ARIZONA STATE LAND DEPARTMENT

OBED M. LASSEN, COMMISSIONER

GEOLOGY AND GROUND-WATER RESOURCES OF THE HARQUAHALA PLAINS AREA, MARICOPA AND YUMA COUNTIES, ARIZONA

BY

D. G. METZGER

PREPARED BY THE GEOLOGICAL SURVEY,
UNITED STATES DEPARTMENT OF THE INTERIOR

Phoenix, Arizona
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WATER RESOURCES REPORT NUMBER 3

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ABSTRACT

The Harquahala Plains area lies in the southwestern part of the State of Arizona about midway between Phoenix and the Colorado River. About two-thirds of the area is in Maricopa County and the rest is in Yuma County. The climate is arid, as the average annual precipitation is about 8 inches.

The principal landforms are mountains, pediments, and the valley floor. Exposed pediments and concealed pediments border the mountains and are cut predominantly on granitic rocks, although in the southeastern part they are cut on volcanic rocks. The valley floor along Centennial Wash slopes 15 to 20 feet per mile southeast, and the position of Centennial Wash is controlled by the sizes of the mountains and the contributing drainage areas. The drainage of the Harquahala Plains area is southeastward to the Gila River.

The rock units in the Harquahala Plains area, as described in this report, are as follows: (1) Precambrian metamorphic and igneous rocks; (2) Paleozoic sedimentary rocks; (3) Cretaceous sedimentary rocks; (4) Cretaceous(?) and Tertiary volcanic rocks; (5) Tertiary(?) intrusive rocks; (6) Quaternary volcanic rocks; and (7) Quaternary alluvium. Only the Paleozoic sedimentary rocks contain diagnostic fossils; the ages of the other rocks are tentative.

Faulting is dominant in the structural history of the Harquahala Plains area, probably beginning in the Precambrian and extending into the Quaternary period. Three major structural episodes since Paleozoic time have been recognized: (1) Folding and faulting of the Paleozoic rocks; (2) mountain building that produced the Cretaceous(?) fanglomerate; and (3) block faulting and tilting that produced the present mountain masses.

The geologic history of the area includes the following events: (1) Erosion of the land surface to low relief at the end of the Precambrian; (2) advances of the Paleozoic seas as early as the Cambrian and as late as the Permian period; (3) intense orogeny between the deposition of the Permian sediments and the deposition of the arkosic conglomerate of Cretaceous(?) age, and erosion to a land surface of low

relief; (4) mountain building in the Cretaceous(?) period; (5) vulcanism in Cretaceous(?) and Tertiary time, and block faulting and tilting; and (6) extrusion of Quaternary basalt, and deposition of alluvium in the basin.

Ground water occurs principally in the alluvium of the basin. The movement of ground water in the basin is under a low gradient, as shown by a difference in water-table elevation of less than 40 feet over a distance of 20 miles. In the lower part of the basin the gradient is extremely low.

Natural recharge to the alluvium of the area occurs by underflow and from streamflow, and rainfall. Of these, the recharge from streamflow is the most important. The natural recharge is probably on the order of a few thousand acre-feet per year. Natural discharge of ground water occurs principally by underflow from the area; a minor amount of water is transpired by phreatophytes.

Ground-water storage in the alluvium is large, owing to the great depth of valley fill and saturated thickness. The quantity of ground water in storage is on the order of several million acre-feet, of which perhaps a million acre-feet could be obtained by lowering the water table 100 feet throughout the area.

The dissolved solids in the water from wells sampled ranged from 432 to 864 ppm (parts per million). The fluoride content in some of the samples was high. The sodium and potassium, calculated as sodium, ranged from 98 to 273 ppm; the percent sodium, from 58 to 89.

A successful irrigation well drilled in 1951 started the recent major agricultural development of the basin. Numerous wells were drilled in 1952-53, and by 1954 the annual ground-water pumpage was about 33,000 acre-feet. Although this quantity of water is much larger than the estimated recharge, it is small compared to the amount of ground water in storage; however, as the ground water is pumped from storage, the water table in the pumped localities will decline. The rate of decline will depend on the rate of withdrawal of water from the basin.

INTRODUCTION

A reconnaissance study of the ground-water resources of the Harquahala Plains area was made by the Geological Survey in cooperation with the Arizona State Land Department, W. W. Lane and Roger Ernst, successive State Land Commissioners. The report is qualitative because data are insufficient to determine the exact recharge, discharge, and storage of water in the basin. However, the general relationships of these parameters and their relative magnitudes are discussed. A detailed investigation would require the extensive collection of geologic and hydrologic data over a long period of time. In addition, much geologic and hydrologic research work as related to ground water would be necessary.

Purpose and Cooperation

Pumping of ground water in relatively large quantities in Arizona began in the twenties. At that time most of the wells were not drilled for irrigation, but were primarily drainage wells drilled to reclaim waterlogged land in the Salt River Valley. The drilling of wells for irrigation began in the thirties, and there has since been a continuous increase in the number of wells and in the amount of land irrigated.

The State Legislature, recognizing the increase in the development of ground water for irrigation and the need for information on the movement and storage, appropriated funds in 1939 for ground-water investigations. These were made by the U. S. Geological Survey in cooperation with the State of Arizona. Succeeding State Legislatures have appropriated funds for continuing these investigations. Most studies under this program have been made in heavily pumped basins, such as the Salt River Valley and lower Santa Cruz areas.

In 1951-52 numerous irrigation wells were drilled in the Harquahala Plains area and it was recognized that this basin had the potential for large-scale development. Therefore, the study described in this report was begun as a part of the State cooperative program to determine, if possible, the original ground-water characteristics and the probable effects of extensive development of ground water in the basin.

Location

The Harquahala Plains area is in southwestern Arizona about midway between Phoenix and the Colorado River (fig. 1). The area is a northwest-trending basin, approximately 12 miles wide and 35 miles long, bounded on the northeast by the Big Horn Mountains and on the southwest by the Eagletail Mountains (pl. 1). The northwest border is formed by the Harquahala and Little Harquahala Mountains, and the southeast border by Saddle Mountain and the Gila Bend Mountains. About two-thirds of the area lies in Maricopa County, and the rest in Yuma County.

The Harquahala Plains area is accessible by the Buckeye-Salome road. This road is graded and graveled but may be impassable after severe cloudbursts. There are rail connections at Salome, on the Santa Fe Railroad, and along the Southern Pacific Railroad, about 5 miles southeast of the area. Transcontinental highways pass through Salome (U. S. Highways 60 and 70) and Buckeye (U. S. Highway 80).

Fieldwork and Maps

Fieldwork was begun in the fall of 1952 and continued intermittently until the spring of 1955. The geologic mapping was done primarily on contact prints of aerial photographs. These were made specifically for this project, and were taken in strips along the mountain fronts. In the spring of 1955 complete aerial coverage of the area was obtained from the Army Map Service. The final map (pl. 1) was compiled from photographs, as no adequate maps of the area were available. Controls were established by triangulation data of the U. S. Coast and Geodetic Survey and from township plats of the Bureau of Land Management. The Maricopa-Yuma County line was taken as the approximate center of the map, and the data based on the 1927 North American datum (Gannet, 1924) were used in plotting the triangulation points on a polyconic projection. The base map was prepared on a scale of 1:63,360 and was reduced to a scale of approximately 1:125,000 for this report.

History of the Area

No evidence has been found to indicate that Indians inhabited the area permanently, although relics such as manos and shards have been found, as well as crude signs made on the ground by putting boulders end to end.

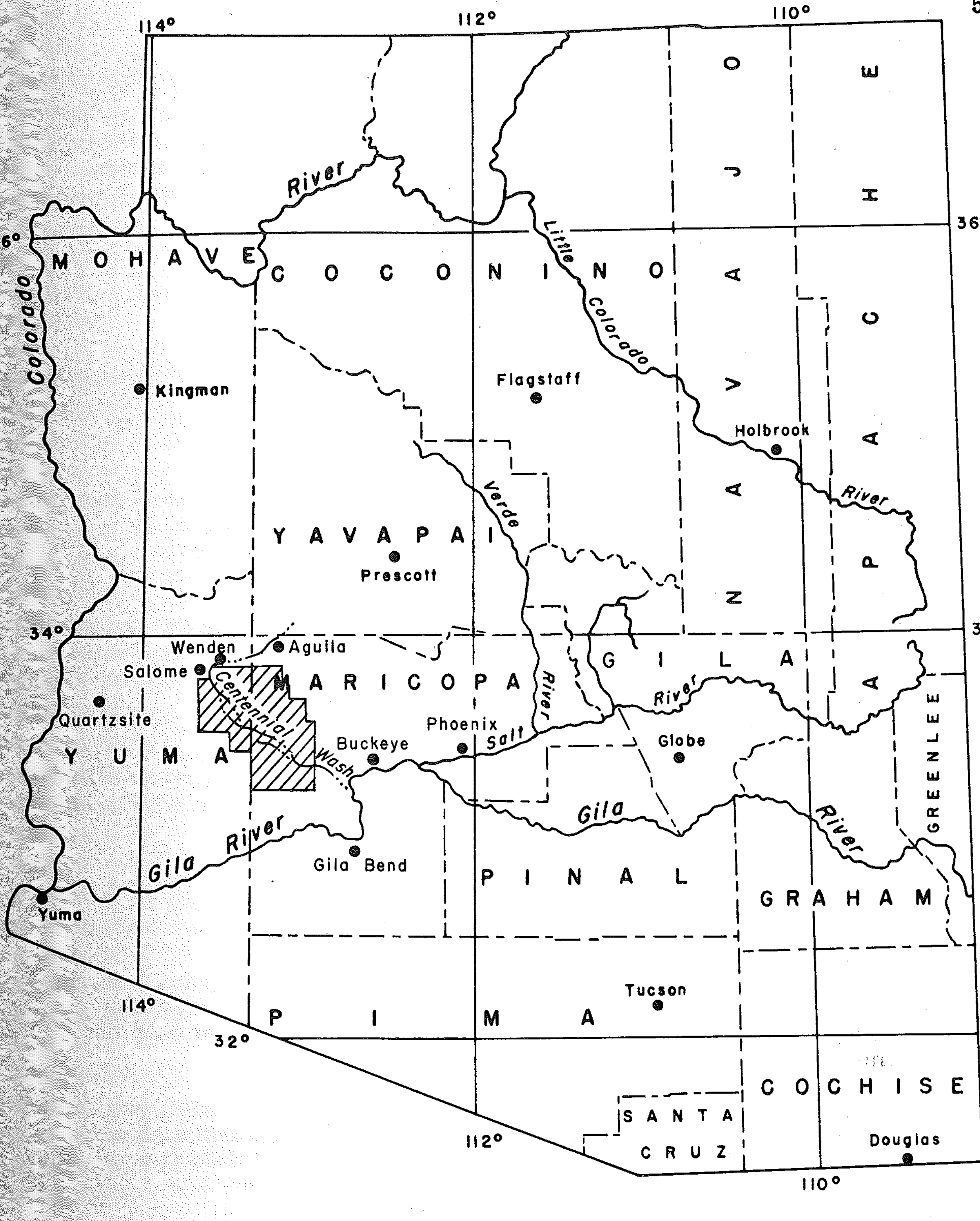

Figure 1.--Map of Arizona showing Harquahala Plains area.

The first white men in the area were prospectors. The first settlement, Harrisburg, was established in 1886 in a small valley — later called Harrisburg Valley — where Centennial Wash passes between the Harquahala and Little Harquahala Mountains. The Bonanza or Harquahala vein system was discovered in 1888, and the mine became by far the largest in the area, with a total production of more than $2\frac{1}{2}$ million dollars in gold, mostly prior to 1900. Water for the mine and adjacent settlement "Harqua Hala" was brought by pipeline from Harrisburg, about 6 miles to the northeast. The mine stimulated interest in the area and numerous smaller mines were located, but only the Harquahala mine has been of major importance.

The Arizona and California Railroad (now a part of the Atchison, Topeka, and Santa Fe Railroad) was completed through McMullen Valley in 1907 and the towns of Salome and Wenden (fig. 1) were founded along the railroad.

Cattle ranching has been a stable industry in the area and has continued to the present day. Probably the first farming on the Harquahala Plains was dry farming attempted between World Wars I and II. These attempts were unsuccessful because of inadequate precipitation, and abandoned homesteads remain throughout the area. Some homesteaders had wells for domestic and stock use but evidently no attempt was made to use ground water for irrigation. At the abandoned Mosher homestead in sec. 31, T. 3 N., R. 9 W., a well was dug entirely by hand, and the depth to water is about 330 feet.

In the late thirties wells were drilled for irrigation in the lower end of the basin, but most of the water was transported downstream out of the Harquahala Plains area, and used to irrigate land on the flood plain of Centennial Wash.

Previous Investigations

The earliest geologic investigations in the Harquahala Plains area were directly related to mining. This work was comparatively detailed, and was confined to the immediate vicinity of the mining claims.

Bancroft (1911) included the Harquahala and Little Harquahala Mountains in a report on the ore deposits of northern Yuma County. Ross (1923) reported in more detail on the geology of the area and also described the wells as part of his reconnaissance of the lower Gila region. Although previous workers mentioned the possibility that some of the rocks were Paleozoic in age, Darton (1925), in his reconnaissance of the Harquahala and Little Harquahala Mountains, was the first to report Carboniferous fossils in the area.

Wilson (oral communication, 1954) studied the geologic structure of Martin Peak in the Little Harquahala Mountains. His stratigraphic section included fossiliferous strata of Cambrian and Permian age and other strata of probable Devonian, Mississippian, and Pennsylvanian age. He also observed that the section was overturned, and that some beds were as much as 175° from their original attitude.

Climatological Data

Long-term precipitation records of the U. S. Weather Bureau are available for the towns of Aguila, Buckeye, Gila Bend, Phoenix, Salome, and Yuma (fig. 1) and are given in table 1. A precipitation station called Harquahala Plains was established in 1953 in sec. 14, T. 2 N., R. 9 W.

The direct relationship between average annual precipitation and altitude at precipitation stations in the region is shown as follows:

Station	Altitude (feet above sea level)	Average annual precipitation (inches)
Yuma	141	3.33
Gila Bend	739	5.58
Buckeye	980	7.54
Phoenix	1,108	7.55
Salome	1,775	8.13
Aguila	2,280	9.71

Salome is the closest station to the Harquahala Plains area, but its altitude is slightly higher. Buckeye is slightly lower in altitude than the area but is about 30 miles east. It is estimated that the average annual precipitation on the Harquahala Plains area is about 8 inches, although some of the mountains may receive more and some of the lower parts of the basin may receive less. Isohyetal maps of the area, prepared by Hiatt (1953), show a range in average annual precipitation from less than 8 inches on the Harquahala Plains to more than 18 inches on the Harquahala Mountains.

During 1905 and 1941 the annual precipitation was 2 to 3 times the average for the period of record (table 1). This abnormal precipitation is important in the study of the ground water in an arid region and will be discussed under "Recharge."

About 80 percent of the annual precipitation in southwestern Arizona occurs during two periods — July through September and December through March. The precipitation during the winter is slightly greater than in summer, and the storms that occur during the two periods are radically different. The summer storms are

Table 1.--Average annual precipitation, in inches, at stations in southwestern Arizona.

Year	Aguila	Buckeye	Gila Bend	Phoenix	Salome	Yuma
1870						3.10
71						.65
72						2.73
73						3.14
74						7.55
75						2.32
76						1.13
77				4.17		3.66
78				8.52		2.88
79				6.40		3.29
80				6.82		.74
81				8.91		.98
82				6.94		1.78
83				7.40		3.96
84				12.83		5.86
85				3.77		2.72
86				5.78		5.35
87				-		3.90
88				-		2.95
89				10.89		4.69
90			5.19	8.46		4.67
91			2.68	4.97		2.67
92		-	6.95	5.94		3.35
93		-	7.11	7.68		3.00
94		7.90	4.25	5.22		2.95
95		5.10	3.29	3.87		1.33
96		9.50	10.21	10.48		2.55
97		4.94	6.69	9.87		4.18
98		6.60	4.78	5.95		2.38
99		3.45	4.92	5.19		.60
1900		5.10	2.12	5.39		.85
01		3.70	2.55	4.87		3.65
02		4.70	-	6.88		1.93
03		-	-	6.61		.98
04		-	-	5.57		1.43
05		21.80	-	19.73		11.41
06		-	-	8.55		5.40
07		9.17	6.32	8.17		2.61
08		9.46	7.69	10.68	11.55	5.93
09		8.33	-	6.17	-	8.63
10		5.30	-	4.32	-	3.93
11		-	-	14.12	-	2.79
12		6.73	-	6.87	-	3.11

Table 1.--Average annual precipitation, in inches, at stations in southwestern Arizona — continued.

Year	Aguila	Buckeye	Gila Bend	Phoenix	Salome	Yuma
1913		5.33	5.64	5.39	-	1.04
14		9.53	8.76	8.98	9.69	3.70
15		10.42	7.53	9.41	10.05	4.33
16		10.88	8.47	9.76	8.89	2.45
17		8.80	4.87	9.60	9.03	2.22
18		10.04	-	11.10	11.20	2.90
19		8.74	9.01	10.31	10.48	2.04
20		6.16	5.85	6.21	10.96	4.75
21		7.00	5.38	3.85	9.17	6.98
22		7.62	5.71	5.96	8.03	3.03
23		10.23	7.29	9.63	13.48	3.91
24	5.45	3.98	2.89	3.03	3.14	.78
25	10.14	4.78	6.62	4.16	8.45	3.78
26	13.30	11.11	-	13.97	8.71	9.23
27	12.18	7.41	-	5.75	9.56	3.92
28	4.30	5.05	2.88	6.19	2.85	.47
29	6.51	3.76	5.48	5.04	2.20	2.36
30	10.61	7.66	5.86	8.04	7.23	1.79
31	18.63	11.19	-	10.32	10.92	5.91
32	10.51	8.86	7.27	6.67	8.70	6.35
33	6.63	7.70	5.67	7.10	6.81	3.56
34	5.67	5.71	3.86	5.87	5.09	2.32
35	18.29	8.48	2.81	10.33	12.74	3.28
36	8.71	6.50	6.82	8.29	6.70	1.29
37	13.19	6.64	4.07	5.37	9.31	4.30
38	8.79	4.11	4.07	4.74	7.99	2.92
39	11.02	9.80	4.97	9.12	10.57	6.66
40	9.83	7.57	7.74	8.48	7.03	2.33
41	18.72	17.12	13.50	17.26	16.75	6.71
42	5.35	4.54	3.37	4.56	4.94	2.41
43	-	6.26	-	9.88	6.99	2.42
44	-	7.19	6.70	8.26	10.53	4.07
45	-	-	5.45	4.27	6.62	4.10
46	-	-	8.32	9.87	7.58	2.25
47	-	3.81	2.66	3.22	2.99	1.03
48	6.53	-	4.17	3.94	4.72	1.83
49	7.91	-	-	6.24	5.00	-
50	-	2.42	2.13	3.96	5.29	3.35
51	10.44	12.85	-	12.82	10.51	4.25

Table 1.--Average annual precipitation, in inches, at stations in southwestern Arizona — continued.

Year	Aguila	Buckeye	Gila Bend	Phoenix	Salome	Yuma
1952	11.73	10.01	6.30	11.06	9.11	3.79
53	3.95	3.79	2.68	2.85	3.99	.42
54	4.46	4.58	3.75	4.66	5.71	.90
Average	9.71	7.54	5.58	7.55	8.13	3.33
Years of record	25	53	49	76	42	84

usually local, and may occur as cloudbursts with rapid runoff. The winter storms are generally regional, and the rainfall is moderate and penetrating. The driest months are May and June, when little or no rainfall occurs.

The summer months are hot. Generally the month having the highest maximum temperature is June, but the heat is usually offset by very low humidity. The humidity increases during July and August and is accompanied by thunderstorm activity. Temperatures above 100°F are common during the summer and extremes of 115°-120°F may occur. During the rest of the year the climate is delightful. Freezing temperatures occur during the winter nights and extreme minimum temperatures of 15°-20°F may occur.

Vegetation

Although the Harquahala Plains area is part of the Sonoran Desert, there is an abundance of vegetation that has adapted itself to the climate. The principal plant on the plains is the creosote-bush; ironwood, palo verde, and mesquite trees grow along the washes. Some of the mesquite and palo verde may use shallow ground water in the southeastern part of the basin, but vigorous trees have been observed where the water table is more than 300 feet below the surface.

The stately sahuaro or giant cactus is the most striking of the various cacti that occur on the foothill slopes, but also present are species of cholla and barrel cactus. Another common plant is the ocotillo. The reader who is interested in the scientific names of these plants may refer to "Arizona Flora" (Kearney and Peebles, 1951).

Acknowledgments and Personnel

Appreciation is expressed to Dr. Eldred Wilson of the Arizona Bureau of Mines for his geologic maps and stratigraphic section of the Martin Peak area. Acknowledgment is made also of the cooperation of the El Paso Natural Gas Co. for maps and altitudes of bench marks established along its gasline.

Personnel who aided in the collection of hydrologic data for this project are: J. M. Cahill, R. H. Garside, R. S. Stulik, and N. P. Whaley. Final drafting of the illustrations was done by Mrs. Ruth S. Allison. The fieldwork was under the direct supervision of H. N. Wolcott, geologist in charge of the Phoenix area office (deceased), and under the general supervision of L. C. Halpenny and J. W. Harshbarger, successive Arizona district supervisors of the Ground Water Branch of the U. S. Geological Survey. The chemical analyses of the water samples were made under the general direction of J. D. Hem and J. M. Stow, successive district chemists of the Quality of Water Branch, U. S. Geological Survey, Albuquerque, N. Mex.

Well-Numbering System

The well numbers used by the Ground Water Branch of the Geological Survey in Arizona are in accordance with the Bureau of Land Management's system of land subdivision. The land survey in Arizona is based on the Gila and Salt River baseline and meridian, which divide the State into four quadrants (fig. 2). These quadrants are designated counterclockwise by the capital letters A, B, C, and D. All land north and east of the point of origin is in A quadrant, that north and west in B quadrant, that south and west in C quadrant, and that south and east in D quadrant. The first digit of a well number indicates the township, the second the range, and the third the section in which the well is situated. The lowercase letters — a, b, c, and d — after the section number indicate the well location within the section. The first letter denotes a particular 160-acre tract, the second the 40-acre tract, and the third the 10-acre tract. These letters are also assigned in a counterclockwise direction, beginning in the northeast quarter (fig. 2). If the location is known to be within a specific 10-acre tract, three lowercase letters are shown in the well number. In the example shown, well number (D-4-5)19caa designates

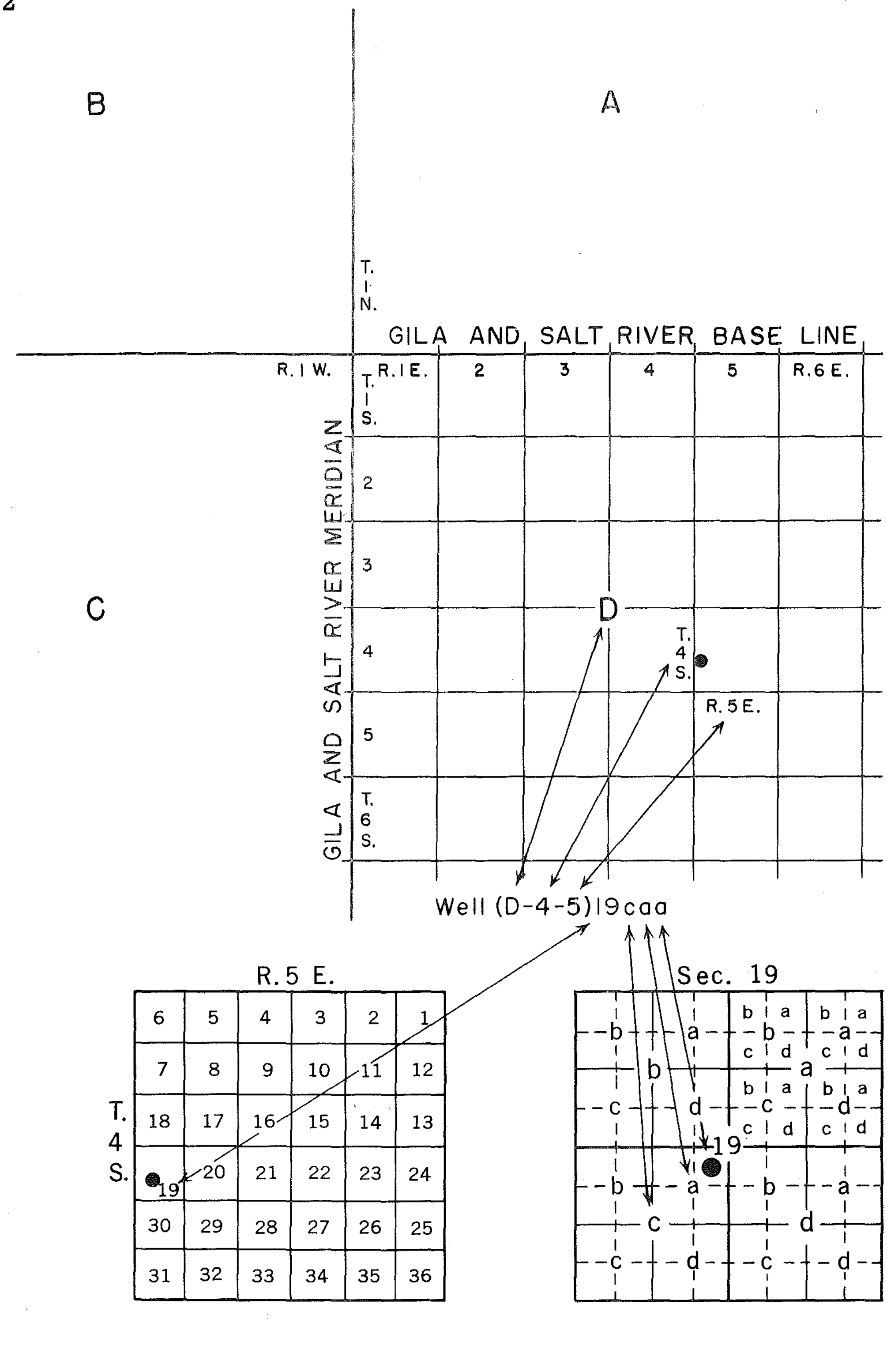

Figure 2.-- Sketch showing well-numbering system in Arizona.

the well as being in the NE$\frac{1}{4}$NE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 19, T. 4 S., R. 5 E. Where there is more than one well within a 10-acre tract, consecutive numbers beginning with 1 are added as suffixes.

PHYSIOGRAPHY

Landforms

The landforms of the Harquahala Plains area are typical of the Sonoran section of the Basin and Range province as defined by Fenneman (1931). The topographic features indicate that the landforms are controlled by block faulting and tilting. The fault blocks have been modified by erosion and sedimentation in a desert environment. These landforms may be divided into (1) mountains, (2) pediments, and (3) valley floor.

Mountains

The mountains may be divided into three general classes as related to rock types. The various mountain forms are the result of uplift and erosion of (1) Precambrian granitic and metamorphic rocks, (2) Cretaceous(?) and Tertiary volcanic rocks, and (3) Quaternary volcanic rocks.

The Harquahala Mountains, formed of Precambrian rocks, are a good example of the first class. Although their crest is somewhat rounded, the ridges break off sharply on both sides and the canyons are V-shaped and steep.

The Eagletail Mountains, made up largely of Cretaceous(?) and Tertiary volcanic rocks, are examples of the second class. These mountains have relatively gentle dip slopes, but the crests are extremely jagged and erosion is far advanced.

The third class is exemplified by unnamed mesas that are capped by Quaternary basalt. In most places the basalt is tilted slightly, and erosion is not as far advanced as in the older volcanic rocks.

Pediments

Exposed and concealed pediments, as described by Bryan (1922), occur extensively along the Gila Bend and Eagletail Mountains, and less commonly along Saddle Mountain and the Harquahala Mountains (pl. 1). They are treated herein as areas of comparatively smooth, hard-rock surfaces which are exposed or are covered with only a thin mantle of rock debris. The pediment slope is commonly a continuation of the alluvial surface toward the steep mountain front. Concealed pediments, as shown on plate 1, are covered by a thicker mantle of rock debris, but they are frequently identifiable by the rolling character of the topography and sometimes by isolated hard-rock outliers. The gradients of the concealed pediments are somewhat greater than those of the alluvial surface.

The exposed and concealed pediments are generally developed on granitic rocks, but in the southeastern part of the basin they are developed on Cretaceous(?) and Tertiary volcanic rocks.

The pediment areas are unfavorable for the development of large quantities of ground water because at most places they are higher than the water table in the basin. The ground-water reservoir does not extend to the limits of the alluvium that covers the pediments.

Valley Floor

The greater part of the Harquahala Plains area represents a downfaulted block forming a basin that has been filled by alluvial materials eroded from the mountains. The altitude of the "plains" surface is governed by the rock constriction at the lower end of the basin.

The land surface along Centennial Wash slopes southeast 15 to 20 feet per mile. Although topographic maps are not available, changes in the gradient are shown by the drainage pattern of Centennial Wash (pl. 1). Between Harrisburg Valley and the vicinity of Lone Mountain, the wash is restricted and the gradient is steeper. Southeast of Lone Mountain it becomes flatter, as indicated by the many distributaries. Farther downstream in T. 2 N., R. 11 W., the channels again coalesce, indicating a steeper gradient for about 7 miles. Throughout the next 10 miles the gradient is flatter, then it steepens again in the reach through the constriction at the southeast end of the basin.

Drainage

The drainage of the Harquahala Plains area is a tributary to the Gila River. Surface water flows to the river only after cloudbursts or prolonged rains. These flows are heavily laden with debris from the mountains. Smaller local storms only transport sediments from the mountains into the valley, where the water disappears and the sediments are deposited. Subsequent local storms move these deposits farther downgradient until they eventually leave the area, but as long as they remain in the basin they affect the drainage pattern and result in constant shifting of channels.

Centennial Wash leaves the Harquahala Plains area in T. 1 S., R. 7 W., and joins the Gila River downstream from Buckeye (fig. 1). The small basin west of Lone Mountain drains into Bouse Wash and thence to the Colorado River. This basin is named Hubbard Plain after an old abandoned homestead. Although the surface drainage of the Hubbard Plain is toward Bouse Wash, the area is shown on plate 1 because the ground water in it may be connected with that in the Harquahala Plains area. This possibility is more fully discussed in the sections on "Recharge" and "Discharge."

Centennial Wash has a definite channel where it enters the area from Harrisburg Valley. Between Lone Mountain and the constriction at the southeast end of the basin, the channel is more or less indefinite, according to the gradient of the stream. In sec. 32, T. 1 N., R. 8 W., there is a definite channel which continues downstream through the constriction.

The position of Centennial Wash in the basin is controlled by the height of the mountains and the contributing drainage areas. The drainage areas on the north side of the basin are much larger and the mountains are higher than the Eagletail Mountains. Therefore, the heavier deposition from runoff from the north has caused Centennial Wash to shift southward.

A major tributary wash that enters the area in T. 5 N., R. 10 W., is named Rogers Wash after a well called Rogers well. The wash drains about 120 square miles, including some of the higher parts of the Harquahala Mountains. Rogers Wash has a definite channel where it enters the Harquahala Plains, but as the gradient decreases, it branches into numerous smaller channels.

GEOLOGY

Southwestern Arizona lies in the Sonoran section of the Basin and Range province (Fenneman, 1931) and is characterized by northwest-trending mountains separated by wide alluvial plains. The topography of the area suggests that the mountains are tilted or uplifted fault blocks, and the basins are the downfaulted counterparts. The mountains are composed of a variety of rock types; the basins are filled with alluvium from the weathering and transportation of rock material from adjacent highlands.

Precambrian granite, gneiss, and schist make up most of the mountain ranges. Paleozoic rocks are exposed in a few of the mountain ranges, but the outcrop areas are comparatively small. Rocks of Triassic and Jurassic age are either absent or have not been recognized in southwestern Arizona. Various sedimentary units have been referred to the Cretaceous but the absence of faunal evidence makes this designation tentative. Representative of these Cretaceous(?) units is a conglomerate that contains pebbles of Paleozoic rocks. The outcrops of the Cretaceous(?) sedimentary rocks are of limited extent. Volcanic rocks of Cretaceous(?) and Tertiary age are common and occur as flows, tuffs, dikes, and necks. The youngest hard rock is a highly vesicular basalt of Quaternary age. The maximum thickness of alluvial materials in the basin is not known, as no wells in the valley have been drilled to basement rock. Although the upper part of the alluvial fill is considered to be of Quaternary age, alluvial beds of Tertiary age probably are present at depth.

The granitic rocks solidified at depth and were exposed after removal of the overburden by erosion. Erosion continued until the region was reduced to one of low or very moderate relief, near the end of the Precambrian. The region was submerged during the Cambrian period and sandstone and shale were deposited. The stratigraphy of the Paleozoic rocks in southwestern Arizona is not well known, but available information indicates that seas covered a large part of the region as late as the Permian period. Intense orogeny occurred in parts of southwestern Arizona in the time interval between the deposition of Permian sediments and the deposition of the Cretaceous(?) sediments, as some of the Paleozoic sedimentary rocks show structural characteristics vastly different from those in the Cretaceous(?) and younger rocks. The presence of fanglomerates of Cretaceous(?) age indicates that severe crustal disturbances occurred in this period. In some localities the Cretaceous(?) sedimentary rocks contain numerous boulders of Paleozoic age, and it is probable that during this time, a considerable volume of the Paleozoic rocks was moved from the region by erosion.

Vulcanism is believed to have begun in the Cretaceous period and to have continued intermittently into the Quaternary. The era of vulcanism was marked by minor structural movements and periods of explosive activity. Some of the tuffs accompanying the vulcanism probably were deposited in water. Basin and Range block faulting probably began in the early Tertiary, although the landforms resulting from this activity have since been modified and in some places obliterated. The block faulting that produced the present mountains probably occurred at the beginning of the Quaternary period. Since that time erosion of the mountains and deposition of alluvial material in the basins have been the principal geologic agents at work. The existence of a lake that extended into the Harquahala Plains in relatively recent Quaternary time indicates that the climate at the time of the lake was wetter than at present.

Rock Descriptions

The rock units of the Harquahala Plains area (pl. 1) are discussed in ascending order as follows: (1) Precambrian metamorphic and igneous rocks; (2) Paleozoic sedimentary rocks; (3) Cretaceous(?) sedimentary rocks; (4) Cretaceous(?) and Tertiary volcanic rocks; (5) Tertiary(?) intrusive rocks; (6) Quaternary volcanic rocks; and (7) Quaternary alluvium.

Precambrian Metamorphic and Igneous Rocks

Precambrian rocks occur in every mountain block surrounding the Harquahala Plains. The predominant rock type is granitic gneiss; other units are gneiss, schist, and granite. The rocks are dated only in the Harquahala and Little Harquahala Mountains, where granitic gneiss is overlain by Paleozoic sedimentary rocks.

Precambrian rocks north of Saddle Mountain may be the oldest in the area. These rocks are chloritic schists that are strongly foliated and contain numerous quartz veins. For the most part the planes of foliation dip steeply eastward.

In the Big Horn Mountains, Precambrian granitic gneiss occupies a large area in the northern part of the range. Coarse-grained white granite, also Precambrian, occurs in a smaller area 2 miles northwest of Big Horn Peak.

Two areas of Precambrian rocks in the Harquahala Mountains are separated by Paleozoic sedimentary rocks (pl. 1). In the western area granitic gneiss is overlain by Paleozoic rocks. Intensive metamorphism in many localities makes it difficult to verify in the field that the gneiss was originally a granite. The gneiss is medium to coarse grained and contains an abundance of quartz and minor amounts of basic minerals. In the eastern area a gneiss and schist complex is in fault contact with the Paleozoic sedimentary rocks. Although the complex has not been dated, the degree of metamorphism, compared to that in the Paleozoic rocks, strongly suggests that the rocks are Precambrian. An alaskite intrusion was observed in the complex. The proximity of the intrusive to the Paleozoic rocks, and the fact that Paleozoic rocks have not been intruded or altered by the alaskite, suggests that the alaskite is Precambrian.

The Little Harquahala Mountains are separated from the Harquahala Mountains by the Harrisburg Valley; however, they are composed of a similar Precambrian granitic gneiss. Lone Mountain is composed of granitic gneiss that has been intruded by numerous dikes and is probably a continuation of the ridge that trends southeastward from the Little Harquahala Mountains.

The Precambrian rocks in the Eagletail Mountains are of two types, a highly contorted gneiss which has a limited areal distribution in the southeastern part of T. 1 N., R. 10 W., but which may have been far more extensive as indicated by some boulders in a conglomerate about 10 miles northwest of the outcrops, and a granitic gneiss characterized by phenocrysts of acid feldspar as long as 1 inch.

The northern part of the Gila Bend Mountains is predominantly Precambrian granitic gneiss similar to that in other mountain blocks of the area.

Paleozoic Sedimentary Rocks

Prominent outcrops of Paleozoic rocks occur in the Harquahala and Little Harquahala Mountains. This Paleozoic sequence rests on granitic gneiss in the Harquahala Mountains. Smaller exposures of Paleozoic rocks crop out in T. 4 N., R. 10 W., and in the southeastern part of the Eagletail Mountains in sec. 21, T. 1 S., R. 10 W.

The Paleozoic rocks have been studied at Martin Peak in T. 4 N., R. 13 W. (pl. 1), by E. D. Wilson (oral communication, 1954). He found fossils of Cambrian age in quartzite and shale at the base of the stratigraphic section and fossils of Permian age in the limestone near the top of the sequence. Between the Cambrian strata and the upper Permian limestone are beds of dolomite, marble, shale, and quartzite of undetermined age, which have been overturned and broken by many faults. The thickness of the sequence is about 2,235 feet according to McKee (1951).

Paleozoic sedimentary rocks occur just outside the area of this report in T. 5 N., R. 10 W. These rocks have been cut by numerous basic dikes, whereas Paleozoic rocks within the area are relatively free from intrusions.

The Paleozoic rocks have been metamorphosed primarily by severe crustal disturbances, and quartzite, phyllite, and marble have been formed.

Cretaceous(?) Sedimentary Rocks

Rock units of probable Cretaceous age occur as outliers of the Harquahala Mountains and in the Eagletail Mountains. No Cretaceous fossils were found, and the only basis for assigning probable Cretaceous age is that the rocks are older than the volcanic rocks assigned to the Cretaceous and Tertiary periods.

Probably the oldest rocks of Cretaceous(?) age in the area crop out in sec. 31, T. 5 N., R. 11 W., and in sec. 8, T. 4 N., R. 11 W. Although the two outcrops are about 2 miles apart, they are correlated on the basis of lithology. The most conspicuous rock in this sequence is an arkosic conglomerate that has a schistose matrix (fig. 3). The well-rounded pebbles are composed of fine-grained quartzite. There are also strata of quartzite and phyllite in the sequence.

Although the age of the schistose conglomerate is in doubt, evidence that might favor a Precambrian age is the absence of Paleozoic rock fragments. Also, the conglomerate exhibits a greater degree of metamorphism than the nearby Paleozoic rocks. On the other hand, evidence favoring an age younger than the Paleozoic for the conglomeratic sequence is the absence of these strata in the stratigraphic section that rests upon the granitic complex about a mile to the northwest. Also, it would be necessary to postulate a fault of considerable throw between the Paleozoic sedimentary rocks and the conglomeratic sequence, and the removal of the Paleozoic rocks between the outcrops

Figure 3.--Schistose conglomerate of Cretaceous(?) age in sec. 30, T. 5 N., R. 11 W.

in sec. 8 and sec. 21, T. 4 N., R. 11 W. Furthermore, in sec. 33, T. 5 N., R. 10 W., near the Alaskan mine, Wilson, Cunningham, and Butler (1934) mention "steeply dipping metamorphosed, impure shale of probable Mesozoic age" exposed in washes on a pediment. On the basis of the preceding evidence, and as no rocks of Triassic or Jurassic age have been found in southern Arizona (McKee, 1951), the conglomeratic sequence is tentatively assigned a Cretaceous age.

Rocks of Cretaceous(?) age crop out in secs. 21, 22, and 27, T. 4 N., R. 11 W., and consist of a fanglomerate composed of large boulders, some as much as 15 feet long. The fanglomerate is faintly stratified and dips northeastward. About 90 percent of the boulders are limestone, dolomite, and quartzite of Paleozoic age, and the remainder are granitic rocks. The angularity of the boulders indicates that they were not transported any great distance. Wilson (1933) and McKee (1947) describe conglomerates which they believe to be of Cretaceous(?) age in Yuma County that are similar to the fanglomerate; a mutual characteristic is the presence of Paleozoic boulders. As no volcanic boulders were recognized in the fanglomerate and because no Triassic or Jurassic rocks are known in southern Arizona, the fanglomerate of the Harquahala Plains area is assigned a Cretaceous(?) age.

Another conglomerate assigned tentatively to the Cretaceous period occurs locally between the Precambrian granitic gneiss and the Cretaceous(?) and Tertiary volcanic rocks in the Eagletail Mountains. The largest area of outcrops is in sec. 21, T. 2 N., R. 11 W. The conglomerate is composed mainly of granitic fragments but contains a few isolated boulders of highly contorted gneiss. The materials in the conglomerate appear to have moved only a short distance. Weathered outcrops have the appearance of granitic gneiss, and only in washes or cliffs, or where an isolated boulder of highly contorted gneiss is found, could the true nature of the rock be determined.

Cretaceous(?) and Tertiary Volcanic Rocks

Pre-Quaternary volcanic rocks are exposed in the Gila Bend, Big Horn, and Eagletail Mountains, in Saddle Mountain, and in one small outcrop in the Harquahala Mountains. In the Big Horn Mountains in T. 3 N., R. 9 W., the volcanic rocks rest on Precambrian granite. The base was not observed elsewhere. The volcanic rocks are composed of agglomerate, tuff, and lava flows which dip about 10° southwestward (fig. 4). The aggregate thickness of the tuff is some hundreds of feet and parts of the unit are definitely bedded, suggesting deposition in water. The lava flows range in composition from acidic to basic, the acidic predominating. Black, brown, and dark-red obsidian is common in the upper part of the sequence.

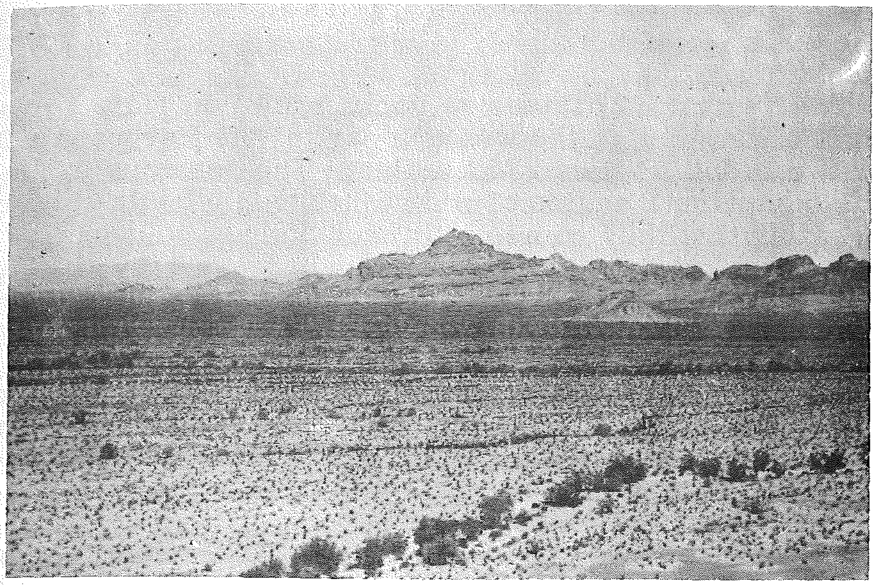

Figure 4.--Big Horn Peak from the southeast. Peak is composed of tuffs and lava flows of Cretaceous(?) and Tertiary age.

The volcanic rocks in the Eagletail Mountains are similar to those in the Big Horn Mountains except that obsidian is absent. Plugs and feeder dikes that crop out in the area were probably the source of much of the volcanic sequence. These volcanic rocks dip southwestward at about 30° and rest in places on Cretaceous(?) conglomerate and elsewhere directly on Precambrian granitic gneiss.

Saddle Mountain is composed of volcanic rocks consisting of agglomerate, tuff, and flows. The base of the volcanic sequence is obscured by alluvial material. Saddle Mountain consists of two fault blocks tilted in opposite directions. Weathering along the structural break has produced the "saddle" feature.

Lava flows and water-laid tuffs compose the volcanic rocks in the Gila Bend Mountains. These rocks strike northwest and dip northeast. The outcrops are subdued, as an extensive pediment has been cut on this volcanic sequence.

Most of the vulcanism in southwestern Arizona occurred during the Tertiary period, although Darton (1925) mentioned an area in Gila County that contains volcanic rocks interbedded with sandstones of Cretaceous age, and also recognized the possibility that some of the volcanic rocks in southwestern Arizona may be of Cretaceous age. Lasky (1947) described volcanic rocks interbedded with limestone of Cretaceous age in southwestern New Mexico. These references, plus the fact that the period of vulcanism was long, were the reasons for the assignment of Cretaceous(?) and Tertiary age to the older volcanic rocks in the Harquahala Plains area.

Tertiary(?) Intrusive Rocks

The Tertiary(?) intrusive rocks shown on plate 1 crop out in three small areas; one in the western part of the Harquahala Mountains, the other two in the Eagletail Mountains. The outcrops in the Harquahala Mountains comprise a series of wide dikes that contain calcium carbonate, suggesting that they came up through Paleozoic rocks.

The two outcrops in the Eagletail Mountains are volcanic necks, the largest of which forms Court House Butte (fig. 5). The butte is composed of a fine-grained light-colored acidic rock, probably rhyolite. It is surrounded by granitic gneiss which weathers more rapidly than the rhyolite, so that the butte now stands out in sharp relief. Numerous related dikes also were observed, but it was impossible to show them on the scale of the base map.

These intrusive rocks are assigned a Tertiary(?) age because they are believed to be related to the volcanic sequence, and because the greater part of the vulcanism probably occurred during the Tertiary period.

Quaternary Rocks

Quaternary rocks in the Harquahala Plains area include volcanic rocks and alluvium.

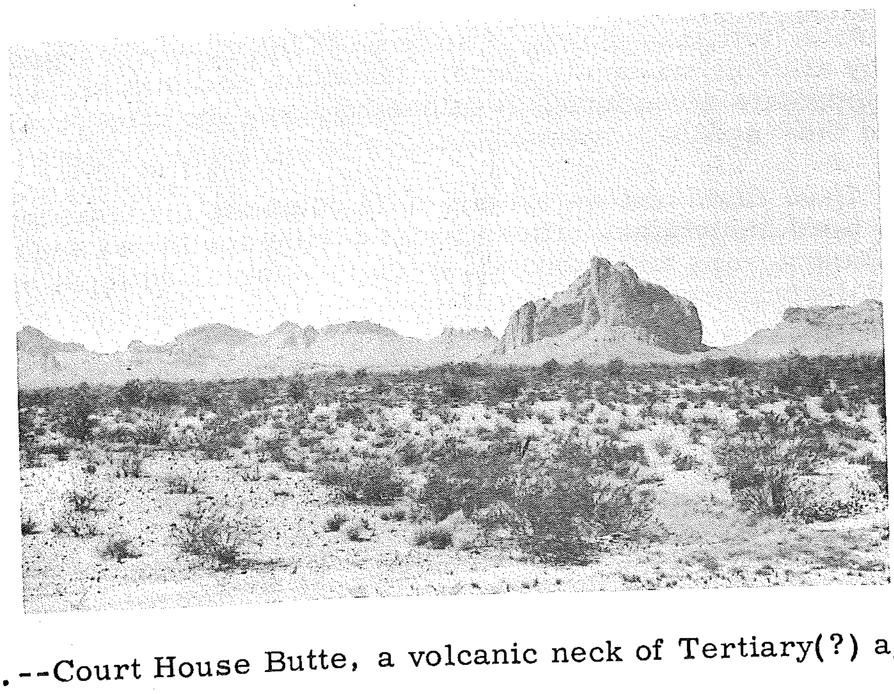

Figure 5.--Court House Butte, a volcanic neck of Tertiary(?) age.

Volcanic rocks.--Volcanic rocks of Quaternary age are widely distributed over the Harquahala Plains area, but the principal occurrences are in the southern part of the area, on Turtleback Mountain, and in T. 4 N., R. 10 W. These rocks consist of dark-gray to black highly vesicular olivine basalt. They weather into rounded boulders having heavy desert varnish. Caliche is formed on the talus slopes and is the result of decomposition of the basalt. The talus slopes obscure the basal contact of the basalt; however, on Turtleback Mountain a flow rests conformably on tuff.

East of the Harquahala Plains area in T. 1 S., R. 5 W., similar basalt rests on Pleistocene alluvium. This relation, plus the fact that in the Harquahala Plains area the basalt is only gently tilted and overlies Cretaceous(?) and Tertiary volcanic rocks, lends credence for the designation of Quaternary age, although it is recognized that some of the basalt may be older than Quaternary. For example, on Turtleback Mountain, Cretaceous(?) and Tertiary volcanic rocks grade upward into a basalt that is petrologically similar to the Quaternary basalt.

Alluvium.--The Quaternary alluvium may be divided into Pleistocene remnant alluvial fans and basin deposits, and Recent alluvium. Of these, only the basin deposits are important in the evaluation of the ground-water resources, as the other two are of limited areal extent.

Remnant alluvial fans are exposed at the bases of Saddle Mountain and the Big Horn and Eagletail Mountains. Those near Saddle Mountain occur between the main mountain mass and the large outlier about a mile to the southwest. These remnant fans are rounded hills of sufficient height that the source of the debris must have been Saddle Mountain. A similar remnant fan was observed at the base of the Big Horn Mountains in sec. 4, T. 3 N., R. 9 W. These fans probably had steep slopes and extended almost to the crests of the mountains. Although such fans no longer exist in the area, the type resembles that of fans in southern Nevada. These remnants may be indicative of a more arid climate because southern Nevada receives less rainfall than most of southwestern Arizona.

The low, rounded hills in the northeastern part of T. 2 N., R. 12 W., also are believed to be remnant alluvial fans. These deposits contain some boulders of Paleozoic limestone, probably from an unknown source in the Eagletail Mountains, although there is a remote possibility that they came from the Little Harquahala Mountains.

The basin deposits underlie much of the Harquahala Plains area and consist of lenses of gravel, sand, silt, and clay. The upper part of these deposits is believed to be Quaternary in age. The long geologic history since the beginning of the Basin and Range structural activity indicates that older alluvium, possibly Tertiary in age, may be present at depth. Although definite information is not available, it is possible that the total thickness of the alluvium may be as much as several thousand feet.

The materials making up the basin deposits were derived from the surrounding mountains. The canyons are the principal avenues by which water carries eroded material into the basin. Runoff from the mountains contains dissolved mineral matter and suspended clay and silt that are carried far out into the basin. The coarser materials move along the stream bottoms, and as the gradient and velocity of the streams decrease these materials are deposited in the form of alluvial fans along the mountain front.

The heterogeneity of the basin deposits is exemplified by the longitudinal sections shown on plate 2. One of these includes columnar sections along line A-A' on plate 1, and passes through the cultivated area southwest of Centennial Wash. The other section is along line B-B' and passes through the cultivated area northeast of Centennial Wash. The sections are drawn northwestward along the axis of the basin. Data were not available for a transverse section.

The section along line A-A' (pl. 2) is about 19 miles long, and extends from well (B-1-9)35dcc to well (B-3-11)16ddd. The most noticeable feature shown by the columnar sections is the large percentage of gravel in wells (B-1-9)26cbc, (B-1-9)34ddc, and (B-1-9)35dcc The columnar sections of the group of five wells farther northwest indicate more clay and silt.

The section along line B-B' is about 9 miles long and extends from well (B-1-8)6bbb through well (B-2-9)11bbb to well (B-3-9)31aa. The columnar sections show that well (B-2-9)14bbb penetrated a greater thickness of permeable material than well (B-2-9)9abb.

The sections indicate the lenticular character of the basin deposits, and they show that individual lenses cannot be correlated. There is no indication of a thick body of clay such as is found in some other basins of southern Arizona.

Contributing drainage area and climate have a marked influence on the composition of basin deposits of Pleistocene age. In general, the larger the drainage area the greater the carrying power of the streams issuing from the mountains. During the Pleistocene epoch, there were many changes in climate. When the climate was arid and runoff small, the debris was less sorted and most of the material was deposited along the mountain fronts. Only the finer material was carried out and deposited in the lower parts of the basin. When the climate was more humid and there was greater runoff, the debris was better sorted. Thus the coarser materials were carried farther from the mountains and the alluvial fans were eroded.

Recent alluvium occurs along Centennial and Rogers Washes where there are definite channels, and along the many washes that issue from the mountains. The Recent alluvium is composed mostly of sand and gravel deposited where gradients were sufficient to carry only the clay and silt farther downstream.

Geologic Structure

Faulting has played a dominant part in the structural history of the Harquahala Plains area, probably beginning in the Precambrian and extending into the Quaternary. No attempt was made to study the structural details, as the major basin-forming faults are concealed by alluvium and can only be inferred from the topography of the area. Major structural episodes since Paleozoic time may be divided into: (1) Folding and faulting; (2) mountain building; and (3) block faulting and tilting.

A period of folding and faulting occurred between the end of the Paleozoic era and the deposition of the arkosic conglomerate of Cretaceous(?) age. The crustal disturbance was severe, and the strata of Paleozoic age were folded and overturned in many places and cut by numerous low-angle faults. This complex structure was not noted in the Cretaceous(?) sedimentary rocks or Cretaceous(?) and Tertiary volcanic rocks.

Evidence of active mountain building in the area is provided by the Cretaceous(?) fanglomerate in secs. 21, 22, and 27, T. 4 N., R. 11 W. The mountains adjacent to which it formed have been completely eroded and their location is not known, but the angularity and size of the larger boulders in the fanglomerate suggest a close source. It is possible that the mountain building resulted from block faulting and tilting, and that it marked the early stages of the Basin and Range structure.

Block faulting and tilting occurred in the latest major structural episode in the area. Normal faulting was accompanied by tilting of the fault blocks (fig. 4). Nolan (1943) stated that the block faulting in the Great Basin section of the Basin and Range province may have begun in the early Oligocene, but he also noted "the apparent greater age of the faulting in... southeastern California and southwestern Arizona." Block faulting and tilting probably were not a continuous process but occurred intermittently, as indicated by the angular unconformities in the Cretaceous(?) and Tertiary volcanic rocks. According to Blackwelder (1948), the present mountains of the Basin and Range province probably formed at the beginning of the Pleistocene epoch.

The culmination of the episode of block faulting and tilting resulted in the formation of fault blocks that were subsequently eroded to produce the present topography of the area. The physiographic evidence is sufficient to postulate block faulting, even though the major basin faults are concealed by alluvium. The trend of the mountains is northwestward (pl. 1), in accordance with the principal structural trend of the region. The Big Horn and Eagletail Mountains and the basin itself conform to this trend. There is also a northeast lineation, however, as exemplified by the Harquahala and Little Harquahala Mountains. There is no evidence of Recent faulting in the Harquahala Plains area, although the possibility of minor earth movement is recognized.

Geologic History

The only rocks in the Harquahala Plains area that can be dated are the Paleozoic sedimentary rocks and the underlying Precambrian granitic gneiss. The ages of the other rock units are tentatively assigned on the basis of physical similarity to dated units in other parts of southern and western Arizona.

The Precambrian granitic rocks originated at considerable depths and the overlying rocks were subsequently removed by erosion. The absence of conglomerate in the Cambrian sedimentary rocks indicates that the land surface had been eroded to moderate or low relief by the end of the Precambrian.

The land surface was depressed beneath the sea during the Cambrian period, as attested by the fossiliferous marine quartzite and shale on Martin Peak. Fossiliferous Permian limestones indicate that the area was submerged during the Permian period. The age of rocks between the Cambrian and Permian is not known, but they represent systems of the Paleozoic other than the Cambrian and Permian.

After the Paleozoic and prior to the deposition of Cretaceous(?) arkosic conglomerate, Paleozoic rocks in the area were severely folded and thrust faulted. Sedimentary rocks of early Mesozoic age have not been recognized in western Arizona, and it is believed that erosion reduced the land surface to one of low relief during the Triassic and Jurassi[c] periods.

The arkosic conglomerate and shale sequence near the Harquahala Mountains was deposited during Cretaceous(?) time. The pebbles in the conglomerate are principally fine-grained quartzite of unknown age. No pebbles of rocks of known Paleozoic age have been found, which is difficult to explain in a conglomerate so near outcrops of such rocks.

The Cretaceous(?) fanglomerate exposed in T. 4 N., R. 11 W., is evidence of a period of major orogenic disturbance. The size, number, and angularity of the boulders indicate that the adjacent mountains were being actively eroded, and it was probably during this time that most of the Paleozoic sedimentary rocks were removed from the area.

Vulcanism probably began during the Cretaceous, attained maximum development during the Tertiary, and continued into Quaternary time. Volcanic rocks regarded as Cretaceous(?) and Tertiary in age comprise about equal thicknesses of lava flows and tuffs. The tuff is indicative of explosive activity, and some of the tuffs apparently were deposited in water. Court House Butte, a volcanic neck, probably was the source of some of the ejected material. The period of vulcanism probably was long, as shown by the thickness of the volcanic series and the angular unconformities that occur within it. It is believed that block faulting and tilting began during this time.

The earlier outpourings of Quaternary basalt, probably from fissures, were followed by structural disturbances that produced the present fault blocks of the area. Subsequently, erosion of the mountains and deposition in the basins resulted in the present topography.

During part of the Quaternary period the climate may have been more arid than the present. Near Saddle Mountain and in the Eagletail and Big Horn Mountains, alluvial hills, interpreted as remnant alluvial fans, are believed to attest to the former aridity. The hills are of such size that only a higher alluvial surface extending back to the mountains could have produced them.

During a more recent part of the Quaternary period there seemingly was abnormally heavy rainfall, for faint shorelines and terraces (fig. 6) in the southeastern part of the Harquahala Plains area are evidence of the former existence of a lake. This lake was probably formed when lava flows blocked the ancient Gila drainage between the present towns of Buckeye and Gila Bend. The water apparently rose rapidly and overflowed the lava dam. The lake extended up the Salt River Valley, the Hassayampa River, and Centennial Wash and into the Harquahala Plains area. After the development of an outlet the lake dwindled rapidly. It is probable that the lake existed during the time of one of the last major continental glaciations of North America.

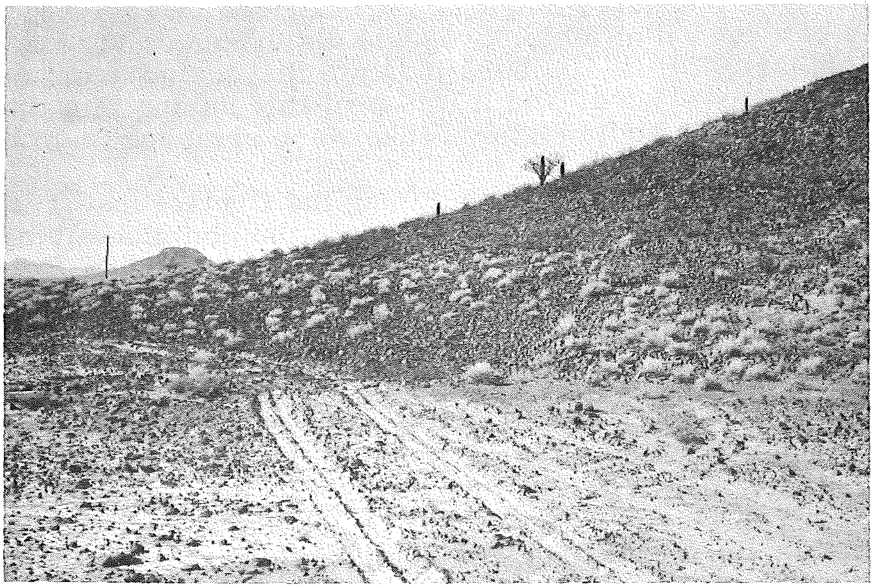

Figure 6.--View of a shoreline of a Pleistocene lake in sec. 13, T. 1 S., R. 8 W. Line between light- and dark-colored brush marks high-water stage and faint terrace of the Pleistocene lake.

GROUND WATER

Occurrence

The Harquahala Plains area, for the purpose of discussion on the occurrence of ground water, may be divided into the mountain or bedrock part, and the plain or alluvial part. The principal aquifers occur in the alluvial deposits.

The greater part of the mountain masses is made up of igneous and metamorphic rocks. These are relatively impermeable but may carry very small quantities of water along fracture zones. A small part of the area is composed of Paleozoic and Cretaceous(?) sedimentary rocks. Outcrops are discontinuous because the rocks are faulted, and it is impossible to project the extent of the rocks beneath the alluvium. The hydrologic characteristics are unknown, as no wells or springs in these sediments are known. Although some ground water occurs in abandoned mine shafts in the mountains, the amounts are small. There is little likelihood that large quantities of ground water move through the mountains because of the preponderance of relatively impermeable igneous and metamorphic rocks.

The principal aquifers in the area are the sand and gravel lenses in the Quaternary alluvium of the basin. The alluvium occurs in discontinuous lenses of clay, silt, sand, and gravel. Because of this heterogeneity, wells not more than a mile apart may penetrate entirely different types of alluvial materials. One well may penetrate a preponderance of fine-grained sediments and produce only a few hundred gpm (gallons per minute); another may encounter coarser materials and yield as much as 3,000 gpm. Wells (B-1-9)26cbc, (B-1-9)34dcc, and (B-1-9)35dcc (pl. 2, section A-A'), which penetrated numerous gravel lenses, have a high yield and specific capacity. The wells in the northwestern part of T. 1 N., R. 9 W., and in T. 1 N., R. 10 W. (pl. 2, section A-A'), encountered more clay and silt, and the yields were not as great. Well (B-2-9)14bbb (pl. 2, section B-B'-B'') penetrated more coarse material than the other 3 wells shown, and its yield is somewhat greater. As underground conditions cannot be foreseen, only test drilling will reveal such relationships. There is a hydraulic interconnection between aquifers, however, as is shown by wells in localized areas that have about the same depth to water.

Information on wells is given in table 2 and the depths to water are shown on plate 1. The depths to water are greater upstream along Centennial Wash and from the wash toward the mountains. For example, the shallowest depth to water was 17 feet in well (C-1-8)13dcd along Centennial Wash at the lower end of the basin; the greatest depth to water was 424 feet in well (B-3-11)17bd along Centennial Wash about 30 miles upstream, just east of Lone Mountain. Another example is provided by a depth to water of 93 feet in well (C-1-8)4bbd within half a mile of Centennial Wash, and of 325 feet in well (C-1-9)17dcc about 5 miles southwest of Centennial Wash.

Movement

Spirit-level lines were run to various wells to establish their altitude. The altitude and slope of the water table could then be obtained, and the direction of ground-water movement within the basin ascertained. Ground water moves downgradient and is controlled solely by gravity, much in the manner of surface-water flow. The rate of movement of ground water is very slow, generally only a few feet or hundreds of feet a year.

Plate 1 shows that the difference in altitude of the water table at well (B-3-11)16ddd and that 20 miles distant at the southeast end of the basin is less than 40 feet. The slope of the water table thus is about 2 feet per mile, and the direction of movement of ground water in the basin is southeastward. The low gradient may be attributed to the high permeability of the alluvium, as well as possibly to a rather low rate of recharge. The cross sections (pl. 2) show that before development there was an extensive area in the lower part of the basin in which the hydraulic

Table 2.--Descriptions of wells in Harquahala Plains area, Maricopa and Yuma Counties, Ariz.

(a) See fig. 2 for sketch map that shows numbering and location system used in Arizona.
(b) Reported.
(c) T, turbine; C, cylinder; N, none.
(d) E, electric; NG, natural gas; G, gasoline; D, diesel; W, wind.
(e) I, irrigation; D, domestic; S, stock; N, none; O, observation.

Location (a)	Owner	Type of well and date completed	Depth reported (feet)	Casing diameter (inches)	Perforated zone (feet)	Depth to water measured below lsd (feet)	Date	Pump			Yield measured (gpm)	Date	Use (e)	Temp. (°F)	Date sampled	Remarks
								Type (c)	Power (d)	Horse-power						
(B-1-8)																
6bbb	G & G Mining Co.	Cable tool - Oct. 1954	600	18	-	150	4-14-55	N	N	-	-	-	I	-	-	
19abb	--	do. - --	-	16	-	119	6-29-55	T	D	-	-	-	I	-	-	
(B-1-9)																
6ccc	Centennial Farms	Rotary - Dec. 1953	1,420	20 to 16	400-1,420	150-160(b)	1-54	T	NG	-	-	-	I	94	8-19-54	
7bcc	Associated Farms, Inc.	do. - Jan. 1953	840	20 to 16	400- 840	236	1-14-54	T	NG		750(b)	-	I			Abandoned.
						264	3-30-55									
7dcc	Harqua Valley Farms, Inc.	do. - Jan. 1953	915	20 to 16	406- 915	208(b)	1-53	T	NG	300	1400	6-30-53	I	93	6-30-53	
12ddb	--	-- - --	-	10	-	134	12-10-52	C	G	-	-	-	S	-	-	
20bbb	Gordon Cameron	Rotary - 1952	900	--	-	203	12- 9-52	T	NG	-	2500	6-30-53	D,I	90	6-30-53	
														90	8-19-54	
21bcc1	E. Shephard	Cable tool - Oct. 1952	1,068	20	350- 825	179	12- 9-52	T	NG	280	2250(b)	-	I			Abandoned owing to excessive pumping of sand.
					900-1,058											
21bcc2	Do.	Rotary - May 1953	1,033	20 to 16	400-1,033	178(b)	5-53	T	NG	-	-	-	I	90	8-19-54	
26acb	M. E. Grummel	Cable tool - --	267	10	150- 249	125(b)	9- 8-53	-	-	-	200(b)	-	-	-	-	Abandoned.
26ccb	H. T. Grummel	Rotary - May 1952	1,015	20	371-1,015	143	10- 1-52	T	NG	300	3500	6-30-53	I	82	6-30-53	Gravel packed.
						155	1-14-54				3200	8-19-54		82	8-19-54	
28dcc	H. W. Harrison	do. - June 1953	1,030	20 to 16	348- 903	195(b)	6-53	T	NG	300	2400	8-19-54	I	87	8-19-54	
34ccc	--	-- - --	-	6	-	-	-	C	WG		-	-	S	-	-	
34dcc	H. Friemel	Rotary - May 1953	845	20 to 16	200- 812	187	1-14-54	T	NG	-	2200	6-30-53	I	81	8-19-54	
						190	4-13-55				2400	8-19-54		80	-	
35dcc	Fulton & Boerner	do. - Feb. 1953	910	20 to 16	240- 730	160(b)	2-53	T	NG	-	2600	6-30-53		79	6-30-53	
(B-1-10)																
1ccc	Centennial Valley Farms	-- - Jan. 1953	917	18 to 12	344- 777	257(b)	1-53	T	NG	350	1900	6-30-53		88	6-30-53	
1dcc	Do.	-- - Feb. 1953		20 to 16	384- 800	205(b)	2-53	T	NG	400	1600	6-30-53		92	6-30-53	
(B-2-8)																
17daa	O. C. Stockbridge	Cable tool - --	600	--	-	239	3-23-55	T	D	-	1600	8-17-54	I	89	8-17-54	
28dcc	Jack Clem	-- - --	-	--	-	240(b)	9-52	C	G	-	-	-	-	83	9-22-52	
(B-2-9)																
7abb	F. G. Hilvert Co.	-- - Sept. 1952	1,692	20 to 16	400-1,692	270(b)	9-52	-	-	-	-	-	-	-	-	Abandoned owing to production difficulties.
9abb	Do.	Rotary - July 1952	1,540	20 to 16	400-1,500	248(b)	7-52	T	NG	325	2800	9-22-53	I	94	9-22-52	
											3000	7- 2-53				
											2800	8-17-54				
10bbb	Do.	-- - Mar. 1953	1,300	20 to 16	-	-	-	T	NG	-	-	-	-	92	7- 2-53	
11ada	Jack Clem	-- - --	390	6	-	230(b)	12- 6-17	C	WG	-	-	-	S	83	9-22-52	Burned place well.
11bbb	Mary E. Farms, Inc.	Rotary - Jan. 1952	1,500	20 to 16	275-1,355	235	1-31-52	T	NG	235	3000	7-16-52	I	95	7-16-52	
							1-25-54			275	2900	7- 2-53		95	7- 2-53	
											2700	8-17-54		94	8-17-54	
13baa	R. Blecha	-- - Jan. 1954	603	18	-	253	3-23-55	T	D	300	2000	8-17-54	I	91	8-17-54	
14bbb	Mary E. Farms, Inc.	Rotary - Sept. 1951	1,530	20 to 16	294-1,452	200(b)	9-51	T	D	-	2900	9-26-52	I	89	7-16-52	
														90	3-25-55	
(B-2-10)																
14dcb	--	-- - --	-	--	-	245	3-31-55	N	N	-	-	-	-	-	-	Abandoned.
16bbb	--	-- - --	494	6	-	278	9-25-52	C	G	-	-	-	S	78	3-31-55	Court House well.
						279	2-27-53									
						279	1-25-54									
						278	2-11-55									
23bba	--	-- - --	305	6	-	249	4-14-55	N	N	-	-	-	-	-	-	Abandoned.
(B-3-9)																
31aa	--	Dug - --	-	Uncased, 48		327	9-22-52	N	N	-	-	-	-	-	-	Abandoned. Mosher well.
						327	2-27-53									
						327	1-25-54									
(B-3-11)																
16ddd	Bryan Hamilton Cattle Co.	-- - --	-	10	-	400	9-26-52	C	G	-	-	-	S	-	-	
17bd	Do.	-- - --	493	6	-	424	3-27-46	C	G	-	-	-	S	-	-	Well has been destroyed.
18bbb	Coffman & Fine	Rotary - May 1952	815	--	-	-	-	-	-	-	-	-	-	-	-	Abandoned.
20bbb	Do.	do. - 1952	1,165	--	-	-	-	-	-	-	-	-	-	-	-	Do.
34daa	Bryan Hamilton Cattle Co.	-- - --	392	6	-	350(b)	5-29-46	C	G	-	-	-	D,S	-	-	
(B-4-9)																
30aa	--	-- - --	340	6	-	330	3- 7-55	C	W	-	-	-	S	-	-	
(B-4-11)																
15a	--	-- - --	-	6	-	-	-	C	W	-	-	-	S	-	-	
(B-5-10)																
33cc	--	-- - --	-	--	-	200	3- 7-55	C	W	-	-	-	S	-	-	
(C-1-7)																
32ac	Dr. Ward	-- - --	36	6	-	30	4-12-46	N	N	-	-	-	O	-	-	
32cb	--	-- - --	57	--	-	31	4-12-46	-	-	-	-	-	-	-	-	
(C-1-8)																
4bbd	Jack Gable	-- - --	200	6	-	93	10- 1-52	C	WG	-	-	-	S	93	10- 1-52	
						96	1-11-54									
13bdb	R. L. Ward	-- - --	235	16	-	38(b)	1953	-	-	40	900	7-22-53	-	78	7-22-53	
											600	7-13-55		76	7-13-55	
13cbb	Roy Davis	Cable tool - 1939	137	16	Open	26(b)	1939	N	N	-	-	-	I	-	-	
13dcb	R. L. Ward	-- - 1937	218	20" to 60' depth	20- 60	21(b)	1948	T	E	40	-		I			
13dcd	Do.	-- - 1938	70	20" to 60' depth	20- 60	17	3-21-46	T	E	-	-	-	I			Observation well.
						18	10-22-47									
						21	10-13-48									
						19	3- 4-49									
						20	3-23-50									
						21	1-26-51									
						16	2- 5-52									
14abb	Do.	-- - 1938	195	20" to 100' depth	50- 100	45(b)	1948	T	E	100	2400	7-22-53	I	82	7-13-55	
											2000	7-13-55		82		
14abc	Do.	-- - 1948	225	20" to 70' depth	50- 70	46	3- 4-49	T	E	20	300	7-13-55	I	80		
14adb	Do.	-- -- --	708	20 to 16	150- 225	37(b)	1954	T	E	60	800	7-13-55	I	81		
					229- 287											
					304- 323											
					363- 397											
					416- 517											
17acc	D. D. Nichols, Jr.	-- - --	200	8		100(b)	1954	-	-	-	35(b)	-	D	-	-	
20adb1	Roy Davis	Cable tool - 1936	240	12	Open	91(b)	1937	T	E	-	-	-	I	-	-	
20adb2	Do.	do. - 1953	550	15	-	-	-	-	-	-	-	-	I	-	-	
22bbc	Do.	do. - 1948	500	16	-	56	3-21-46	T	E	-	-	-	I	-	-	Abandoned.
22bcc	--	-- - --	-	36		56	3-21-46	C	W	-	-	-		74	3-21-46	Abandoned. Formerly Volcanic School well.
						56	10-23-47									
						56	10-13-48									
						56	3- 4-49									
						57	1-26-51									
						56	2- 5-51									
						58	12-14-53									
32	Roy Davis	-- - --	89	6		66	5- 6-55	C	W	-	-	-	S	-	-	
33d	--	-- - --	-	24		70	5- 6-55	N	N	-	-	-	-	-	-	Abandoned.
(C-1-9)																
2bcc	W. L. Dees	Cable tool - 1954	366	16	-	187(b)	1954	T	D	-	1500(b)	4-55	I	79	4-13-55	
11dcb	L. H. Meredith	do. - Mar. 1955	400	16	-	195	3- 9-55	-	-	-	-	-	I	-	-	
16da	Roy Davis	do. - --	-	6 or 8	-	265	4- 1-55	C	W	-	-	-	S	-	-	
17dcc	J. E. Plaster	do. - Dec. 1954	502	16	375- 502	323	3- 9-55	N	N	-	-	-	I	-	-	
(C-1-10)																
12ada	--	-- - --	-	--	-	299	3- 9-55	C	WG	-	-	-	S	-	-	

gradient was very low. The water table ranged in altitude from 968 to 970 feet over an area of about 20 square miles. The altitude of the water table in well (B-2-9)13bba was lower than others in the area, but this is believed to have been a temporary condition resulting from pumping.

Recharge

Natural recharge to the alluvium of the Harquahala Plains area occurs from underflow, streamflow, and rainfall. Artificial recharge occurs at the northwest end of the basin by seepage of irrigation water pumped in the Harrisburg Valley.

Natural underflow in the alluvium occurs from Harrisburg Valley and along Rogers Wash into the basin, as shown by the depths to water of less than 100 feet upstream from the points where the washes enter the area. Downstream the depth to water increases abruptly to more than 300 feet. Other possible sources of underflow may be Hubbard Plain and the area southeast of Turtleback Mountain. Harrisburg Valley has a narrow constriction at its mouth. Here, the width of the alluvial plain is less than a quarter of a mile, bedrock is probably shallow, and the amount of underflow must be small. This natural underflow probably has been diminished by pumping from wells upstream in Harrisburg Valley. Bedrock in the Rogers Wash area is probably shallow, and although the alluvial plain is wider, the underflow is probably small. In each of two areas, Hubbard Plain and the area southeast of Turtleback Mountain, there are alluvial gaps about 2 miles wide in the upland surrounding the Harquahala Plains area. Water may enter the basin through these gaps, or leave the basin through them; there are no data to indicate either the direction or the amount of movement.

Streamflow occurs only after cloudbursts or prolonged rains, and the streams seldom flow for more than a few days. Recharge to the ground-water reservoir occurs through the gravel and sand after the water has saturated the material under the streambed. The longer the stream flows, the greater the amount of recharge. Recharge from streamflow occurs in Centennial Wash, Rogers Wash, and the numerous unnamed washes that originate in the mountains. The drainage area of Centennial Wash upstream from the point where it enters the Harquahala Plains is about 640 square miles, including some of the higher elevations of the Harquahala Mountains. Flows in Centennial Wash generally occur during the thunderstorm season of July, August, and September. This wash has been observed to be flowing about 50 feet wide where it enters Harquahala Plains, yet, by the time the flow has reached the locality east of Lone Mountain, the stream has broken into numerous branching channels and the water usually disappears within a short distance. It has been reported (Babcock and Cushing, 1942) that desert washes of this type may contribute as much as 50 percent of their flow to ground-water recharge.

Rogers Wash, which drains an area of about 120 square miles, and numerous smaller washes have flows similar in character and timing if not in amount to that of Centennial Wash. Streamflow from all sources probably furnishes more than 90 percent of the recharge to the area.

The amount of direct recharge from rainfall upon the valley floor is probably negligible, as there is seldom enough rainfall to saturate the soil sufficiently to cause recharge.

Water from wells in Harrisburg Valley is pumped into a canal and transported to irrigate the acreage in the northwestern part of the Harquahala Plains (pl. 1). Before the canal was lined, it undoubtedly furnished recharge in excess of normal underflow. At present, however, only seepage from irrigated fields contributes to recharge from this source.

In the lower part of the Harquahala Plains about 6,000 acres are under irrigation. Although part of the water pumped probably returns by seepage to the ground-water reservoir, it is not considered as a form of recharge to the basin, in that the water came from storage, and the seepage is simply returning to storage. Therefore, during the irrigation cycle, only the water pumped less that returning as seepage is considered as contributing to depletion of storage.

The amount of annual recharge to the Harquahala Plains area varies considerably. During periods of abnormally high rainfall — such as 1905 and 1941 (table 1) — the amount of recharge may be many times the long-term average. During the years of normal or subnormal rainfall, the amount of recharge is probably much below the average and may be negligible. The result is that most of the recharge to the basin in a period of several decades may occur during only a few years.

The amount of recharge to the Harquahala Plains by underflow and streamflow cannot be computed at the present time. However, on the basis of estimates that have been made for other basins in southern Arizona, it is believed that this quantity would be of the order of a few thousand acre-feet annually. This figure is only of academic interest and has little relation to the development of the basin. It is believed that pumping from the basin already exceeds by several times the amount of recharge.

Discharge

Ground water is discharged naturally from the Harquahala Plains area by underflow and by transpiration from phreatophytes. A little water from wells at the southeast end of the basin is exported to irrigate land on the flood plain of Centennial Wash downstream from sec. 24, T. 1 S., R. 8 W. The rest of the discharge from the basin is by evapotranspiration of water pumped for irrigation within the basin. It is this pumping that is depleting storage within the basin.

The discharge by underflow from the southeast end of the basin is difficult to evaluate because of the existence of Quaternary basalts. The flood plain of Centennial Wash is narrow where the wash leaves the basin, and as there is no suggestion of a deep alluvial channel, the amount of underflow through the exposed alluvium probably is small. However, some underflow may leave the basin through alluvium beneath the Quaternary basalts. It is difficult to determine what the basalt rests upon because of the manner in which it weathers, but there are some areas farther downstream where similar basalt rests directly on alluvium.

Some ground water may leave the basin as underflow through alluvium in secs. 30 and 31, T. 1 S., R. 7 W.

Only a limited area in the lower end of the basin has a water table shallow enough to support phreatophytes. Here, the native vegetation is primarily mesquite, and some of these trees may be taking water from the ground-water reservoir, but the quantity used must be very small.

In an undeveloped basin, total discharge should equal total recharge. Therefore, if recharge is a few thousand acre-feet per year, the natural discharge also must be of this magnitude.

Storage

Much of the alluvium of the basin is unconsolidated, and the alluvium contains interstices (pore spaces) between the grains. Beneath the water table, interstices that have not been filled by cementation are filled with water. In the saturated alluvium, the percentage of the total volume of rock that is occupied by water is called porosity, and this is true storage. However, not all the water can be removed because some of it is retained by molecular attraction, particularly in the finer grained rocks. Actually, clay generally contains more water than gravel, but molecular attraction prevents the clay from yielding this water. The coarser the grains, the less the influence of surface tension. This is the reason that sand and gravel are the best aquifers. The amount of water that will drain from a unit of rock under the influence of gravity is called specific yield. In alluvium, this may be in the order of 10 or 20 percent of the total rock volume.

More than 100,000 acres of the basin is underlain by a large thickness of alluvium. The depth to bedrock is not known, but geologic evidence suggests that the basin is comparable to other large basins of Arizona in which bedrock has been encountered at 4,000 to 6,000 feet.

This would indicate a large quantity of ground water in storage in the basin, but economic considerations, which are beyond the scope of this report, would materially reduce the amount of water available for withdrawal. Assuming a specific yield of 10 percent, the layer of alluvium in the first 100 feet below the water table would contain more than 1,000,000 acre-feet of ground water. This is a sizable quantity compared to the present annual pumpage of about 33,000 acre-feet.

Quality of Water

Chemical analyses of the water from 23 wells in the Harquahala Plains area are shown in table 3. Five of the wells have been sampled twice. One sample was collected in 1946 and the others between 1952 and the spring of 1955.

The most significant characteristic observed from the tabulated analyses is the comparatively small range in the concentration of dissolved solids. The concentration ranges from a low of 432 to a high of 864 ppm. Frequently the maximum content of dissolved solids in ground water in alluvium in other parts of Arizona is much greater, in places amounting to several thousand ppm.

Ground water in the Harquahala Plains area is being used successfully for irrigation. Although the chemical analyses show a relatively high percent sodium in water from wells sampled, the content of dissolved solids is comparatively low, and thus far there have been no quality-of-water problems in the area.

An inspection of the chemical analyses shows that, in general, the ground water southwest of Centennial Wash contains more dissolved solids than that northeast of the wash. Water from wells southwest of Centennial Wash generally has a concentration of dissolved solids of more than 600 ppm, a specific conductance of more than 1,000 microhos, a bicarbonate content of more than 200 ppm, and a sodium and potassium content, calculated as sodium, of more than 200 ppm. Analyses of water from wells northeast of the wash show in general a concentration of dissolved solids of less than 500 ppm, a specific conductance of less than 900 micromhos, bicarbonate of less than 170 ppm, and sodium and potassium of less than 160 ppm (table 3). The analysis of water from well (B-2-10)16bbb is not included in the foregoing generalizations because the well is a considerable distance northwest of the developed areas. The better chemical quality of water northeast of Centennial Wash is believed to be due primarily to the proximity of recharge areas. As the water moves downgradient, it picks up additional dissolved mineral matter.

Table 3.--Chemical analyses of water from wells in Harquahala Plains area, Maricopa and Yuma Counties, Ariz.
(Chemical constituents in parts per million except as indicated)

(a) See fig. 2 for sketch map that shows numbering and location system in Arizona.
(b) Analysis shows a borate (BO_3) content of 3.0 parts per million.
(c) Analysis shows a carbonate (CO_3) content of 5 parts per million, whereas all other analyses show zero carbonate.

Location (a)	Date of collection	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids		Hardness as $CaCO_3$		Percent sodium	Sodium adsorption ratio	Specific conductance (micromhos at 25°C)
											Sum	Tons per acre-ft.	Total	Noncarbonate			
(B-1-9)																	
6ccc	8-19-54	27	22	12	198	287	151	83	2.8	22	659	.90	104	0	80	8.4	1,060
7dcc	6-30-53	22	68	9.2	216	234	324	90	3.2	17	864	1.18	208	16	69	-	1,320
20bbb	6-6-53	27	19	7.6	206	270	145	92	4.8	16	650	.88	78	0	85	-	1,060
20bbb	8-19-54	-	-	-	-	293	-	99	-	-	-	-	-	-	-	-	1,100
21bcc	8-19-54	-	-	-	-	253	-	92	-	-	-	-	-	-	-	-	997
26ccb	6-30-53	-	-	-	-	229	-	122	-	-	-	-	-	-	-	-	1,030
26ccb	4-13-55	22	9.5	7.4	205	231	117	121	2.6	13	612	.83	54	0	89	12	1,030
28da	8-19-54	-	-	-	-	277	-	130	-	-	-	-	-	-	-	-	1,100
34dcc	6-30-53	28	20	12	204	259	119	134	2.8	13	660	.90	100	0	82	-	1,100
35dcc	6-30-53	23	16	10	273	355	142	152	4.0	14	809	1.10	81	0	88	-	1,260
(B-1-10)																	
1ccc	6-30-53	27	25	15	191	302	122	104	2.8	13	649	.88	124	0	77	-	1,070
1dcc	6-30-53	-	-	-	-	327	-	98	-	-	-	-	-	-	-	-	1,100
(B-2-8)																	
17daa	8-17-54	-	-	-	-	141	-	92	-	-	-	-	-	-	-	-	691
28dcc	9-22-52	45	20	6.8	118	149	67	90	4.0	7.8	432	.59	78	0	77	-	693
(B-2-9)																	
9abb	9-22-52	36	28	16	124	162	119	59	1.4	17	480	.65	86	0	76	-	710
9abb	7-2-53	-	-	-	-	165	-	61	-	-	-	-	-	-	-	-	734
10bbb	7-2-53	-	-	-	-	153	-	67	-	-	-	-	-	-	-	-	732
11ada	9-22-52	18	14	3.7	156	141	84	129	-	4.2	478	.65	50	0	87	-	883
11bbb	8-17-54	-	-	-	-	158	-	-	-	-	-	-	-	-	-	-	751
(c)11bbb	3-25-55	41	28	22	101	147	102	95	1.1	8.5	476	.75	160	32	58	3.4	769
13baa	8-17-54	41	24	9.0	111	146	75	90	3.6	6.5	432	.59	97	0	71	4.9	686
14bbb	9-26-52	-	-	-	-	150	-	69	-	-	-	-	-	-	-	-	709
14bbb	3-25-55	41	25	21	98	154	111	78	1.3	8.9	460	.63	149	23	59	3.5	738
(B-2-10)																	
16bbb	3-31-55	17	11	14	169	286	78	73	2.8	32	538	.73	85	0	81	8.0	895
(C-1-8)																	
4bbd	10-11-52	53	19	4.6	222	182	180	137	4.4	11	720	.98	66	0	88	-	1,130
14abb	7-22-53	50	16	4.4	204	207	129	124	4.8	11	645	.88	58	0	88	-	1,030
(b)22bbc	3-21-46	8.2	11	2.6	248	331	47	170	7.0	0	657	.89	38	0	-	-	1,120
(C-1-9)																	
2bcc	4-13-55	28	13	11	239	293	125	154	-	13	727	.99	78	0	87	12	1,220

The analyses show a rather high fluoride content in the water; in fact, only three samples had less than 1.5 ppm, the concentration limit set by the U. S. Public Health Service in 1946 as being permissible in drinking water on interstate carriers. Although this is of little importance in the use of water for irrigation, it is generally recognized that an excess of fluoride may cause mottling of the tooth enamel of children who drink such water during the time their permanent teeth are forming.

RECENT DEVELOPMENT

In the fall of 1951 a well (B-2-9)14bbb was drilled for the Mary E. Farms to a depth of 1,530 feet. This well had a static water level of about 200 feet below the surface, and produced more than 3,000 gpm for irrigation. The successful completion of this well created an interest in the area, and 20 other wells were drilled in 1952-53. By the spring of 1954, 7,000 acres were under cultivation — 6,000 acres in the lower end of the basin and 1,000 in the upper end, the latter being supplied from wells in Harrisburg Valley.

Additional incentive for the development of ground water in the basin occurred in 1954 when the Bureau of Land Management approved more than 100 desert-land entries in the lower part of the Harquahala Plains. The approval was only tentative, and applicants cannot receive title to the lands unless or until Arizona laws are changed to allow the appropriation of underground water. Notwithstanding this uncertainty, many applicants proceeded with the development of their lands; some irrigation wells were drilled the first year after the approvals, and other assessment work was done. "Assessment work" is the term describing the improvements that are required each year to hold the permit for desert-land entry, and the applicants have 4 years in which to drill a well and put a crop under cultivation.

Well data to and including the spring of 1955 are given in table 2, and some of the drillers' logs are given in table 4. A typical surface installation for an irrigation well is shown in figure 7.

The major irrigation development occurred during the period 1952-53, and in 1955. However, it has not progressed to a stage where large declines in water level are noticeable. The declines have been local, and cones of depression resulting from pumping have not extended far enough to affect water levels in the network of observation wells. In the southern part of T. 1 N., R. 9 W., occasional measurements (table 2) indicate a decline of 3 to 4 feet per year from 1952 to 1955.

The static water levels in wells used for irrigation range from 17 to 323 feet. In T. 1 S., R. 8 W., yields of irrigation wells range from 300 to 2,400 gpm. Elsewhere in the basin, the range is from

Table 4.--Logs of selected wells in Harquahala Plains area, Maricopa and Yuma Counties, Arizona.

	Thickness (feet)	Depth (feet)
(B-1-9)6ccc		
Surface sand and clay	90	90
Clay	40	130
Sandy clay	260	390
Clay	310	700
Gray sand	177	877
Boulders and sand	28	905
Coarse gray sand	375	1280
Gray sand	140	1420
TOTAL DEPTH		1420
(B-1-9)21bcc2		
Surface sand and clay	200	200
Clay with small streaks of very fine sand	200	400
Sandy clay	100	500
Fine sand	60	560
Coarse sand	40	600
Clay	25	625
Fine sand	25	650
Sticky clay with streaks of sand	70	720
Sandy clay	80	800
Clay with streaks of sand	60	860
Sandy clay	60	920
Clay	60	980
Sand and clay	25	1005
Coarse sand	28	1033
TOTAL DEPTH		1033
(B-1-9)26ccb		
Surface sand and clay	50	50
Clay and sand	290	340
Sand and rock, fine gravel	200	540
Fine sand, small gravel	89	629
Hard sand, small gravel	184	813
Red bed and sand, gravel	110	923
Red bed and hard sand, gravel	92	1015
TOTAL DEPTH		1015
(B-2-9)14bbb		
Surface sand and clay	94	94
Sand, streaks clay	134	228
Sand, clay, streaks gravel	232	460
Sand and gravel	80	540
Streaks sand, clay, gravel	120	660
Cemented sand, boulders	180	840
Hard sand, streaks conglomerate small boulders	140	980
Hard sand, streaks hard clay	80	1060
Hard sand	190	1250
Sand, streaks conglomerate with clay streaks	100	1350
Hard brown sand, shells, conglomerate	99	1449
Hard shale, streaks sand and shells	31	1480
Very hard brown sand	50	1530
TOTAL DEPTH		1530

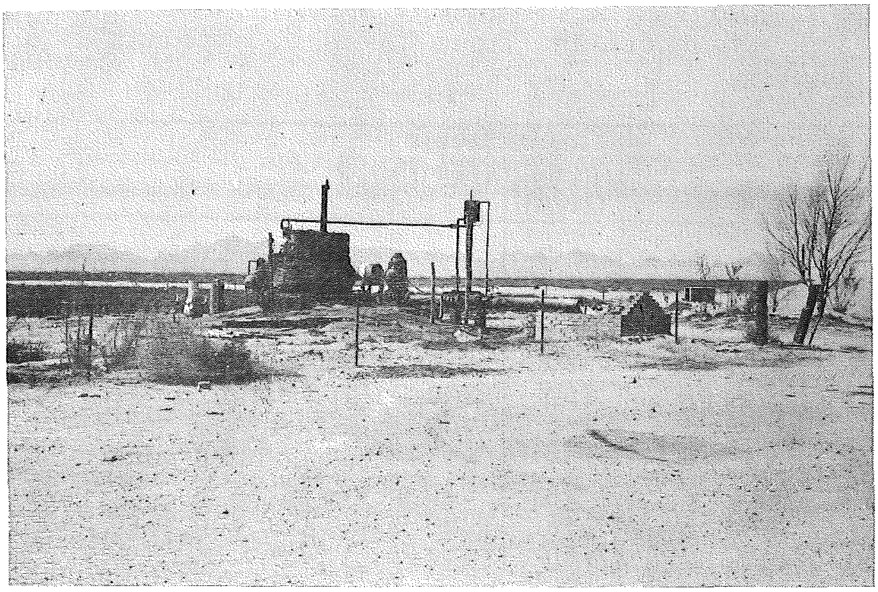

Figure 7.--Well (B-2-9)11bbb. Typical irrigation well in the Harquahala Plains area. Power is by natural gas.

1,400 to 3,500 gpm, and wells of lesser production have been abandoned. The specific capacity of wells ranges from a low of 3 to a high of 80 gpm per foot of drawdown. Most of the successful irrigation wells have specific capacities of 40 to 60 gpm per foot of drawdown.

Five wells drilled for irrigation have been abandoned. Well (B-1-9)7bcc had a low specific capacity and a resulting low production. The casing in well (B-1-9)21bcc1 collapsed owing to the excessive pumping of sand. A successful well was drilled later 120 feet to the east. Well (B-2-9)7abb had "production difficulties." Wells (B-3-11)18bbb and (B-3-11)20bbb were never test pumped and were reported as abandoned "due to insufficient water-bearing formation."

Table 2 shows that 12 of the wells drilled for irrigation are more than 1,000 feet deep and that 6 are more than 1,400 feet deep. Although the basin is only partly developed, some of the advantages and disadvantages of deep wells can be discussed. In a "water-mining" economy such as that of southern Arizona — that is, an economy in which advantage is taken of stored ground water by withdrawing it at a rate in excess of recharge — as the water table declines a deep well will still have an adequate supply provided the lower part of the well penetrates productive aquifers. On the other hand, if adequate gravel lenses are penetrated within 200 or 300 feet below the water table, additional depth will be of questionable value. The basin deposits are so heterogeneous that it is impossible to state what is an adequate depth. The depth would vary from locality to locality, depending solely on the amount of permeable material encountered.

FUTURE GROUND-WATER SUPPLY

Certain facts pertaining to the development of the ground-water supply are pointed out here. Ground-water withdrawal in 1954 was about 33,000 acre-feet, and that for 1955 was expected to be about the same. The recharge into the basin probably is only a fraction of this amount, and at least to date has been balanced by a continuation of the natural discharge; thus all the water being pumped is coming from storage. The storage is very large, but as pumping continues the water table in the pumped areas will decline, and the rate of lowering will depend entirely on the amount of development. In other areas in Arizona that are irrigated solely by water pumped from storage, the water table is declining at rates ranging from a foot to 15 feet per year.

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