supply well 3, which are near the proposed route of the water-supply pipeline, could be used as standby wells, if they were equipped with pumps and connected with the pipeline. Pumps capable of supplying 500 gpm probably would be adequate to withdraw available water from these wells.

9. If future camp expansion requires a larger water supply than that currently contemplated, consideration should be given to drilling additional wells in the vicinity of test wells 6, 9, and 10, which are far enough from other proposed wells to eliminate the possibility of local overdraft due to concentrated pumping.

10. If maximum efficiency of production is to be achieved, it is suggested that locations for future supply wells should be at least 2,000 feet from known or probable faults, and further that the wells should be spaced not less than 2,000 feet apart.

11. Finally, the relationships between ground waters beneath Government-owned lands in T. 2 N., Rs. 5, 6, and 7 E.; T. 3 N., R. 5 E.; T. 4 N., R. 5 E.; and those portions of T. 2 N., Rs. 8 and 9 E.; T. 3 N., R. 6 E.; and T. 4 N., R. 6 E., not already acquired for the Training Center, and the water beneath lands now incorporated in the Training Center, have not been established.

Thus, it is not known whether withdrawals from the four irrigation wells at the north end of Surprise Spring Basin, which were drilled shortly before June 1952, and further possible ground-water development in the basin might adversely affect the water supply available for the training center at some future date. The investigation to be undertaken during the 1953 fiscal year will aid in defining the areas critical to the protection of the water supply. Until the results of this work are available, serious consideration should be given to withdrawing these lands from public entry.

TEST-WELL LOGS

During the period January to September 1952, the U.S. Geological Survey carefully logged the test wells during the course of their construction. The logs compiled during the test-drilling program are included in table 4 on the following pages.

It should be noted that there are no data for test wells 4 and 7. These two sites were shown on the original test-well location map prepared by W.O. Wagner, but wells were never drilled owing to the unfavorable location with respect to the geology and topography.

Table 4. Test-well logs

[ft, foot]

Material	Thickness (ft)	Depth (ft)
Test well 1. In Mesquite Basin. Altitude: 1,856.2 ft. Casing diameter 10 inches; drilled Jan. 24–Feb. 15, 1952		
Soil, sandy, soft, yellowish-brown	2	2
Sand, fine to coarse, calcareous, hard, white to brown	8	10
Sand, calcareous, soft, poorly sorted	2	12
Sand, fine to coarse, calcareous, very hard	4	16
Sand, fine to coarse, soft	2	18
Sand, fine to coarse, calcareous, very hard	1	19
Sand, coarse, and gravel, fine; soft	2	21
Clay, silt, and sand, generally fine; light brown, fairly hard; sand in layers	11	32
Gravel, soft; water rose to 4 ft	1	33
Sand, very coarse, with considerable silt and clay; hard, calcareous, light gray-green	23	56
Sand, fine to coarse; gravel, fine to medium; and some silt and clay; soft, buff	5	61
Sand, medium to very coarse, soft, light gray	9	70
Clay; silt; and sand, coarse, calcareous; plastic micaceous, in part in layers	6	76
Clay, sandy to silty, laminated, micaceous, hard green to red	8	84
Sand, fine to medium, silty, soft, dark brown-gray	5	89
Clay, laminated, variegated, micaceous, hard	2	91
Sand, fine to medium, silty, very hard, dark brown-gray	21	112
Clay, silty, and gravel, sandy; in layers, water-bearing	6	118
Clay and sand, silty, in layers, soft, iron-stained	3	121
Sand, medium, silty, very soft to hard, iron-stained	5	126
Sand, medium to coarse, calcareous, with layers of clay, hard	2	128
Sand, medium, silty, variegated, laminated	5	133
Clay, sandy, calcareous, light brown-gray, with calcareous inclusions, hard	8	141

Table 4. Test-well logs—Continued

Material	Thickness (ft)	Depth (ft)
Test well 1—Continued		
Sand, fine to very coarse, silty, laminated, hard to soft, gray-brown	4	145
Clay, calcareous, very hard, with calcareous inclusions, buff	2	147
Sand, coarse, silty, calcareous, laminated, hard, light gray to brown; a few pebbles	5	152
Sand, medium, silty, laminated, gray-brown, soft	9	161
Clay, micaceous, buff, hard	2	163
Sand, medium to coarse, silty, soft, iron-stained, laminated, medium to coarse sand near bottom	16	179
Sand, medium to coarse, micaceous soft, iron-stained	16	195
Clay, sandy to silty, micaceous, calcareous, light green to brown, hard	8	203
Gravel, fine; sand, medium to very coarse; and sand, fine, silty; in alternating layer, fairly hard, light brown-gray, water-bearing	9	212
Sand, medium to very coarse, calcareous cement, light buff, hard to soft	9	221
Silt, sandy, micaceous, some calcareous sand inclusions, very soft, steel gray	27	248
Gravel, medium; sand, very fine to coarse; sand, silty; and clay; in layers, micaceous, light gray, soft, water-bearing	3	251
Sand, fine to coarse, clayey, micaceous, light gray, soft	4	255
Silt, sandy, light green-gray, hard, with some concretions	4	259
Sand, very fine to coarse; and clay, silty; micaceous, light gray, soft	9	268
Silt, sandy, micaceous, steel gray, very soft, with some concretions; and few pebbles in very thin layers	19	287
Clay and silt, laminated, with some pebbles	1	288
Silt, sandy, micaceous, steel gray, soft	6	294
Silt, sandy, clay, silty; laminated, green-gray, hard	4	298
Gravel, coarse to fine, with clay and silt streaks; hard to soft, water-bearing	3	301
Sand, fine to very coarse, clayey, light gray, soft	4	305
Silt, sandy, micaceous, steel gray, soft	4	309

Table 4. Test-well logs—Continued

Material	Thickness (ft)	Depth (ft)
Test well 1—Continued		
Sand and gravel, silty to clayey, light gray, hard	3	312
Gravel, medium to very coarse; and sand, fine to very coarse, silty; in layers, light gray, soft, water-bearing (heaves up in well)	26	338
Clay, calcareous, buff, hard	1	339
Gravel, medium to coarse; and sand, fine to coarse, silty; in layers, light gray, packed, water-bearing	25	364
Sand, fine to coarse, silt, clay, and some gravel, buff, cemented	5	369
Sand, fine to coarse, silty to clayey, light gray to buff, soft; water-bearing below 373 ft	7	376
Clay, slightly sandy, buff, sticky, hard	2	378
Sand, very fine to very coarse, silty to clayey, green to orange, hard, dry; some very hard thin clay streaks	22	400

Water samples bailed during drilling at depths of 210, 316, and 400 ft.
Water temperatures during drilling: 77° to 84°F, increasing with depth.
Water level during drilling: 76 to 125 ft below land surface.
Water level both before and after perforating: 84 ft below land surface.
Perforations: 0.25-inch x 3-inch Mills knife, 8 cuts per round, one round per ft; 203–212, 248–251, 298–301, 314–352, and 372–376 ft.
Cement plug set at 320 ft.

Material	Thickness (ft)	Depth (ft)
Test well 2. In Deadman Basin. Altitude: 1,845.7 ft. Casing diameter 10 inches; drilled Jan. 10–Feb. 4, 1952		
Soil, sandy	8	8
Sand, coarse to very coarse, and few pebbles, gray, soft; some calcareous sand concretions below 30 ft	39	47
Clay, plastic, brown, hard; some black organic fragments	2	49
Sand, coarse to very coarse, and some pebbles, light gray, soft; buff below 52 ft	9	58
Sand, very coarse, clayey, gray, fairly soft	10	68
Sand, very coarse, pebbly, buff, soft; lower 2 ft sand and gravel concretions, very hard calcareous cement	48	116
Clay; sand, fine to coarse; and some pebbles; pale buff, soft	12	128
Sand, coarse to very coarse; and gravel, up to 2-inch; buff, soft; some clay streaks and less gravel 136 to 146 ft; water-bearing	28	156
Clay; sand, fine to coarse; and few pebbles; gray, fairly hard cemented sand concretions 166 to 169 ft	13	169

Table 4. Test-well logs—Continued

Material	Thickness (ft)	Depth (ft)
Test well 2—Continued		
Sand, mostly fine to little coarse, and some silty clay; dark gray, hard; some sand concretions below 180 ft	15	184
Sand, coarse to very coarse, and gravel, coarse; buff, soft	8	192
Clay, sandy to pebbly, reddish-brown hard	2	194
Sand, coarse to very coarse, gravel, and boulders up to 8 inches; buff, soft; water-bearing	29	223
Sand, coarse to very coarse, and some gravel; buff, soft, water-bearing; partially cemented 270 to 275 ft	52	275
Sand, fine to coarse, and few small pebbles; medium gray, soft	8	283
Sand, coarse to very coarse, and fine gravel; buff, soft	2	285
Sand, fine to coarse, medium gray, fairly hard	4	289
Sand, coarse to very coarse, and gravel, up to 1 inch; few streaks of silty sand; gray to buff, fairly soft	12	301
Sand, coarse to very coarse, and gravel; gray to buff, very loose; cemented 330 to 336 ft; water-bearing	43	344
Clay and gravel alternating with streaks of fine sand and streaks of coarse sand and gravel; brown to gray, hard; more sand, red-brown, 360 to 368 ft	24	368
Sand, coarse, and gravel; gray to buff, hard	3	371
Sand, fine to coarse, clayey, cemented (?), gray, hard	9	380
Sand, coarse, gravel, and some boulders, buff to brown, soft, water-bearing	18	398
Sand, coarse, cemented ($CaCO_3$), gray, very hard	2	400
Sand, coarse, and gravel, cemented, buff to gray, rather hard	6	406
Clay; sand, coarse; and gravel, up to 0.50 inch; gray-green, hard; and some clay streaks	15	421
Sand, coarse, and gravel, up to 2-inch; cemented, buff to brown, fairly hard	7	428
Clay, sandy, pebbly, medium brown, very hard	4	432
Sand, fine to very coarse, and gravel, up to 2-inch; loosely cemented ($CaCO_3$), vivid orange-red, fairly soft; lower 2 ft a cobble conglomerate; water-bearing	12	444
Clay, fine sandy to silty, and some pebbles; dark brown, hard, some organic spots, and iron stains	18	462

Table 4. Test-well logs—Continued

Material	Thickness (ft)	Depth (ft)
Test well 2—Continued		
Sand, very coarse, and gravel; cemented, light gray, hard	2	464
Sand, fine to very coarse, cemented, dark gray, hard cemented gravel streak 492 to 493 ft	42	506
Sand, very coarse, and gravel, coarse, orange-brown, loose (heaves up in well); water-bearing	6	512
Clay, sandy, dark brown, hard	2	514
Sand, fine to coarse, and gravel; cemented, dark gray, hard	5	519
Sand, fine to coarse, cemented, dark gray, hard	7	526

Water samples bailed during drilling at depths of 135, 290, 385, and 510 ft.
Water temperatures during drilling: 67° to 70°F, increasing with depth.
Water level during drilling: 42 ft below land surface.
Water level both before perforating: 42 ft below land surface.
Perforations: 0.25-inch x 3-inch Mills knife, 6 cuts per round, one round per ft; 136–152, 194–224, 305–330, 336–344, 380–398, 432–444, and 506–512 ft.
Cement plug set at 526 ft.

Material	Thickness (ft)	Depth (ft)
Test well 3. In Deadman Basin. Altitude: 1,850.2 ft. Casing diameter 10 inches; drilled Jan. 11–Mar. 3, 1952.		
Soil, sandy to silty, light brown, hard	8	8
Sand, fine to coarse, light buff, soft	4	12
Clay, calcareous, plastic, sticky, light gray	12	24
Gravel, medium to fine, and some sand	1	25
Clay, red- to yellow-brown, plastic	3	28
Sand, very fine to coarse, light buff, soft; few pebbles	5	33
Sand and clay, with layers of fine sand and silty clay, gray	21	54
Sand, fine, silty, few coarse grains, micaceous, yellow-gray	19	73
Clay, sandy, silty, yellow-gray, hard	6	79
Sand, fine, silty, yellow-brown	14	93
Sand, largely fine, silty, yellow, brown, gray, and lavender streaks; medium and coarse fraction increasing with depth	29	122
Sand, silty, soft to hard; proportion of sand greatly increased over that from 93 to 122 ft	19	142
Gravel, fine to very coarse, and sand, fine to coarse	3	145

Table 4. Test-well logs—Continued

Material	Thickness (ft)	Depth (ft)
Test well 3—Continued		
Sand, very fine, silty, hard, a few concretions, gray	43	188
Clay, very fine sandy, dark brown, plastic, hard; some white $CaCO_3$ layers	1	189
Sand, fine to coarse, silty, some pebbles 0.50 inch, olive green, hard; iron stains abundant; yellow-green from 189–190	3	192
Sand, coarse to very coarse, and gravel to 0.50 inch; streaks of fine sandy clay; light brown, fairly soft	4	196
Sand, very fine to medium, silty; some coarse sand-streaks, and some clay; light brown, hard; some layers of cemented ($CaCO_3$) sand	36	232
Sand, coarse to very coarse, and gravel to 1-inch, red-brown, soft	4	236
Clay, fine to very coarse sandy, and some pebbles to 0.25 inch; dark brown, extremely hard; white $CaCO_3$ fragments	12	248
Sand, coarse to very coarse; and gravel to 3 inch; few streaks of silty sand; light brown, soft, some $CaCO_3$ cementing; water bearing	10	258
Sand, very fine to very coarse, silty; some gravel to 1-inch; medium brown, hard. Gray, green, violet, and red colors 258 to 259 ft	14	272
Sand, coarse to very coarse, some fine to medium, and gravel to 6 inches, buff, soft; heaves up in hole; water-bearing	28	300
Sand, coarse to very coarse, some fine to medium; some gravel to 1-inch; buff, soft; heaves up in hole; gray-brown from 320 to 332 ft	32	332
Sand, fine to medium, dark brown-gray, firm; some 1-inch gravel from 332 to 340 ft; some fine sandy clay streaks 346 to 360 ft	28	360
Sand, very fine silty to some very coarse, and clay; dark gray-brown, fairly hard; hard iron-stained light brown clay 360 to 362 ft; hard light brown clay and 0.50 inch gravel 373 to 374 ft	14	374
Sand, medium to very coarse, and gravel to 3 inches, light brown to buff, soft; heaves up in hole; water-bearing	6	380
Sand, medium to very coarse, some gravel to 2 inches, and streaks of clay; brown-buff, soft; cemented ($CaCO_3$) 390 to 396 ft	16	396
Sand, medium to very coarse, and gravel to 3 inches, gray to buff, soft; some $CaCO_3$ cemented sand and gravel; clayey fine to coarse sand with red-brown, very hard, white $CaCO_3$ stringers from 408 to 410 ft; water bearing	20	416
Sand, medium to very coarse, occasional gravel to 2 inches, brown-buff, soft; gravel to 4 inches 444 to 456 ft; water-bearing; many cemented ($CaCO_3$) fine to coarse sand concretions, gray-brown, very hard from 499 to 510 ft	94	510

Table 4. Test-well logs—Continued

Material	Thickness (ft)	Depth (ft)
Test well 3—Continued		
Sand, fine to very coarse, cemented, gray-brown, hard	2	512

Water samples bailed during drilling at depths of 236, 294, 404, and 470 ft.
Water temperatures during drilling: 76° to 82°F, increasing with depth.
Water level during drilling: 44.6 to 55.0 ft below land surface.
Water level both before perforating: 46.5 ft below land surface.
Perforations: 0.25-inch x 3-inch Mills knife, 6 cuts per round, one round per ft; 248–258, 272–300, 374–380, 396–408, 410–416, and 444–456 ft.
Cement plug set at 512 ft.

Material	Thickness (ft)	Depth (ft)
Test well 5. In Surprise Spring Basin. Altitude, 2,271.5 ft. Casing diameter 10 inches; drilled Feb. 25–Mar. 14, 1952.		
Sand, fine to very coarse, light orange, soft, wind blown	13	13
Gravel, fine to coarse, light buff to light orange, arkosic, soft	6	19
Clay, slightly sandy, calcareous, flocculent, light green-gray, hard	4	23
Gravel, fine, and sand, fine to very coarse; arkosic, calcareous soft, with small basalt pebbles, water-bearing	1	24
Clay, slightly sandy to silty, calcareous, micaceous, light green-gray, hard	4	28
Gravel, fine, sandy, arkosic, soft; heaves up in well	5	33
Clay, slightly sandy, silty, micaceous, calcareous, sticky, light green-gray, hard	3	36
Sand, fine to very coarse, slightly silty and clayey, micaceous, light buff, packed, very hard, except from 42 to 46 ft which is soft and water-bearing	12	48
Clay, sandy, silty, calcareous, light brown, hard to soft	11	59
Silt, sandy, clayey, calcareous, micaceous, light green-gray; compact and fairly hard	8	67
Sand, coarse to very coarse, some silt, occasional pebbles; arkosic, light buff, compact and medium hard	4	71
Sand, very fine to medium, silty, clayey, buff hard	7	78
Sand, fine to very coarse, silty, clayey, micaceous, arkosic, slightly iron-stained, soft, water-bearing	10	88
Gravel, fine; and sand, medium to very coarse, arkosic, micaceous, soft; water-bearing	5	93
Gravel, fine to medium; sand, coarse to very coarse; clayey, brown-gray, angular, soft; water-bearing	3	96
Sand, coarse to very coarse; and gravel, fine; arkosic, light buff, soft, water-bearing	20	116
Clay, sandy, calcareous, micaceous, light yellow to brown, hard	7	123

Table 4. Test-well logs—Continued

Material	Thickness (ft)	Depth (ft)
Test well 5—Continued		
Sand, coarse to very coarse, gravelly; sand, fine, silty; and clay; in layers, buff to green to brown, moderately soft, with some sandstone concretions, water-bearing	4	127
Sand, very fine to coarse, clayey, light yellow to buff, hard	6	133
Sand, coarse to very coarse, some gravel, silty, clayey, light orange, soft	14	147
Sand, medium to very coarse, clayey, silty, light brown, hard	2	149
Gravel, fine to coarse; and sand, coarse to very coarse; slightly silty, light buff, soft, water-bearing	3	152
Sand, coarse to very coarse; and little gravel, in very thin laminae, silty, arkosic, light buff, soft, water-bearing	37	189
Sand, medium to very; coarse, slightly silty and clayey, white to buff; contains thin cemented sand layers, very thin gravel layer at top, and a few calcareous sandstone concretions, in part water-bearing. Sand, clayey to slightly silty, strong sulfurous smell, temperature over 110°F, 225 to 227 ft; possibly a minor fault zone	50	239
Sand, coarse to very coarse, slightly silty and clayey, with very small amount of gravel and a few pebbles; arkosic, micaceous, light to dark buff, soft, water-bearing	10	249
Gravel, medium to coarse; and sand, coarse to very coarse; silty, clayey; micaceous, arkosic, white to buff, soft, water-bearing	7	256
Gravel, coarse to fine, sandy, cobbley, angular to well rounded, gray-buff, soft, water-bearing	3	259
Sand, fine to very coarse, cemented, hard	2	261
Gravel, fine to coarse, sandy, cobbley, arkosic, soft, water-bearing	7	268
Silt, sandy to clayey, light brown to green-gray, micaceous, hard	2	270
Gravel, cemented, non-water-bearing	1	271
Gravel, fine to coarse; sand, coarse to very coarse, layered; slightly iron-stained in upper few feet, but grading into a gray-buff to buff below, in part slightly silty, with a few calcareous sandstone concretions, soft, water-bearing throughout	31	302
Gravel, medium to coarse, only slightly sandy, arkosic, light gray to buff, soft, clean, quite well sorted, soft, water-bearing	1	303
Sand, coarse to very coarse, silty, slightly clayey, gravelly, poorly assorted, medium hard; some clay in colloidal suspension, poorly water-bearing	22	325
Gravel, fine to coarse; and sand, very coarse; clayey, arkosic, light buff, medium soft, poorly water-bearing	3	328

Table 4. Test-well logs—Continued

Material	Thickness (ft)	Depth (ft)
Test well 5—Continued		
Sand, fine to very coarse, slightly silty, clayey, gravelly, light buff, medium soft, in part water-bearing	10	338
Gravel, fine to coarse; and sand, fine to coarse; silty to clayey, brown-gray to buff, soft; some colloidal clay, water-bearing	3	341
Sand, fine to very coarse, silty to clayey, slightly gravelly, gray-buff, medium hard, poorly water-bearing but soft and water-bearing below 356 ft	22	363
Gravel, fine to coarse; and sand, fine to coarse; somewhat silty, arkosic, light gray-buff to white, soft, water-bearing	4	367
Sand, fine to very coarse, gravelly, and clayey to silty, buff, relatively compact, partly water-bearing	33	400

Water samples bailed during drilling at depths of 140, 255, 336, and 396 ft.
Water temperatures during drilling: 81° to 96°F, increasing with depth, except for the zone 225–227 ft in which temperature was greater than 110°F.
Water level during drilling: 20 to 34 ft below land surface.
Water level both before perforating: 25.0 ft below land surface.
Perforations: 0.25-inch x 3-inch Mills knife, 8 cuts per round, one round per ft; 149–152, 189–192, 239–259, 261–268, 271–305, 325–330, and 356–377 ft.
Cement plug set at 400 ft.

Material	Thickness (ft)	Depth (ft)
Test well 6. In Surprise Spring Basin. Altitude; 2,403.6 ft. Casing diameter 10 inches; drilled Mar. 12–Apr. 8, 1952.		
Soil, very fine to very coarse sandy, soft, light gray-brown	3	3
Clay, fine to very coarse sandy, hard, red-brown	2	5
Sand, very fine to very coarse, soft, light gray	7	12
Sand, medium to coarse, soft, gray-brown; some gravel to 1-inch from 12 to 17 ft; brown silty clay streaks from 31 to 46 ft; fairly hard, packed, with some caliche from 48 to 56 ft	44	56
Sand, medium to very coarse, and some gravel to 3 inches, fairly soft, gray-brown; becomes very fine to very coarse from 60 to 190 ft; water-bearing below	134	190
Sand, very fine to very coarse, and silty sand streaks, occasional gravel to 2 inches; over-all fairly soft, gray-brown; hard cemented sand concretions from 190 to 198 ft, and from 210 to 212 ft; water-bearing	50	240
Sand, very fine to very coarse, and some gravel to 2 inches, soft, gray-brown; occasional cobbles to 6 inches; water-bearing	52	292
Sand, very fine to fine, silty, fairly soft, dark gray	8	300
Sand, fine to very coarse, and gravel to 3 inches, soft, brown-gray, water-bearing	4	304
Sand, very fine to fine, silty, fairly hard, dark gray	5	309

Table 4. Test-well logs—Continued

Material	Thickness (ft)	Depth (ft)
Test well 6—Continued		
Sand, fine to very coarse, and some gravel to 3 inches, soft, brown-gray; more gravel in zones from 314 to 332 ft and from 336 to 352 ft; water-bearing	45	354
Sand, fine to very coarse, hard, brown-gray, cemented	6	360
Sand, very fine to very coarse, with occasional gravel to 1-inch, soft, brown-gray, more gravel from 370 to 372 ft; water-bearing	12	372
Sand, fine to very coarse, and some gravel to 1 inch, hard, gray-brown, cemented	6	378
Sand, fine to very coarse, and gravel to 1-inch, soft, gray-brown, water-bearing; heaved up in casing 6 ft	4	382
Sand, fine to very coarse, with some gravel to 1 inch, hard, gray-brown, cemented	2	384
Sand, fine to very coarse, and gravel to 2 inches, soft, gray-brown; streaks of fine silty sand and less gravel from 390 to 408 ft; cemented zone from 402 to 404 ft; largely water-bearing	24	408
Sand, very fine to fine and some medium to very coarse, silty; with gravel to 0.50 inch; fairly soft, gray-brown; coarse sand from 412 to 413 ft; water-bearing	5	413
Sand, very fine to fine, and some very coarse, very hard, gray	3	416
Sand, fine to very coarse, and some gravel to 1-inch, hard, gray-brown; cemented	6	422
Sand, very fine to medium, fairly soft, gray-brown, alternating with very coarse sand streaks about 1 ft thick from 426 to 432 ft; water-bearing	10	432
Sand, very fine to very coarse, silty, fairly hard packed, gray-brown; occasional cobbles to 7 inches from 438 to 442 ft	10	442
Sand, very fine to very coarse, silty, and gravel to 3 inches, fairly hard, gray-brown, partially cemented, largely water-bearing	8	450
Water samples bailed during drilling at depths of 286, 354, 403, and 450 ft. Water temperatures during drilling: 70° to 72°F, increasing with depth. Water level during drilling: 147.6 ft below land surface. Water level both before perforating: 147.6 ft below land surface. Perforations: 0.25-inch x 3-inch Mills knife, 6 cuts per round, one round per ft; 240–246, 300–304, 312–332, 336–356, 370–372, and 378–390 ft. Cement plug set at 449 ft.		
Test well 8. In Deadman Basin. Altitude: 1,890.9 ft. Casing diameter 10 inches; drilled Mar. 26–May 16, 1952.		
Soil, sandy to silty, buff-brown, hard near bottom	12	12
Sand, very fine to coarse; some silt; and a few cobbles; calcareous, light brown, soft	12	24
Sand, fine to very coarse, slightly silty; and some fine gravel; some iron stain, buff- brown, soft, dry. Less gravel and cleaner with depth	14	38

Table 4. Test-well logs—Continued

Material	Thickness (ft)	Depth (ft)
Test well 8—Continued		
Sand, very fine to coarse, and silt; clayey, micaceous, light brown, fairly hard; in hard and soft layers below 54 ft	45	83
Silt, clayey, and some fine sand, calcareous, micaceous, gray-brown, fairly hard	16	99
Sand, very fine to very coarse, poorly sorted; and some gravel and cobbles up to 5 inches; micaceous, gray-brown, very hard, dry	12	111
Sand, fine to medium, some coarse, micaceous, gray-brown, soft, dry	5	116
Sand, coarse and some fine; and fine gravel; brown, hard	1	117
Sand, very fine to very coarse, poorly sorted; and some gravel and cobbles to 5 inches; gray-brown, soft, water-bearing. Water rose to 88 ft overnight	21	138
Sand, very fine to very coarse, poorly sorted; some very large cobbles up to 6 inches; gray-brown to buff, very hard, water-bearing	6	144
Sand, fine to coarse, poorly sorted, micaceous; and silt; gray-brown, moderately hard, slightly water-bearing	6	150
Sand, very fine to very coarse, poorly sorted; some silt and fine gravel; micaceous, gray-brown, soft, slightly water-bearing	8	158
Sand, very fine to very coarse, poorly sorted; occasionally silty; and some gravel and cobbles up to 4 inches; gray to gray-brown, soft to occasionally hard, largely water-bearing	46	204
Clay, silty, laminated, considerably iron-stained, olive-gray to gray, some thin dark chocolate-brown layers, hard	2	206
Sand, very fine to medium and some coarse, micaceous; and silt; olive-gray to brown-gray, soft, occasional layers of clay 0.25 inch thick, moderately water-bearing	9	215
Sand, very fine to very coarse, poorly sorted, micaceous; some silt; gravel; and cobbles up to 6 inches; gray-brown, hard, moderately water-bearing	5	220
Sand, mostly very coarse, some fine and medium; occasionally silty; and considerable gravel and cobbles; gray, soft. The percentage of coarse sand, gravel, and cobbles decreases gradually with depth, largely water-bearing	13	233
Sand, fine to medium, micaceous; and silt; calcareous, cemented, gray-brown to gray, very hard. Considerable gravel and cobbles 236 to 237 and 245 to 247 ft; slightly water-bearing	14	247
Sand, very fine to very coarse, micaceous; some gravel; and cobbles up to 5 inches; gray-brown, moderately soft, largely water-bearing	13	260
Sand, mostly coarse, some fine to medium; gravel, mostly coarse, some fine; and cobbles up to 7 inches; gray to gray- brown, soft, highly water-bearing	30	290
Sand, fine to coarse, poorly sorted, some concretions, strongly cemented, calcareous and siliceous cement, light gray to gray, very hard	2	292

Table 4. Test-well logs—Continued

Material	Thickness (ft)	Depth (ft)
Test well 8—Continued		
Sand, very fine to very coarse, mostly fine to medium, poorly sorted, micaceous; some silt; and some gravel and cobbles; gray to gray-brown, soft, water-bearing	48	340
Sand, fine to medium; silt; and some gravel; gray-brown, cemented, very hard, slightly water-bearing	17	357
Sand, very fine to very coarse, mostly medium and coarse, micaceous; and some gravel; gray-brown to buff, soft, water-bearing	38	395
Sand, fine to very coarse, mostly coarse; and gravel, fine to medium, some coarse; and few cobbles; partially cemented, gray to brownish-gray, hard to soft, moderately water-bearing. Sandy below 403 ft	12	407
Sand, fine to medium, some coarse, clayey, micaceous; silt; gravel, fine to medium with some coarse; and some cobbles up to 5 inches; gray to brownish-gray, partially cemented, hard, slightly water-bearing. Less silt and more coarse sand with depth	12	419
Clay, silty, sandy, considerably iron stained, light to medium brown, hard	1	420
Sand, fine to very coarse, mostly medium and coarse, concretionary; and gravel, fine to very coarse; and some cobbles up to 10 inches; calcareous, partially cemented, gray to brownish-gray, hard to moderately hard, moderately water-bearing. Cemented 420 to 427 ft	39	459
Sand, fine to coarse; and gravel, mostly fine to medium; gray-brown, some cementation, moderately hard, water-bearing	4	463
Sand, fine to very coarse, mostly medium and coarse; gravel, mostly fine and medium, some coarse; and a few cobbles up to 5 inches; gray-brown, fairly soft, largely water-bearing. Occasional hard lenses of cemented sand and gravel. Somewhat finer-grained 487 to 500 ft	60	523
Clay, silty to sandy; and few gravel; light to dark gray, banded, hard	2	525
Sand, mostly fine to medium, some coarse; silt; considerable gravel; and some clay; light to dark gray, calcareous, moderate cementation, hard, moderately water-bearing	13	538
Sand, very fine to very coarse; gravel, mostly fine; and some cobbles up to 4 inches; brownish-gray, fairly soft, water-bearing. Hard to moderately hard sand and gravel beds below 542 ft, in part water-bearing	41	579
Sand, fine to coarse, mostly fine to medium; and some fine gravel 579 to 589 and 599 to 601 ft; calcareous, partially cemented, light to medium gray, moderately hard, moderately water-bearing	22	601
Sand, very fine to coarse; and some silt; calcareous, cemented, light to medium gray, extremely hard	10	611
Clay, silty to sandy, dark brown, considerable iron-stained, hard	5	616
Sand, fine to coarse; silt; and occasional thin lenses of clay; calcareous, partially cemented, buff to tan, moderately hard, slightly water-bearing	13	629

Table 4. Test-well logs—Continued

Material	Thickness (ft)	Depth (ft)
Test well 8—Continued		
Clay, micaceous, silty to sandy, dark brownish gray, moderately hard	3	632
Sand, fine to medium silt; and some gravel 642 to 643 ft; clayey, cemented, calcareous, brown to buff, hard, slightly water-bearing	11	643
Sand, fine to coarse; some silt; and fine to some coarse gravel; calcareous, partially cemented, buff to light gray, moderately hard, moderately water-bearing	30	673
Sand, fine to very coarse; and gravel, mostly fine to medium; some coarse; occasionally silty, brown to gray-brown, soft, water-bearing. Partially cemented below 682 ft.	13	686
Clay, silty to sandy, considerable biotite mica and iron-stained, calcareous, generally dark grayish-brown, hard, occasionally sticky (plastic). Occasional lenses of gray, cemented, fine sand; and occasional thin layers of laminated, dark chocolate brown, noncalcareous clay	62	748
Silt, clay, and considerable fine sand, micaceous, dark grayish-brown, soft. Considerably less dense and compact than clay above. Occasional thin lenses of cemented sand	10	758
Clay, silty, occasionally sandy, considerable biotite mica, color varies from buff to gray, but generally grayish-brown, occasionally calcareous, hard. Some thin layers of laminated non-calcareous, clay, various shades of gray and brown. Occasional thin layers of clayey silt with fine sand; also thin lenses of gray, cemented, clayey, fine sand.	31	789
Sand, fine to medium, some coarse, micaceous, medium brown, soft, moderately water-bearing	3	792
Clay, silty, occasionally sandy, micaceous, slightly calcareous, medium to dark brown, hard	6	798
Sand, fine to medium, highly micaceous, moderately cemented, calcareous, light to medium gray, moderately hard	2	800

Water samples bailed during drilling at depths of 163, 252, 472, 474, 564, 653, 794, and 800 ft.
Water temperatures during drilling: 73° to 90.5°F, increasing with depth.
Water level during drilling: 88 to 92 ft below land surface.
Water level both before perforating: 88.3 ft below land surface.
Perforations: 0.25-inch x 3-inch Mills knife, 6 cuts per round, one round per ft; 500–523, 540–565, 584–605, 640–646, and 660–684 ft. If greater yield is desired at cost of a probable increase in fluoride, the following intervals could be perforated: 260–290, 396–403, 427–459, and 466–487 ft.

Material	Thickness (ft)	Depth (ft)
Test well 9. In Surprise Spring Basin. Altitude: 2,514.2 ft. Casing diameter 10 inches; drilled Apr. 15–May 26, 1952.		
Soil, fine to very coarse sandy and gravelly, brown, fairly hard	3	3
Caliche (calcium carbonate), white, very hard	2	5
Sand, fine to very coarse, and some gravel to 3 inches, gray-brown, hard; boulders to 20 inches and thin caliche (calcium carbonate) layers from 5 ft to 7 ft; no gravel from 40 ft to 44 ft	39	44
Clay, very fine to very coarse sandy, brown, very hard	36	80

Table 4. Test-well logs—Continued

Material	Thickness (ft)	Depth (ft)
Test well 9—Continued		
Sand, very fine to very coarse, silty, brown, fairly hard, calcium carbonate cement	3	83
Clay, very fine to very coarse sandy, brown, hard	5	88
Sand, very fine to very coarse, and gravel to 4 inches, brown, fairly soft	4	92
Clay, silty, and very fine to very coarse sandy, brown, hard	32	124
Clay, silty and fine sandy, brown, fairly soft; contains black organic material and some iron stains	2	126
Clay, silty and fine sandy; some coarse sand; brown, fairly hard; contains some caliche (white calcium carbonate), more coarse to very coarse brittle sand from 186 to 210 ft	84	210
Sand, very fine to very coarse; some silty clay; gray-brown, hard, cemented; fine to coarse brown sandy clay from 214 to 215 ft	14	224
Sand, fine to coarse; occasional gravel; and cobbles up to 5 inches; gray, fairly hard, partially cemented	20	244
Sand, very fine to very coarse; occasional gravel; and cobbles up to 5 inches; gray, soft; pebbles smaller, to 0.50 inch, and more silty from 328 ft to 338 ft; very hard, round, fine to coarse sand concretions from 340 to 358 ft; partially cemented and fairly hard from 358 ft to 392 ft; in part water-bearing	148	392
Sand, fine to coarse, and some gravel with boulders larger than 10 inches; gray, very hard drilling; at least partially cemented with an extremely hard calcareous cement; Calcite (?) crystal approximately 1 inch long observed on cobble recovered from 410 ft; gray, fine to coarse sand heaves in hole from 415 ft to 415 ft 6 inches; in part water-bearing	38	430
Water samples bailed during drilling at depths of 366 and 421 ft. Water temperatures during drilling: 75° to 76°F, increasing with depth. Water level during drilling: 244 to 252 ft below land surface. Water level both before perforating: 250 ft below land surface. Perforations: 0.25-inch x 3-inch Mills knife, 6 cuts per round, one round per ft; 300–328, and 340–401 ft. Bottom of casing at 418 ft.		
Test well 10. In Deadman Basin. Altitude: 2,020.2 ft. Casing diameter 10 inches; drilled May. 26–July 18, 1952.		
Sand, fine to coarse; occasionally silty, some thin lenses of caliche; some thin lenses of fine to medium gravel; buff to tan, soft. No real soil or soil profile; grains are fresh	18	18
Sand, fine to very coarse; mostly coarse; and gravel, mostly fine to medium, some coarse, some cobbles up to 6 inches; medium to light grayish-brown, soft to hard due to compaction, no cemented grains found. Interbedded calcareous, whitish clay from 76 to 78 ft. Some cementation and large cobbles up to 8 inches from 85 to 86 ft. Generally less coarse from 93 to 96 ft	94	112
Sand, fine to coarse, mostly fine; and considerable clay and silt; gray-brown to brown, calcareous, hard	4	116

Table 4. Test-well logs—Continued

Material	Thickness (ft)	Depth (ft)
Test well 10—Continued		
Sand, fine to very coarse, mostly very coarse; and gravel, mostly fine; grayish brown, moderately hard, partially water-bearing. Some medium to coarse gravel 143 to 144 ft; some caliche at 160 ft; considerable biotite and magnetite giving a dark grayish color to the cuttings 173 to 179 ft; cemented sand and gravel at 191 ft; coarse gravel 194 to 195 ft	84	200
Sand, fine to coarse, mostly coarse; and gravel, fine to coarse; some small cobbles, gray-brown, soft, water-bearing	20	220
Sand, fine to coarse, mostly coarse; and considerable fine gravel, some medium; gray-brown, moderately soft, water-bearing	57	277
Sand, fine to coarse, mostly coarse; and gravel, fine to coarse; occasionally calcareous, gray- brown, soft, water-bearing. Mostly fine but little tan coarse gravel 293 to 303 ft; some cobbles up to 4 inches 303 to 318 ft	41	318
Sand, fine to coarse, mostly fine to medium gray-brown, soft, water-bearing	8	326
Sand, fine to coarse, mostly fine to medium, considerable biotite, dark brownish-gray, soft, water-bearing	10	336
Sand, fine to coarse, mostly coarse; and gravel, mostly fine to medium, with some coarse; gray-brown to gray, soft, water-bearing. Cemented sand and gravel 381 to 382 ft	53	389
Sand, fine to coarse, mostly fine, with considerable silt and clay, dark grayish-brown, soft, partially water-bearing	8	397
Sand, fine to coarse, mostly coarse; and gravel, mostly fine, with some medium to coarse; gray- brown, soft water-bearing. Considerable amounts of medium and coarse gravel 401 to 407, 411 to 414, and 416 to 426 ft	29	426
Sand, fine to coarse; and some gravel, mostly fine; gray-brown, soft, water-bearing	22	448
Sand, fine to coarse, mostly coarse; gravel, fine to coarse; and some cobbles up to 6 inches; light grayish-brown, soft, water-bearing. Considerable basalt gravel and cobbles from 456 to 458 ft	11	459
Sand, fine to coarse; and some fine gravel; cemented, calcareous, gray-brown, hard, partially water- bearing	19	478
Sand, fine to coarse, mostly coarse; and gravel, fine to coarse; gray-brown, soft, water-bearing. Some what cemented 479 to 481 ft	9	487
Sand, fine to coarse, silty, cemented, considerable biotite, dark brownish-gray, hard, partially water-bearing	9	496
Sand, fine to coarse, mostly coarse; and gravel, mostly fine to medium, some coarse; partially cemented, gray-brown, moderately soft, water- bearing. Bail test indicates bottom-hole material very good water-bearing formation	5	501

Note: Sands, largely quartz and feldspar with varying amounts of magnetite, biotite (phlogopite), grains subrounded to angular and poorly sorted, color is largely gray-brown, but is commonly gray when there is considerable biotite and magnetite. Gravels and cobbles area largely altered and unaltered granitics with gneiss and granite (?) with some basalt, and quartzite, usually subrounded to rounded.

Table 4. Test-well logs—Continued

Material	Thickness (ft)	Depth (ft)
Test well 10—Continued		
Water samples bailed during drilling at depths of 270, 314, 386, 450, and 501 ft.		
Water temperatures during drilling: 82° to 88.5°F, increasing with depth.		
Water level during drilling: 189 to 200 ft below land surface.		
Water level both before perforating: 189.3 ft below land surface.		
Perforations: 0.25-inch x 3-inch Mills knife, 6 cuts per round, one round per ft; 280–293, 305–317, 345–389, 416–426, 450–460, and 480–487 ft.		
Owing to coarseness of perforations and relatively fine loose material, well has tendency to sand in. After perforating, well sanded to 470 ft; after "fanning" it sanded to nearly 400 ft below land surface. Well is to be sand pumped.		
This well started 15 ft S. 50° E. of present location; drilled to a depth of 120 ft; abandoned when driller tried to straighten hole and casing parted leaving starter in hole. Log the same as for upper 120 ft of test well 10.		
Test well 11. South of Surprise Spring Basin. Altitude: 2,531.6 ft. Casing diameter 10 inches; drilled June 6–July 25, 1952		
Soil, sandy, loose, gray-brown	2	2
Clay, fine to coarse sandy, very hard, red-brown; veinlets of calcium carbonate	32	34
Sand, fine to very coarse, clayey; some small (0.50-inch) pebbles; fairly hard, red-brown; color change to gray-brown and no clay present at 47 ft	54	88
Sand fine to medium, some very coarse; occasional cobbles to 3 inches; fairly soft, gray-brown	20	108
Sand, very fine to very coarse, hard, gray-brown; silty clay streaks from 108 to 112 ft, and generally more fine material from 122 to 160 ft	80	188
Sand, fine to very coarse, and gravel to 2 inches; soft, gray-brown	4	192
Sand, very fine to very coarse, clayey; streaks of very coarse sand and gravel to 0.50 inch; hard, gray-brown; some veinlets of white calcium carbonate	12	204
Sand, medium to coarse, and some very coarse, very hard, medium gray, fairly well sorted	12	216
Sand, very fine to very coarse; some pebbles to 0.50 inch; hard, gray-brown; streaks of very hard silty fine sand from 216 to 220 ft; some gravel to 1 inch; softer from 230 to 240 ft	24	240
Sand, fine to very coarse, and gravel and boulders larger than 5 inches; hard, gray-brown; calcium carbonate crystals (calcite) well developed in vesicles of basalt cobble	10	250
Sand, very fine to medium and some very coarse, silty, hard, gray-brown	4	254
Clay (interstitial); sand, mostly medium to very coarse, some fine to medium; and gravel, mostly fine, occasional cobbles; fairly soft; light gray-brown	8	262
Clay, very sandy, mostly fine to medium, a little coarse, fairly soft, medium grayish-brown	4	266
Sand, coarse to very coarse, with some clay; fairly soft, light gray-brown	4	270
Sand, mostly coarse to very coarse, some medium; gravel, very fine to fine; and clay, interstitial; fairly soft, light gray-brown	4	274
Sand, mostly coarse to very coarse; considerable gravel, very fine to medium; and some cobbles; fairly soft, light gray-brown	15	289

Table 4. Test-well logs—Continued

Material	Thickness (ft)	Depth (ft)
Test well 11—Continued		
Sand, mostly medium, some fine and coarse; with a little very fine gravel; and much interstitial clay; rather hard; plastic and cohesive when wet; light gray-brown. Sand finer and gravel absent 298 to 308, 326 to 329, and 331 to 335 ft. Slight increase in clay, and gravel coarser (fine to medium) 308 to 326 and 329 to 331 ft	46	335
Sand, mostly medium to very coarse; and gravel, mostly very fine to medium, some cobbles to 2 inches; fairly soft, gray-brown	4	339
Sand, fine to coarse; some clay and silt; and a little gravel 339 to 346 ft; fairly soft, gray-brown	11	350
Sand, mostly medium to very coarse; and gravel, mostly very fine to medium, some to 2 inches; occasional thin clayey streaks; fairly soft, light gray-brown. Lesser and finer gravel 368 to 388 ft	38	388
Sand, mostly medium to very coarse, some fine to medium; gravel, mostly fine, a few small cobbles; clay, interstitial, apparently fills much of pore space, comes up in large chunks, plastic when wet, hard when dry, increasingly micaceous below 420 ft; rather soft, medium gray-brown. Drilling water has peculiar milky appearance and feels soapy; probably contains bentonite. Encountered first water at 424 ft; rose rapidly to 340 ft. No discernible change in formation; beds below 424 ft may be clean sands and gravels alternating with clayey sands and gravels	61	449
Sand, mostly coarse to very coarse, some medium to coarse; and considerable gravel, mostly fine, some medium; contains some maroon basalt pebbles largely altered to clay; rather soft, yellowish-gray-brown, good water-bearing material. Drilling water contains milky. From 510 to 558 ft quantity and size of gravel varies slightly in beds 3 to 10 ft thick and drilling water somewhat more milky; occasional clay streaks 543 to 558 ft	109	558
Clay, containing much sand, very fine to very coarse, and a little fine gravel from 558 to 598 ft; pale lavender-brown from 558 to 575 ft, becoming increasingly darker yellow-brown below; moderately to strongly calcareous, and occasionally cemented, quite hard. Drilling water is very milky. Streak of loose, coarse sand and medium gravel encountered at 638 to 639 ft	86	644

Note; Sand grains are predominantly quartz and feldspar, with minor amounts of biotite, magnetite, and granitic minerals; subangular to subrounded. Gravel and cobbles largely gneiss and granitics, with few basalt and some metamorphic rocks; subrounded to rounded.

Water samples bailed during drilling at depths of 452, 557, and 644 ft.
Water temperatures during drilling: 90° to 100°F, increasing with depth.
Water level during drilling: 335 to 340 ft below land surface.
Water level both before perforating: 335 ft below land surface.
Perforations: 0.25-inch x 3-inch Mills knife, 6 cuts per round, one round per ft; 450–525, 538–548, and 550–558 ft.
Cement plug set at 644 ft.

Material	Thickness (ft)	Depth (ft)
Test well 12. In Surprise Spring Basin. Altitude: 2,442.0 ft. Casing diameter 10 inches; drilled July 29–Sept. 3, 1952.		
Soil, poorly developed, sandy	3	3
Sand, fine to coarse, poorly sorted, iron-stained, red to buff, soft	32	35
Sand, fine to coarse, mostly coarse; some fine gravel; buff to tan, soft. Coarse gravel from 42 to 48 ft	13	48

Table 4. Test-well logs—Continued

Material	Thickness (ft)	Depth (ft)
Test well 12—Continued		
Sand, fine to coarse, mostly coarse; some fine gravel; buff to tan, partially cemented or hard packed, intermittently hard and soft	20	68
Gravel, fine to coarse; and sand, fine to coarse, mostly coarse; buff to tan, soft	26	94
Sand, fine to coarse, mostly coarse, some fine to medium gravel, somewhat more mica (biotite) than above, gray-brown, soft	20	114
Gravel, fine to coarse; some small cobbles; and sand, fine to coarse, mostly coarse; gray-brown, moderately hard	6	120
Sand, fine to coarse, mostly coarse; and some gravel, mostly very fine; gray-brown, hard. Occasional beds cemented with calcium carbonate	35	155
Sand, fine to coarse, mostly coarse; occasionally some fine gravel, with little to no medium or coarse gravel; gray-brown, hard to soft, intermittently cemented, partially water-bearing. Sand is intermixed with a whitish, possibly calcareous or bentonitic colloidal clay, which remains suspended in water	145	300
Sand, fine to coarse, mostly very coarse; and gravel, fine to very fine; gray-brown, moderately soft, some cementation, largely water-bearing	20	320
Sand, fine to coarse, mostly coarse; some very fine gravel; gray-brown, hard, intermittent cementation, partly water-bearing	18	338
Sand, fine to very coarse, mostly very coarse; and gravel, very fine to fine, with occasional pebbles; gray-brown, moderately soft, largely water-bearing	8	346
Gravel, fine to coarse; some pebbles; and sand, fine to very coarse, mostly very coarse; gray-brown soft, largely water-bearing. Cemented from 347 to 350 ft	13	359
Sand, fine to very coarse, mostly very coarse; and gravel, very fine to fine; gray-brown, moderately soft, largely water-bearing	10	369
Sand, very fine to coarse, mostly medium and coarse; little to no fine gravel; gray-brown, hard, intermittent cementation, partly water-bearing	31	400
Sand, fine to very coarse, mostly very coarse; gravel very fine to fine; and occasional pebbles; gray-brown, moderately soft, largely water-bearing	20	420
Sand, very fine to coarse, mostly medium and coarse; and little to no fine gravel; gray-brown, poorly water-bearing hard, intermittent cementation	27	447
Sand, very fine to coarse, clayey, and some silt, light gray to gray-brown, hard, some cementation, essentially not water-bearing	10	457
Sand, fine to very coarse, mostly very coarse; some fine gravel, gray-brown, very soft, heaving sand, largely water-bearing	12	469

Table 4. Test-well logs—Continued

Material	Thickness (ft)	Depth (ft)
Test well 12—Continued		
Gravel, fine to coarse; few small cobbles; and sand, fine to coarse, mostly coarse; gray-brown, hard, calcareous cementation, poorly water-bearing	3	472
Sand, very fine to coarse, mostly coarse; and some gravel, fine to very fine; gray-brown, hard intermittent cementation, poorly water-bearing	28	500

Note: The sands are predominantly quartz and feldspars with some mica minerals (biotite); are poorly sorted, angular to subrounded, highly calcareous. The gravels are predominantly gneisses and basalts with considerable amounts of quartzite and granitics, poorly sorted, rounded to subrounded, generally, exceedingly few coarse gravels encountered.

Water samples bailed during drilling at depths of 296, 300, 358, 410, 450, 469, and 500 ft.
Water temperatures during drilling: 82° to 84.7°F, increasing with depth.
Water level during drilling: 189.2 to 191.0 ft below land surface.
Water level before perforating: 189.4 ft below land surface.
Perforations: 0.25-inch x 3-inch Mills knife, 6 cuts per round, one round per ft; 300–320, 338–370, and 400–420 ft.

CHEMICAL ANALYSES

The chemical analyses shown in table 5 are for water samples collected at selected depths during the course of drilling and for a sample collected by Mr. W.O. Wagner near the end of the 8-hour well-capacity tests made on the test wells and on the old Navy supply wells. The samples were analyzed by the Sanitation Division Laboratory, Public Works Office, Eleventh Naval District. The results are expressed in the same manner as shown on their water-analysis form. Also included are the depth, or source, and the temperature of each sample.

Samples taken during the construction of wells 5, 11, and 12 contained colloidal clays, possibly bentonitic, which would not settle out even when the samples were allowed to stand for periods of a week or more. Nevertheless, when the wells were test-pumped, the water in wells 5 and 11 soon cleared and became free of any observable suspended matter. The discharge from test well 12 was still somewhat cloudy after 8 hours of pumping, but probably would have cleared after additional pumping.

Table 5. Chemical analyses of waters for three old Navy supply wells and for ten test wells, Marine Corps Training Center, Twentynine Palms, California

[Analyses by the Sanitation Division Laboratory, Public Works Office, Eleventh Naval District. Analyses in parts per million. ft, foot; °F, degrees Fahrenheit; —, no data]

Old Navy supply wells 1, 2, and 3			
U.S. Navy Lab. no.	**1489**	**1490**	**1485**
Date	**4-8-52**	**4-9-52**	**4-1-52**
Depth sampled (ft)	([1])	([1])	([1])
Temperature (°F)	77	73	74
Total hardness ($CaCO_3$)	92	94	72
Calcium hardness ($CaCO_3$)	74	80	58
Magnesium hardness ($CaCO_3$)	18	14	14
Alkalinity P ($CaCO_3$)	0	0	3
Alkalinity M ($CaCO_3$)	62	58	90
Caustic alkalinity (OH)($CaCO_3$)	0	0	0
Free carbon dioxide (CO_2)	0	0	0
Chloride (Cl)	58	56	204
Sulphate (SO_4)	280	290	276
Iron (Fe)	0	0	0
Silica (SiO_2)	18	18	18

Footnotes at end of table.

Table 5. Chemical analyses of waters for three old Navy supply wells and for ten test wells, Marine Corps Training Center, Twentynine Palms, California—Continued

Old Navy supply wells 1, 2, and 3—Continued			
pH	8.1	8.15	8.25
Phosphate (PO_4)	0	0	0
Turbidity	1	.5	—
Boron (B)	.37	.4	1.2
Fluoride (F)	7.5	11	4.5
Total dissolved solids	560	580	870

Test well 1, Mesquite Basin				
U.S. Navy Lab. no.	**1431**	**1435**	**1446**	**1458**
Date	**2-6-52**	**2-8-52**	**2-15-52**	**3-6-52**
Depth sampled (ft)	210	316	400	([1])
Temperature (°F)	77	81	80.5	85
Total hardness ($CaCO_3$)	47	38	44	26
Calcium hardness ($CaCO_3$)	44	34	36	20
Magnesium hardness ($CaCO_3$)	3	4	9	6
Alkalinity P ($CaCO_3$)	4	3	0	8
Alkalinity M ($CaCO_3$)	50	46	50	34
Caustic alkalinity (OH)($CaCO_3$)	0	0	0	0
Free carbon dioxide (CO_2)	—	—	7	0
Chloride (Cl)	72	70	70	66
Sulphate (SO_4)	374	340	325	258
Iron (Fe)	.3	0	.3	.1
Silica (SiO_2)	6	6	10	10
pH	8.4	8.3	7.5	8.9
Phosphate (PO_4)	—	—	—	—
Turbidity	—	—	—	—
Boron (B)	.9	.9	.5	.52
Fluoride (F)	14	14	12	8
Total dissolved solids	710	630	640	580

Test well 2, Deadman Basin					
U.S. Navy Lab. no.	**1411**	**1416**	**1417**	**1425**	**1445**
Date	**1-15-52**	**1-22-52**	**1-29-52**	**2-1-52**	**2-19-52**
Depth sampled (ft)	134	290	385	512	([1])
Temperature (°F)	67	70	70	69.5	72
Total hardness ($CaCO_3$)	118	126	140	134	160
Calcium hardness ($CaCO_3$)	98	104	114	112	126
Magnesium hardness ($CaCO_3$)	20	22	36	22	34
Alkalinity P ($CaCO_3$)	0	0	3	0	0
Alkalinity M ($CaCO_3$)	90	82	86	84	70
Caustic alkalinity (OH)($CaCO_3$)	0	0	0	0	0
Free carbon dioxide (CO_2)	0	0	0	2	0
Chloride (Cl)	126	154	160	152	188
Sulphate (SO_4)	375	318	318	280	381
Iron (Fe)	0	—	.1	0	.1
Silica (SiO_2)	10	—	10	14	18
pH	8.0	8.0	8.2	7.9	8.0
Phosphate (PO_4)	—	—	—	—	0
Turbidity	30	—	—	—	2

Footnotes at end of table.

Table 5. Chemical analyses of waters for three old Navy supply wells and for ten test wells, Marine Corps Training Center, Twentynine Palms, California—Continued

Test well 2, Deadman Basin—Continued					
Boron (B)	1.00	1.06	1.08	1.00	1.1
Fluoride (F)	5	5	5	4	4
Total dissolved solids	860	840	860	810	830
Test well 3, Deadman Basin					
U.S. Navy Lab. no.	**1444**	**1448**	**1452**	**1453**	**1479**
Date	**2-15-52**	**2-20-52**	**2-27-52**	**2-28-52**	**3-13-52**
Depth sampled (ft)	236	295	400	470	([1])
Temperature (°F)	76	78	75	82	83
Total hardness ($CaCO_3$)	90	70	78	52	62
Calcium hardness ($CaCO_3$)	80	56	66	44	50
Magnesium hardness ($CaCO_3$)	10	14	12	8	12
Alkalinity P ($CaCO_3$)	0	0	0	3	3
Alkalinity M ($CaCO_3$)	72	62	66	82	68
Caustic alkalinity (OH)($CaCO_3$)	0	0	0	0	0
Free carbon dioxide (CO_2)	5	0	9	0	0
Chloride (Cl)	340	296	300	240	280
Sulphate (SO_4)	446	341	372	319	268
Iron (Fe)	.1	.1	.1	.1	.1
Silica (SiO_2)	10	14	6	12	16
pH	7.7	8.0	7.5	8.3	8.3
Phosphate (PO_4)	0	.4	.2	.4	—
Turbidity	—	—	—	—	—
Boron (B)	1.5	1.2	1.1	.9	.7
Fluoride (F)	7.5	3.5	3.5	2.5	4
Total dissolved solids	1,240	1,160	1,160	980	980
Test well 5, Surprise Spring Basin					
U.S. Navy Lab. no.	**[2]1454**	**1457**	**1469**	**1480**	**1492**
Date	**2-29-52**	**3-6-52**	**3-12-52**	**3-14-52**	**4-16-52**
Depth sampled (ft)	140	255	336	396	([1])
Temperature (°F)	81	87.5	84.5	86	93
Total hardness ($CaCO_3$)	—	38	28	24	7
Calcium hardness ($CaCO_3$)	—	10	18	14	7
Magnesium hardness ($CaCO_3$)	—	28	10	10	—
Alkalinity P ($CaCO_3$)	—	0	0	2	14
Alkalinity M ($CaCO_3$)	—	42	76	68	70
Caustic alkalinity (OH)($CaCO_3$)	—	0	0	0	0
Free carbon dioxide (CO_2)	—	1	0	0	0
Chloride (Cl)	24	18	16	16	12
Sulphate (SO_4)	60	83	35	37	24
Iron (Fe)	—	.1	—	.1	0
Silica (SiO_2)	—	14	—	18	18
pH	—	7.9	8.1	8.2	9.0
Phosphate (PO_4)	—	—	—	—	.8
Turbidity	—	—	—	—	—
Boron (B)	—	.08	—	—	.3
Fluoride (F)	—	.6	.7	1	1.1
Total dissolved solids	200	195	140	130	140

Footnotes at end of table.

Table 5. Chemical analyses of waters for three old Navy supply wells and for ten test wells, Marine Corps Training Center, Twentynine Palms, California—Continued

Test well 6, Surprise Spring Basin					
U.S. Navy Lab. no.	**1482**	**1484**	**1486**	**1488**	**1500**
Date	**3-20-52**	**3-24-52**	**3-31-52**	**4-3-52**	**4-23-52**
Depth sampled (ft)	286	354	404	450	([1])
Temperature (°F)	70	71	72	75	74
Total hardness ($CaCO_3$)	152	200	150	170	184
Calcium hardness ($CaCO_3$)	122	152	126	146	140
Magnesium hardness ($CaCO_3$)	30	48	24	14	44
Alkalinity P ($CaCO_3$)	0	0	0	0	0
Alkalinity M ($CaCO_3$)	70	62	58	56	62
Caustic alkalinity (OH)($CaCO_3$)	0	0	0	0	0
Free carbon dioxide (CO_2)	1	1	1	8	4
Chloride (Cl)	106	128	116	118	122
Sulphate (SO_4)	93	150	120	90	120
Iron (Fe)	0	0	0	.1	0
Silica (SiO_2)	14	18	10	14	16
pH	7.9	7.9	7.9	7.5	7.7
Phosphate (PO_4)	.2	—	.2	.1	0
Turbidity	—	—	—	—	—
Boron (B)	.13	.07	.09	0	.24
Fluoride (F)	.4	.3	.4	.4	.3
Total dissolved solids	380	440	380	400	430

Test well 8, Deadman Basin					
U.S. Navy Lab. no.	**1491**	**1493**	**1502**	**1501**	**1503**
Date	**4-9-52**	**4-15-52**	**4-25-52**	**4-25-52**	**4-30-52**
Depth sampled (ft)	163	252	472	474	564
Temperature (°F)	74	77.5	75	80	82.3
Total hardness ($CaCO_3$)	112	82	80	126	74
Calcium hardness ($CaCO_3$)	102	78	68	106	62
Magnesium hardness ($CaCO_3$)	10	4	12	20	12
Alkalinity P ($CaCO_3$)	0	0	0	0	0
Alkalinity M ($CaCO_3$)	74	70	72	72	74
Caustic alkalinity (OH)($CaCO_3$)	0	0	0	0	0
Free carbon dioxide (CO_2)	1	1	0	0	0
Chloride (Cl)	152	134	152	168	160
Sulphate (SO_4)	300	325	300	319	300
Iron (Fe)	0	0	0	0	0
Silica (SiO_2)	14	10	10	14	10
pH	7.9	7.9	8.0	8.0	8.1
Phosphate (PO_4)	0	.5	0	0	—
Turbidity	—	—	—	—	—
Boron (B)	.9	.7	.54	.63	.5
Fluoride (F)	4	5	3.6	5	3.2
Total dissolved solids	780	700	750	820	780
U.S. Navy Lab. no.	**1511**	**1512**	**1513**	**1515**	—
Date	**5-6-52**	**5-14-52**	**5-15-52**	**5-28-52**	**6-26-52**
Depth sampled (ft)	653	794	800	([1])	([3])

Footnotes at end of table.

Table 5. Chemical analyses of waters for three old Navy supply wells and for ten test wells, Marine Corps Training Center, Twentynine Palms, California—Continued

Test well 8, Deadman Basin—Continued					
Temperature (°F)	88	88	89	85	84.7
Total hardness ($CaCO_3$)	58	102	80	102	—
Calcium hardness ($CaCO_3$)	46	86	70	82	—
Magnesium hardness ($CaCO_3$)	12	16	10	20	—
Alkalinity P ($CaCO_3$)	3.0	0	0	0	—
Alkalinity M ($CaCO_3$)	88	38	50	74	—
Caustic alkalinity (OH)($CaCO_3$)	0	0	0	0	—
Free carbon dioxide (CO_2)	0	5	1	0	—
Chloride (Cl)	166	196	188	196	—
Sulphate (SO_4)	300	365	340	298	—
Iron (Fe)	0	0	0	—	—
Silica (SiO_2)	8	14	10	18	—
pH	8.2	7.5	7.9	8.0	—
Phosphate (PO_4)	—	—	—	—	—
Turbidity	—	—	—	—	—
Boron (B)	—	—	—	.7	—
Fluoride (F)	3.0	4.3	4	1.5	1.4
Total dissolved solids	800	1,080	1,032	860	—

Test well 9, Surprise Spring Basin			
U.S. Navy Lab. no.	**1510**	**1514**	**1557**
Date	**5-6-52**	**5-15-52**	**7-21-52**
Depth sampled (ft)	366	418	([1])
Temperature (°F)	75	76	78
Total hardness ($CaCO_3$)	52	32	34
Calcium hardness ($CaCO_3$)	36	22	26
Magnesium hardness ($CaCO_3$)	16	10	8
Alkalinity P ($CaCO_3$)	0	4	3
Alkalinity M ($CaCO_3$)	76	80	72
Caustic alkalinity (OH)($CaCO_3$)	0	0	0
Free carbon dioxide (CO_2)	2	0	0
Chloride (Cl)	20	12	17
Sulphate (SO_4)	76	30	25
Iron (Fe)	0	0	0
Silica (SiO_2)	10	16	16
pH	7.9	8.3	8.4
Phosphate (PO_4)	—	—	—
Turbidity	—	—	1
Boron (B)	—	0	.01
Fluoride (F)	0.4	0.4	.5
Total dissolved solids	184	187	140

Test well 10, Deadman Basin			
U.S. Navy Lab. no.	**1540**	**1544**	**1545**
Date	**7-2-52**	**7-7-52**	**7-9-52**
Depth sampled (ft)	270	314	386
Temperature (°F)	82	83.4	83.7
Total hardness ($CaCO_3$)	116	130	114
Calcium hardness ($CaCO_3$)	98	108	98
Magnesium hardness ($CaCO_3$)	18	22	16

Footnotes at end of table.

Table 5. Chemical analyses of waters for three old Navy supply wells and for ten test wells, Marine Corps Training Center, Twentynine Palms, California—Continued

Test well 10, Deadman Basin—Continued			
Alkalinity P ($CaCO_3$)	0	0	0
Alkalinity M ($CaCO_3$)	88	78	82
Caustic alkalinity (OH)($CaCO_3$)	0	0	0
Free carbon dioxide (CO_2)	—	2	0
Chloride (Cl)	132	150	126
Sulphate (SO_4)	180	318	242
Iron (Fe)	.1	0	0
Silica (SiO_2)	14	16	10
pH	7.7	7.9	7.9
Phosphate (PO_4)	—	—	—
Turbidity	—	—	—
Boron (B)	—	—	—
Fluoride (F)	1.6	2.6	1.6
Total dissolved solids	560	700	600
U.S. Navy Lab. no.	**1553**	**1555**	**1560**
Date	**7-11-52**	**7-15-52**	**7-25-52**
Depth sampled (ft)	450	501	([1])
Temperature (°F)	87.2	85	83
Total hardness ($CaCO_3$)	94	90	150
Calcium hardness ($CaCO_3$)	78	78	130
Magnesium hardness ($CaCO_3$)	16	12	20
Alkalinity P ($CaCO_3$)	0	0	0
Alkalinity M ($CaCO_3$)	76	92	76
Caustic alkalinity (OH)($CaCO_3$)	0	0	0
Free carbon dioxide (CO_2)	0	0	0
Chloride (Cl)	128	110	136
Sulphate (SO_4)	240	215	245
Iron (Fe)	0	0	0
Silica (SiO_2)	24	10	24
pH	8.1	8.1	8.2
Phosphate (PO_4)	—	—	—
Turbidity	—	—	—
Boron (B)	.12	.11	.14
Fluoride (F)	1.4	1.7	1.6
Total dissolved solids	600	540	640

Test well 11, South or Surprise Spring Basin				
U.S. Navy Lab. no.	**1552**	([4])	([4])	**1589**
Date	**7-10-52**	**7-14-52**	**7-15-52**	**8-7-52**
Depth sampled (ft)	452	566	557	([1])
Temperature (°F)	90	—	—	96
Total hardness ($CaCO_3$)	26	—	—	8
Calcium hardness ($CaCO_3$)	13	—	—	5
Magnesium hardness ($CaCO_3$)	13	—	—	3
Alkalinity P ($CaCO_3$)	0	—	—	20
Alkalinity M ($CaCO_3$)	94	—	—	100
Caustic alkalinity (OH)($CaCO_3$)	0	—	—	0
Free carbon dioxide (CO_2)	20	—	—	0

Footnotes at end of table.

Table 5. Chemical analyses of waters for three old Navy supply wells and for ten test wells, Marine Corps Training Center, Twentynine Palms, California—Continued

Test well 11, South or Surprise Spring Basin—Continued				
Chloride (Cl)	2	—	—	10
Sulphate (SO_4)	77	—	—	15
Iron (Fe)	0	—	—	—
Silica (SiO_2)	18	—	—	20
pH	7.3	—	—	8.9
Phosphate (PO_4)	—	—	—	—
Turbidity	—	—	—	—
Boron (B)	—	—	—	—
Fluoride (F)	.7	—	—	1.1
Total dissolved solids	220	—	—	154

Test well 12, Surprise Spring Basin				
U.S. Navy Lab. no.	**1597**	**1598**	**4**	**5**
Date	**8-14-52**	**8-14-52**	**8-25-52**	**8-26-52**
Depth sampled (ft)	296	300	408	450
Temperature (°F)	82	82	84	84.4
Total hardness ($CaCO_3$)	37	42	33	39
Calcium hardness ($CaCO_3$)	30	35	28	34
Magnesium hardness ($CaCO_3$)	7	7	5	5
Alkalinity P ($CaCO_3$)	3	3	6	14
Alkalinity M ($CaCO_3$)	56	68	67	90
Caustic alkalinity (OH)($CaCO_3$)	0	0	0	0
Free carbon dioxide (CO_2)	0	0	0	0
Chloride (Cl)	17	17	17	16
Sulphate (SO_4)	75	44	58	46
Iron (Fe)	—	—	—	—
Silica (SiO_2)	19	25	22	20
pH	8.0	8.1	8.5	8.3
Phosphate (PO_4)	—	—	—	—
Turbidity	—	—	—	—
Boron (B)	—	—	—	—
Fluoride (F)	—	.5	.8	—
Total dissolved solids	178	160	170	174

U.S. Navy Lab. no.	**6**	**7**	**8**
Date	**8-27-52**	**8-28-52**	**9-9-52**
Depth sampled (ft)	469	500	([1])
Temperature (°F)	84.5	84.7	80
Total hardness ($CaCO_3$)	34	30	35
Calcium hardness ($CaCO_3$)	29	26	29
Magnesium hardness ($CaCO_3$)	5	4	6
Alkalinity P ($CaCO_3$)	4	2	1
Alkalinity M ($CaCO_3$)	68	74	64
Caustic alkalinity (OH)($CaCO_3$)	0	0	0
Free carbon dioxide (CO_2)	0	0	0
Chloride (Cl)	16	15	15
Sulphate (SO_4)	41	37	39
Iron (Fe)	—	0	0

Footnotes at end of table.

Table 5. Chemical analyses of waters for three old Navy supply wells and for ten test wells, Marine Corps Training Center, Twentynine Palms, California—Continued

Test well 12, Surprise Spring Basin—Continued			
Silica (SiO_2)	25	19	25
pH	8.2	8.5	8.5
Phosphate (PO_4)	—	—	—
Turbidity	—	—	—
Boron (B)	--	.1	.1
Fluoride (F)	.6	.6	.7
Total dissolved solids	165	163	164

[1]From pump discharge after 8-hour test.
[2]Sample No. 1454 too muddy to run complete analysis.
[3]Recheck on fluoride content only.
[4]Not analyzed because colloidal clay could not be separated from the water.

BAIL TESTS

During the drilling of the test wells, bail tests were run on saturated water-bearing materials at selected depths in each well. These tests were made by bailing water from the well with a 50-gallon bailer as rapidly as possible for a period of half an hour; then, measuring the recovery of the water level for half an hour. The results provide a rough index to the permeability of the deposits exposed in the open hole below the casing shoe. During several bail tests, a few feet to 50 or more feet of loose, running, sandy material "heaved" up into the casing thereby rendering the results inconclusive.

Table 6 shows the results of the bail tests run on the test wells. In all, 31 tests were run.

Table 6. Bail tests on test wells, U.S. Marine Corps Training Center, Twentynine Palms, California
[ft, foot; gal, gallon]

Test well 1		
Depth: 210 ft.		Date: February 6, 1952
Time	**Depth to water (ft)**	**Remarks**
10:10 a.m.	109	Start of bail test.
10:20	172	End of test; bailed about 275 gallons of water; and had heaved up about 30 ft in casing during bailing.
10:25	168	
10:33	163	
10:45	163	

Conclusion: Bail test inconclusive for permeability of formation tapped because of sand heaving up in casing.

Table 6. Bail tests on test wells, U.S. Marine Corps Training Center, Twentynine Palms, California—Continued

Test well 1—Continued

Time	Depth to water (ft)	Remarks
Depth: 316 ft.		Date: February 8, 1952
2:45 p.m.	82	Start of test.
3:15	118	End of test; bailed about 450 gallons of water; silty sand heaved up about 40 ft in casing during bailing.
3:20	117.2	
3:25	117.2	
3:30	117.2	Resumed drilling.
Conclusion: Bail test inconclusive as above.		
Depth: 400 ft.		Date: February 15, 1952
8:45 a.m.	84	
10:15	84	Start of test; bailed about 800 gallons of water.
11:45	84	End of test; leaky bailer made recovery measurements impossible. Do not believe there was much drawdown.
Conclusion: Test indicates that materials at 400 ft have good permeability.		

Test well 2

Time	Depth to water (ft)	Remarks
Depth: 134 ft.		Date: January 15, 1952
8:40 a.m.	47.6	
3:35	47.4	
3:40	47.4	Start of bail test.
4:10		End of bail test; bailed about 480 gallons of water; sand heaved up about 10 ft in casing during bailing.
4:12	73.6	
4:17	55.1	
4:22	51.4	
4:30	45.2	
Conclusion: Test indicates only fair permeability of formation owing to sand heaving up in casing.		

Table 6. Bail tests on test wells, U.S. Marine Corps Training Center, Twentynine Palms, California—Continued

Test well 2—Continued

Depth: 290 ft. Date: January 23, 1952

Time	Depth to water (ft)	Remarks
8:00 a.m.	42.0	
10:25	43.15	Start of bail test.
10:55		End of bail test; bailed about 480 gallons of water.
10:56	47.0	
11:00	42.75	

Conclusion: Bail test indicates good permeability of formation tested.

Depth: 385 ft. Date: January 29, 1952

Time	Depth to water (ft)	Remarks
8:50 a.m.	43.16	
8:55	43.16	Start of bail test.
9:25		End of bail test; bailed about 480 gallons of water.
9:26	43.16	No measurable drawdown.

Conclusion: Bail test indicates a high permeability of formation tested.

Depth: 512 ft. Date: February 1, 1952

Time	Depth to water (ft)	Remarks
8:00 a.m.	42.0	
3:00 p.m.	43.65	Start of bail test.
3:30		End of bail test; bailed about 460 gallons of water; sand heaved up about 8 ft in casing during drilling.
3:31	47.5	
3:33	44.8	
3.39	43.83	

Conclusion: Bail test indicates good permeability of formation tested even though sand heaved up in casing.

Table 6. Bail tests on test wells, U.S. Marine Corps Training Center, Twentynine Palms, California—Continued

Time	Depth to water (ft)	Remarks
Test well 3		
Depth: 236 ft.		Date: February 15, 1952
8:00 a.m.	48	
9:10	65.55	Start of bail test.
9:30		End of bail test; bailed about 190 gallons of water.
9:32	77.0	
9:33	76.2	
9:34	75.2	
9:35	74.5	
9:36	73.9	
9:37	73.4	
9:42	70.2	
Conclusion: Bail tests indicate fair permeability of formation tested.		
Depth: 294 ft.		Date: February 20, 1952
8:00 a.m.	48.5	
9:00	65.1	Start of bail test.
9:30		End of bail test; bailed about 460 gallons of water; sand heaved up about 16 ft in casing during drilling.
9:32	83.6	
9:33	82.7	
9:34	81.6	
9:35	80.45	
9:37	78.1	
9:42	73.1	
Conclusion: Same as above.		

Tahle 6. Bail tests on test wells, U.S. Marine Corps Training Center, Twentynine Palms, California—Continued

Test well 3—Continued

Time	Depth to water (ft)	Remarks
Depth: 404 ft.		Date: February 27, 1952
8:00 a.m.	51.0	
8:30	58.59	
8:40		Start of bail test.
9:10		End of bail test; bailed about 640 gallons of water; sand heaved up about 15 ft in casing during bailing.
9:13	81.75	
9:14	78.55	
9:15	76.6	
9:16	75.15	
9:17	73.85	
9:18	72.85	
9:23	68.1	

Conclusion: Bail test indicates fairly good permeability of materials tested even though sand heaved up in casing.

Depth: 470 ft		Date: February 28, 1952
8:00 a.m.	55.0	
2:45 p.m.	56.53	Start of bail test.
3:15		End of bail test; bailed about 730 gallons of water; sand heaved up about 16 ft in casing during bailing.
3:20	89.83	
3:21	86.53	
3:22	83.48	
3:23	80.53	
3:25	75.48	
3:30	65.23	

Conclusion: Same as above.

Table 6. Bail tests on test wells, U.S. Marine Corps Training Center, Twentynine Palms, California—Continued

Test well 5

Depth: 140 ft. Date: February 29, 1952

Time	Depth to water (ft)	Remarks
8:15 a.m.	25.01	
1:30 p.m.	25.0	Start of bail test.
1:40	75	End of bail test; bailed about 275 gallons of water; sand heaved up about 60 ft in casing during drilling.
2:00	69.2	

Conclusion: Owing to heaving sand, test was inconclusive.

Depth: 255 ft. Date: March 6, 1952

Time	Depth to water (ft)	Remarks
8:00 a.m.	24	
1:00 p.m.	29.6	Start of bail test.
1:30	95.6	End of bail test; bailed about 950 gallons of water; sand heaved up about 50 ft in casing during bailing.
1:35	83.1	
1:40	74.6	
1:45	63.1	
1:50	56.2	
1:55	53.4	

Conclusion: Same as above.

Depth: 336 ft. Date: March 12, 1952

Time	Depth to water (ft)	Remarks
8:00 a.m.	21.07	
9:30	34.80	Start of bail test.
10:00	57.7	End of bail test; bailed about 750 gallons of water; sand heaved up about 40 ft in casing during bailing.
10:05	57.7	
10:10	47.1	
10:15	38.0	
10:20	33.4	
10:25	29.2	
10:30	27.7	

Conclusion: Bail test indicates fair permeability of formation even though masked by heaving sand.

Table 6. Bail tests on test wells, U.S. Marine Corps Training Center, Twentynine Palms, California—Continued

Test well 5—Continued

Depth: 396 ft.		Date: March 14, 1952
Time	**Depth to water (ft)**	**Remarks**
8:00 a.m.	21.7	
10:00 a.m.	31.5	Start of bail test.
10:35	130.6	End of bail test; bailed about 1,620 gallons of water; sand heaved up nearly 100 ft in casing during bailing.
10:40	120.2	
10:45	109.6	
10:50	98.7	
10:55	88.7	
11.00	80.1	
11.05	71.4	
11:10	63.9	
11:15	58.3	

Conclusion: Same as above.

Test well 6

Depth: 286 ft.		Date: March 20, 1952
9:00 a.m.	147.6	
2:50 p.m.	158.8	
2:53		Start of bail test.
3:23		End of bail test; bailed about 600 gallons of water; sand had heaved up about 50 ft in casing during bailing.
3:30	213.4	
3:32	213.0	
3:34	212.2	
3:36	210.7	
3:38	209.1	
3:30	208.3	
3:45	206.4	

Conclusion: Test inconclusive owing to sand heaving up in casing.

Table 6. Bail tests on test wells, U.S. Marine Corps Training Center, Twentynine Palms, California—Continued

Test well 6—Continued

Depth: 354 ft. Date: March 24, 1952

Time	Depth to water (ft)	Remarks
9:00 a.m.	147.6	
3:22 p.m.	154.3	
3:26		Start of test.
3:56		End of test; bailed about 650 gallons of water; sand heaved up about 4 ft in casing during bailing.
4:00	158.4	
4:01	156.2	
4:02	155.0	
4:03	153.9	
4:06	151.8	
4:11	150.4	

Conclusion: Test indicates that materials at 354 ft have a fairly good permeability.

Test well 8

Depth: 252 ft. Date: April 15, 1952

Time	Depth to water (ft)	Remarks
1:40 p.m.	108.5	Start of test.
1:55	212.0	End of test; bailed about 450 gallons of water. Stopped test after 15 minutes, as there was danger of losing drilling water.
2:00	211.3	
2:05	210.7	
2.10	210.1	
2.15	209.6	
2:20	208.0	
2:30	208.7	

Conclusion: Test indicates that materials at 252 ft have poor permeability.

Table 6. Bail tests on test wells, U.S. Marine Corps Training Center, Twentynine Palms, California—Continued

Test well 8—Continued

Time	Depth to water (ft)	Remarks
Depth: 564 ft.		Date: April 29, 1952
9:45 a.m.	88.5	Start of test.
10:25	108.0	End of test; bailed about 650 gallons of water.
10:30	89.5	
10:35	89.2	
10:40	88.8	
10:45	88.7	
10:50	88.6	
10:55	88.57	
11:00	88.5	

Conclusion: Bail test indicates that materials at 564 ft have very good permeability.

Test well 9

Time	Depth to water (ft)	Remarks
Depth: 366 ft.		Date: May 6, 1952
11:10 a.m.	250	Bailed about 60 gallons of water to obtain sample for analysis. No detectable change in water level.
11:30	250	

Conclusion: Not enough water bailed to provide a conclusive test of permeability

Time	Depth to water (ft)	Remarks
Depth: 421 ft.		Date: May 15, 1952
9:00 a.m.	250	
9:50	—	Start of bail test.
10:23	—	End of test; bailed about 600 gallons of water; sand heaved up about 8 ft during test.
10:36	250	Only accurate measurement obtained.

Conclusion: Bail test indicates that materials at 421 ft have a very good permeability.

Table 6. Bail tests on test wells, U.S. Marine Corps Training Center, Twentynine Palms, California—Continued

Test well 10		
Depth: 314 ft.		Date: July 2, 1952
Time	**Depth to water (ft)**	**Remarks**
11:15 a.m.	195	Start of test.
11:45	235+	End of test; bailed about 400 gallons of water; sand heaved up about 15 ft in casing during test.
11:55	218	
12:00 M	214.4	
12:05 p.m.	213	
12:10	212.8	
12:15	210.4	
12:20	209.5	
12:25	209	
Conclusion: Bail test indicates that materials at 314 ft have fair permeability. Heaving sand renders test rather inconclusive.		
Depth: 386 ft.		Date: July 8, 1952
10:25 a.m.	189.7	Start of bail test
10:55	206.3	End of test; bailed about 450 gallons of water; sand heaved up about 8 ft in casing during test.
11:00	200.3	
11:05	194.3	
11:10	191.3	
11:15	190.8	
11:20	189.7	
11:30	189.7	
Conclusion: Bail test indicates that materials at 386 ft have fairly good permeability.		
Depth: 501 ft.		Date: July 14, 1952
1:00 p.m.	189.3	Start of bail test.
1:30	192.3	End of test; bailed about 400 gallons of water; sand heaved up about 6 ft in casing during test.
1:35	190.3	
1:40	189.3	
1:50	189.3	
Conclusion: Bail test indicates that materials at 500 ft have good permeability.		

Table 6. Bail tests on test wells, U.S. Marine Corps Training Center, Twentynine Palms, California—Continued

Test well 11

Time	Depth to water (ft)	Remarks
Depth: 452 ft.		Date: July 10, 1952
12:30 p.m.	338	Start of test.
1:15	—	End of test; bailed about 500 gallons of water; sand heaved up in well only 6 inches during test.
1:20	366	
1:35	351.1	
1:40	347.6	
1:46	345.2	
1:50	343.3	
2:00	341.5	

Conclusion: Bail test indicates that materials at 452 ft have fair permeability.

Time	Depth to water (ft)	Remarks
Depth: 557 ft.		Date: July 14, 1952
8:00 a.m.	335	
3:50 p.m.	344.8	Start of bail test.
4:22	—	End of test; bailed about 450 gallons of water; sand heaved up in well only about 1 foot.
4:48	347.65	
4:55	343.3	
5:00	341.0	
5:06	339.24	
5:14	337.65	
5:20	336.95	
5:25	336.46	
5:30	336.16	
5:37	335.80	

Conclusion: Bail test indicates that materials at 557 ft have fairly good permeability.

Table 6. Bail tests on test wells, U.S. Marine Corps Training Center, Twentynine Palms, California—Continued

Test well 11—Continued		
Depth: 644 ft.		Date: July 22, 1952
Time	**Depth to water (ft)**	**Remarks**
8:00 a.m.	335	
3:05 p.m.	339.64	Start of bail test.
3:56	—	End of test; bailed about 450 gallons of water; no material heaved up in casing.
4:04	357.00	
4:09	354.18	
4:15	351.04	
4:20	348.99	
4:25	347.52	
4:30	345.43	
4:35	344.09	
4:40	342.41	
4:50	340.09	
5:00	338.55	
5:20	336.50	
5:39	335.54	

Conclusion: Bail test indicates that materials at 644 ft have fair permeability.

Test well 12		
Depth: 300 ft.		Date: August 14, 1952
12:55 p.m.	191	Start of test
1:28	200	End of test; bailed about 500 gallons of water; sand did not heave up in well.
1:30	198.5	
1:35	193.5	
1:40	191	
1:45	190.8	
1:50	190.8	

Conclusion: Bail test indicates that materials at 300 ft have fairly good permeability.

Table 6. Bail tests on test wells, U.S. Marine Corps Training Center, Twentynine Palms, California—Continued

Test well 12—Continued

Depth: 408 ft.		Date: August 25, 1952
Time	**Depth to water (ft)**	**Remarks**
11:00 a.m.	189.5	Start of bail test.
11:33	216.5	End of test; bailed about 500 gallons of water; sand did not heave up in well.
11:41	212.8	
11:46	198.2	
11:51	193.2	
11:56	191.4	
12:01	190.5	
12:06	190.2	

Conclusion: Bail test indicates that materials at 408 ft have fair permeability.

Depth: 469 ft.		Date: August 27, 1952
11:40 a.m.	190.1	
12:20 p.m.		Start of bail test.
12:49	215	End of test; about 500 gallons of water bailed out; sand did not heave up in well.
12:53	210.7	
12:55	201.2	
12:56	200.7	
12:57	197.7	
12:58	195.7	
1:00	193.8	
1:05	190.6	
1:11	189.5	
1:16	189.2	
1:20	189.0	

Conclusion: Bail test indicates that materials at 469 ft have fair permeability.

Table 6. Bail tests on test wells, U.S. Marine Corps Training Center, Twentynine Palms, California—Continued

Test well 12—Continued		
Depth: 500 ft.		Date: August 28, 1952
Time	Depth to water (ft)	Remarks
3:15 p.m.	189.4	Start of bail test.
3:46	216	End of test; about 500 gallons of water bailed out; sand did not heave up in well.
3:48	211.1	
3:50	209.6	
3:53	207.3	
3:55	204.4	
4:00	200.5	
4:05	196.3	
4:10	192.9	
4:15	191	
4:20	189.4	
Conclusion: Bail test indicates that materials at 500 ft have fair permeability.		

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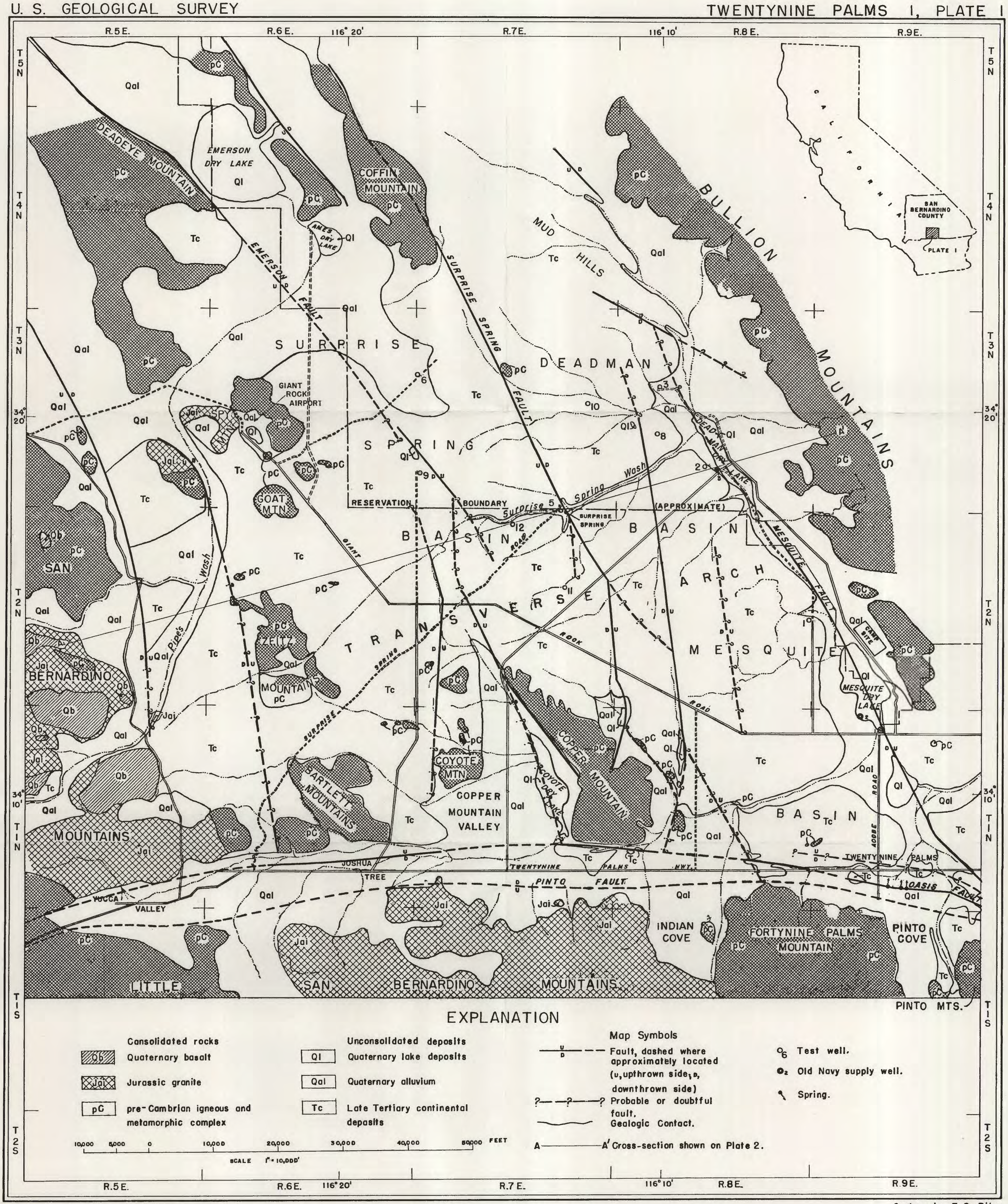

Base from Metropolitan Water District map of Twentynine Palms, modified from aerial photos.

Geology by F. S. Riley

MAP OF THE TWENTYNINE PALMS BASIN, CALIFORNIA SHOWING RECONNAISSANCE GEOLOGY AND LOCATION OF TEST WELLS

GENERALIZED SECTION A-A' ACROSS THE TWENTYNINE PALMS BASIN
SHOWING UNCONSOLIDATED DEPOSITS AND WATER-LEVEL PROFILES