Underground Waters Of Salt River Valley, Arizona

By: Willis Thomas Lee

1905

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Water-Supply and Irrigation Paper No. 136

Series { B. Descriptive Geology, 67
K. Pumping Waters, 10
O, Underground Waters, 37

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

UNDERGROUND WATERS

OF

SALT RIVER VALLEY, ARIZONA

BY

WILLIS THOMAS LEE

WASHINGTON
GOVERNMENT PRINTING OFFICE
1905

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
HYDROGRAPHIC BRANCH,
Washington, D. C., June 1, 1904.

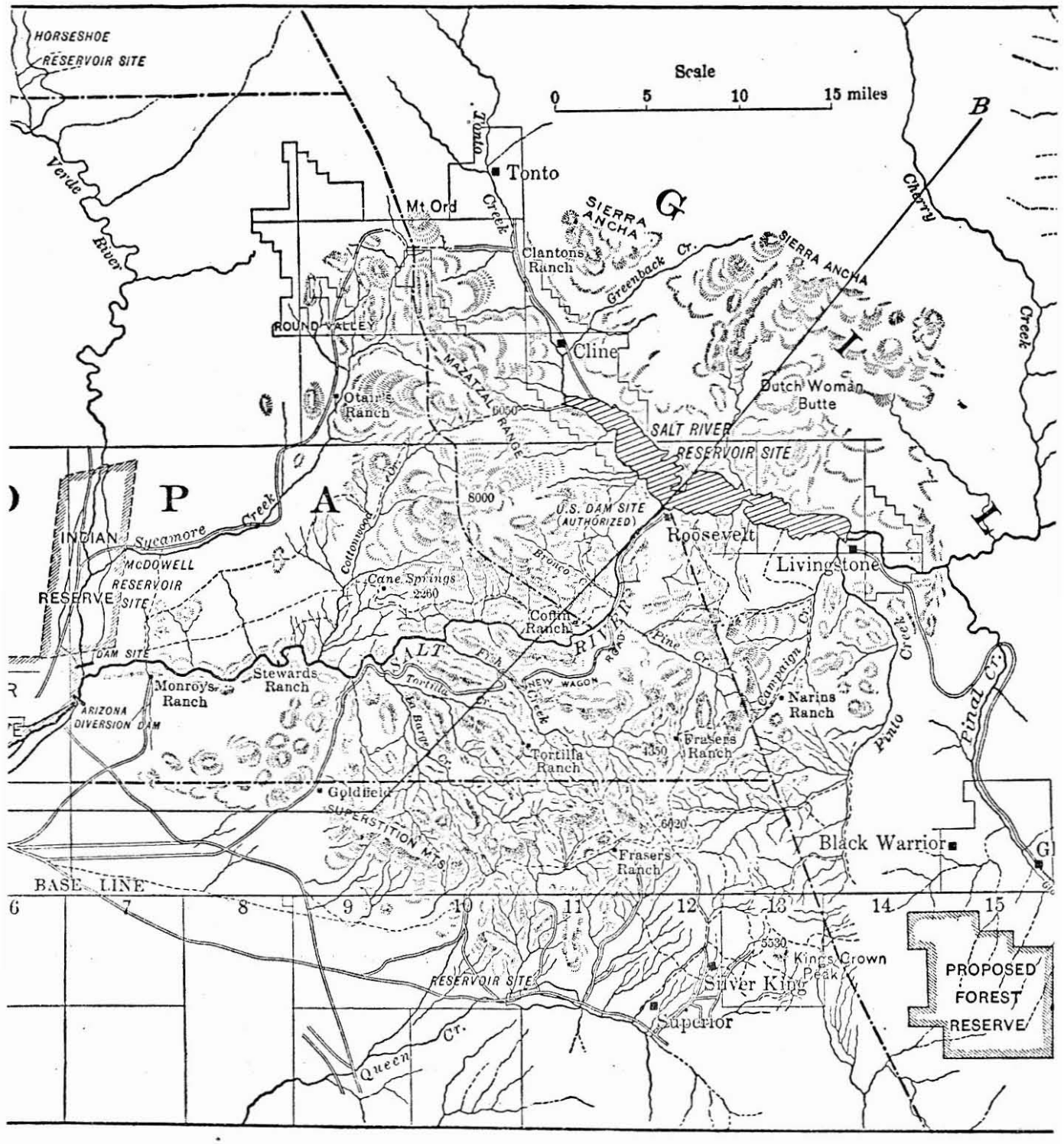
SIR: I forward herewith a report on the underground waters of Salt River Valley, Arizona, by Willis T. Lee, and recommend that it be published as a water-supply and irrigation paper.

Mr. Lee, under the direction of Mr. N. H. Darton, geologist in charge of the western section of hydrology, has made a detailed investigation of the underground waters and geology of Salt River Valley, in the Phoenix region and eastward, and I believe the results will be of value and interest to a large number of persons. The region is one in which the problem of water supply is of great importance, for its prosperity is entirely dependent upon the utilization of the surface and underground waters.

Very respectfully,

F. H. NEWELL,
Chief Engineer.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.



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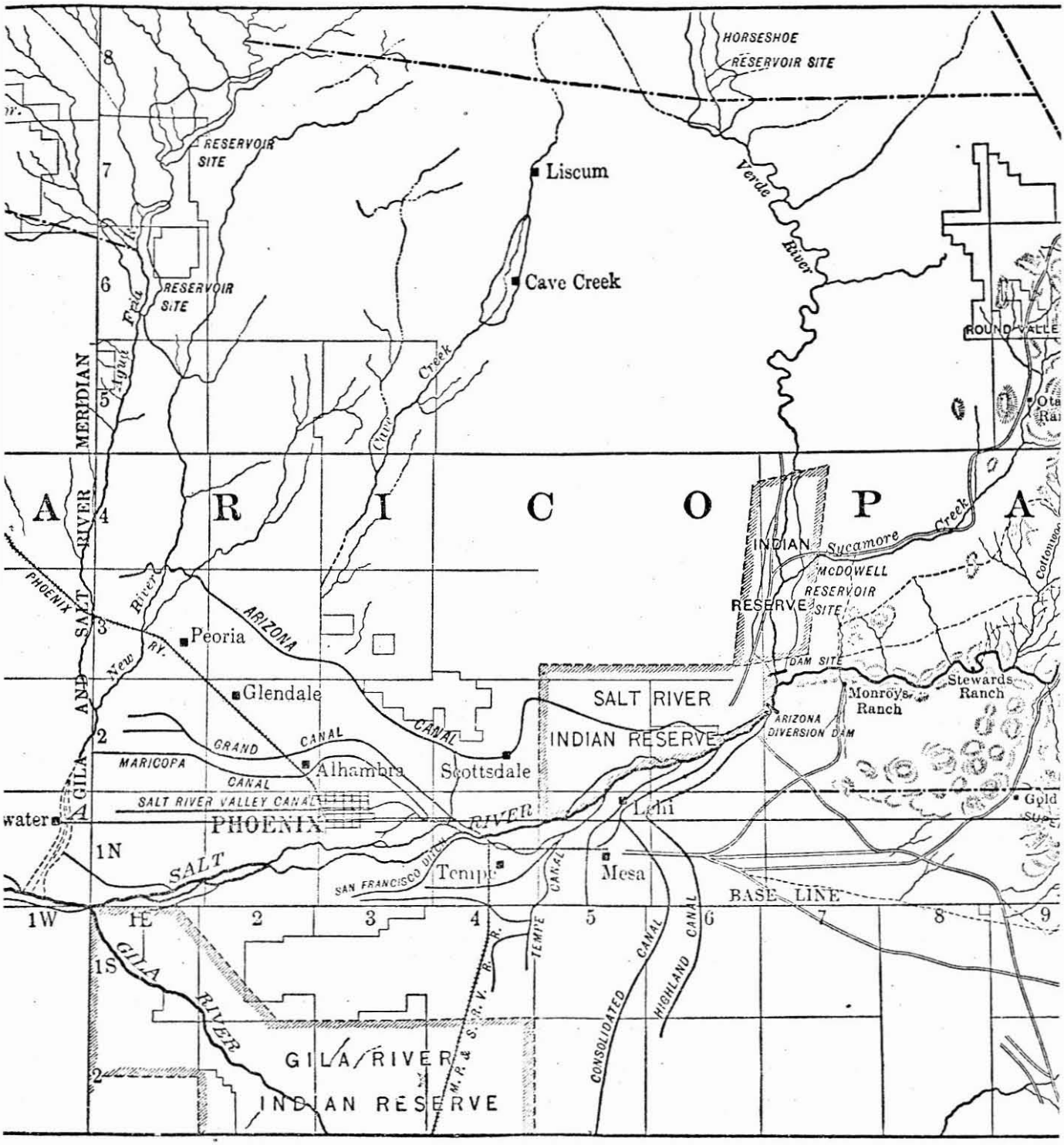

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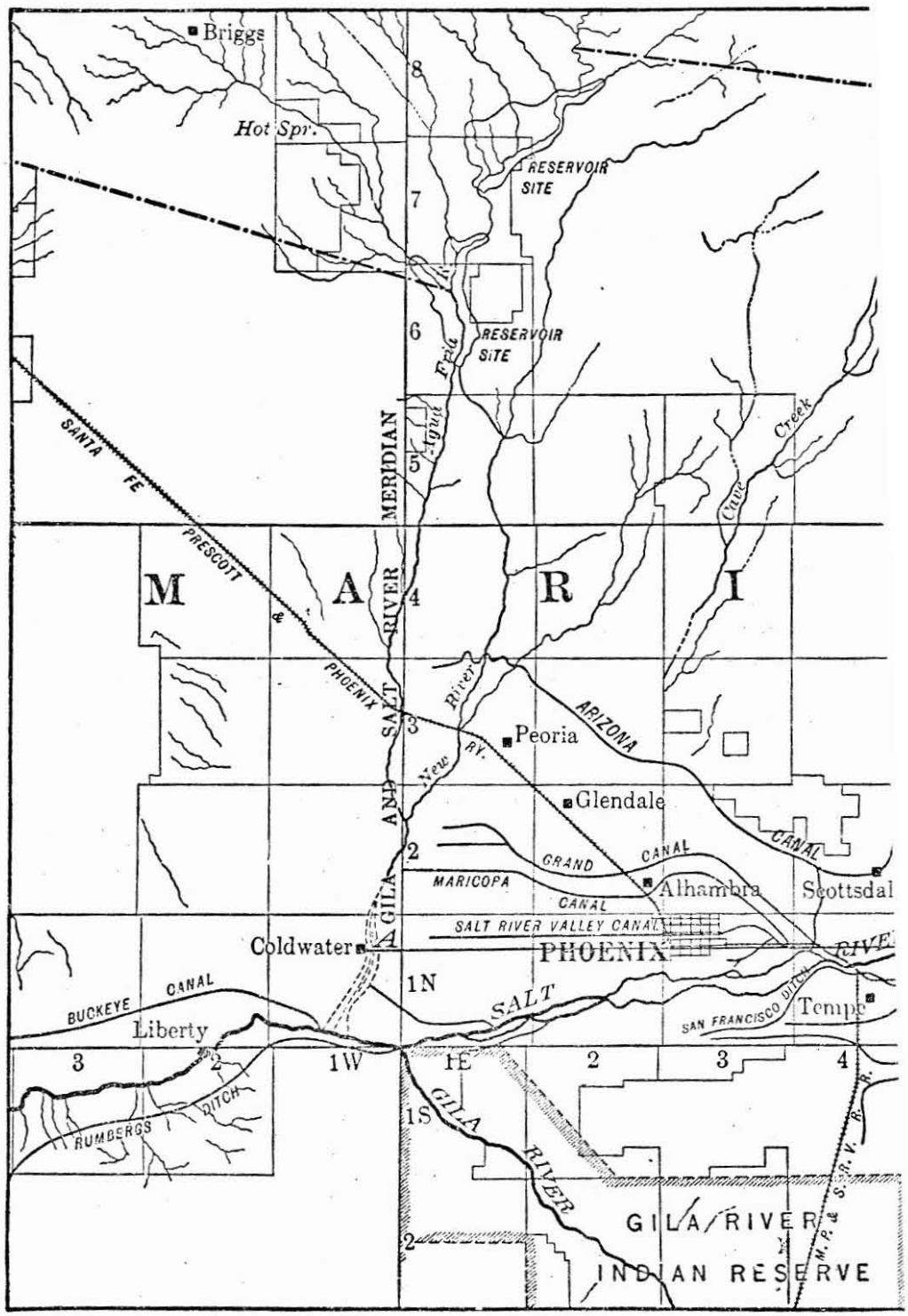
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Agua
Creek
Cave
SANTA FE PRESCOTT & PHOENIX
MERIDIAN
M A R I
SALT RIVER
AND GILA
River
New RV.
Peoria
ARIZONA
Glendale
CANAL
GRAND CANAL
MARICOPA CANAL
Alhambra
Scottsdal
SALT RIVER VALLEY CANAL
Coldwater
PHOENIX
RIVE
BUCKEYE CANAL
Liberty
SALT
SAN FRANCISCO DITCH
Tempe
RUMBERGS DITCH
GILA RIVER
GILA RIVER INDIAN RESERVE
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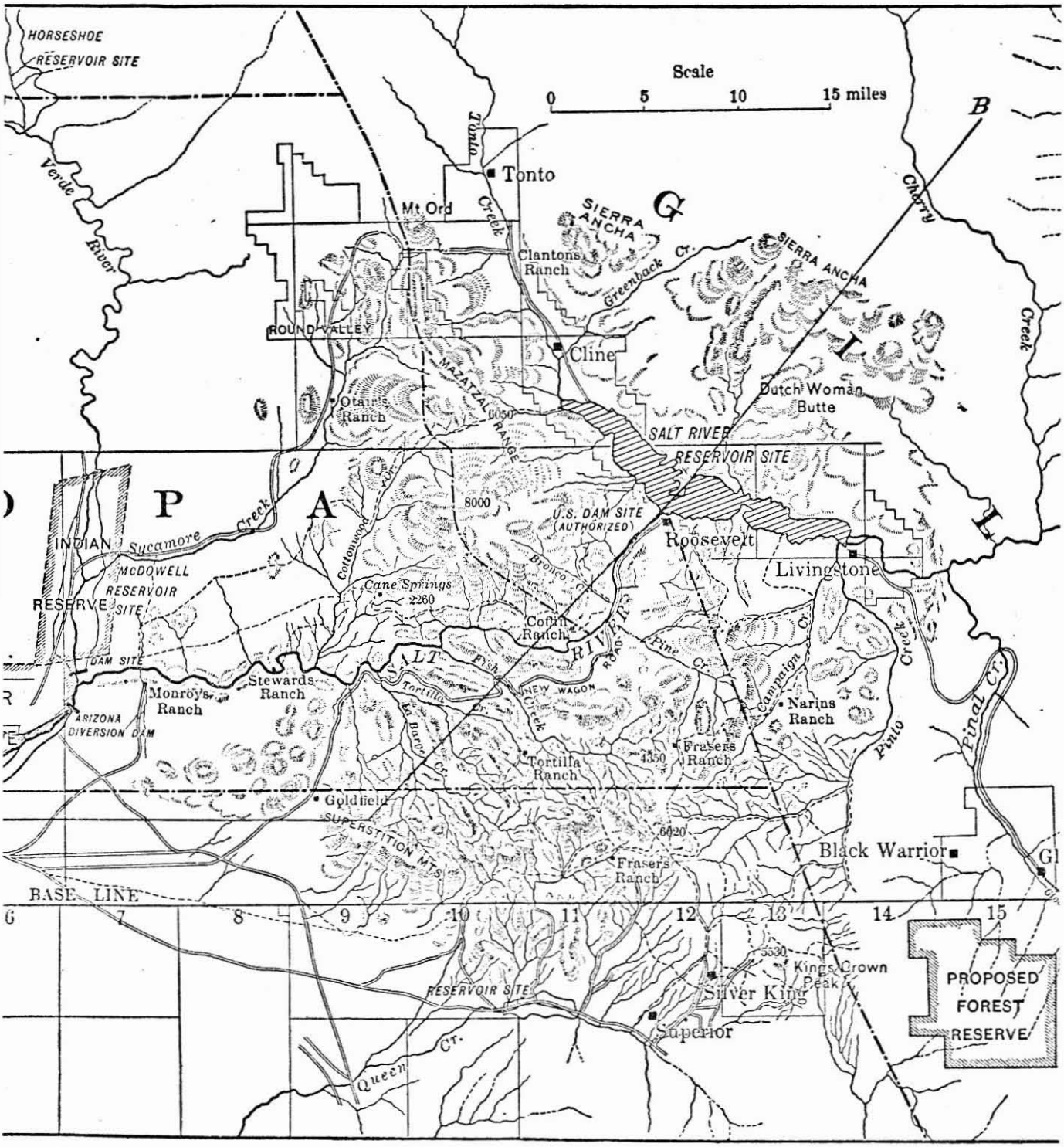

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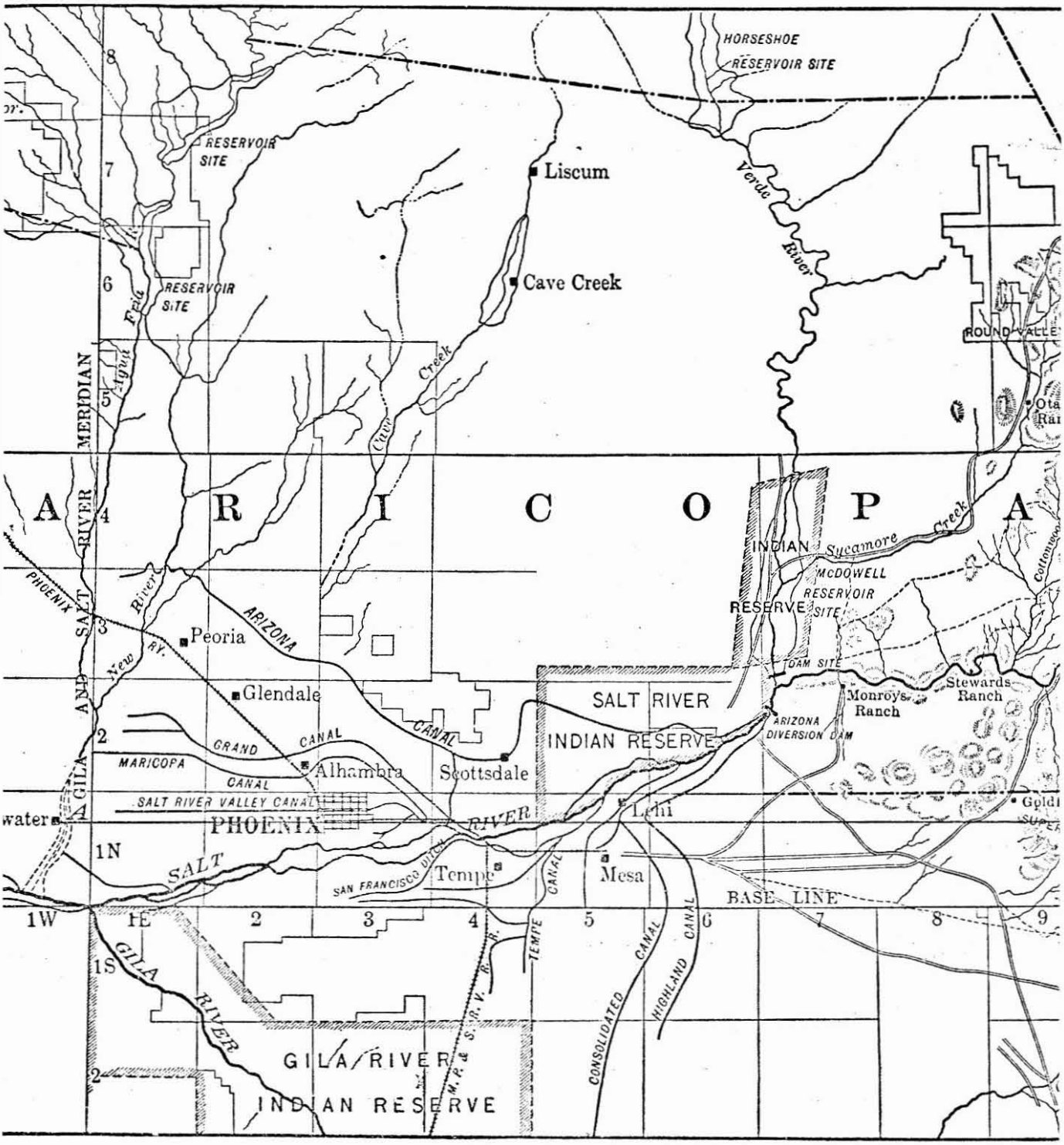

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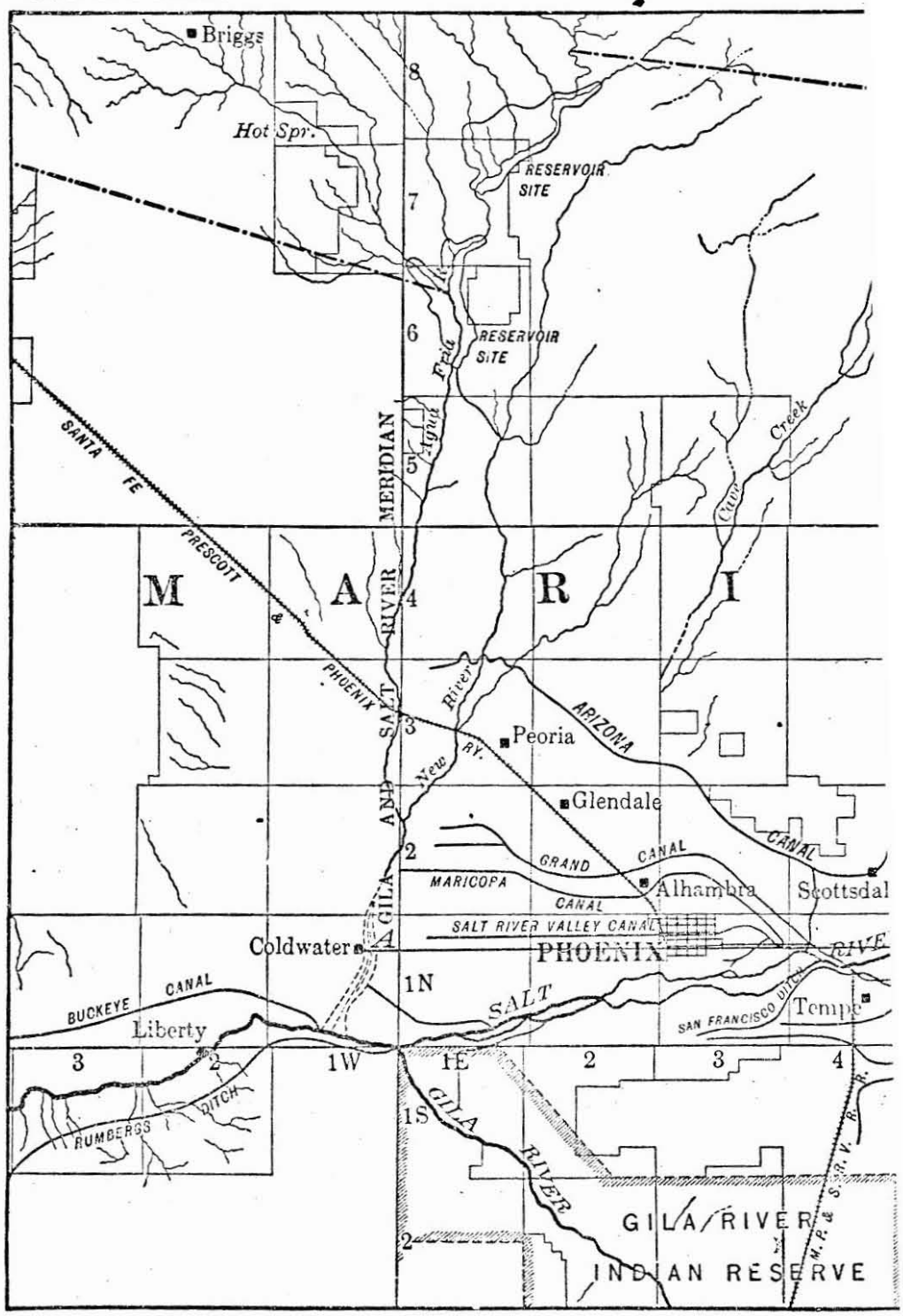
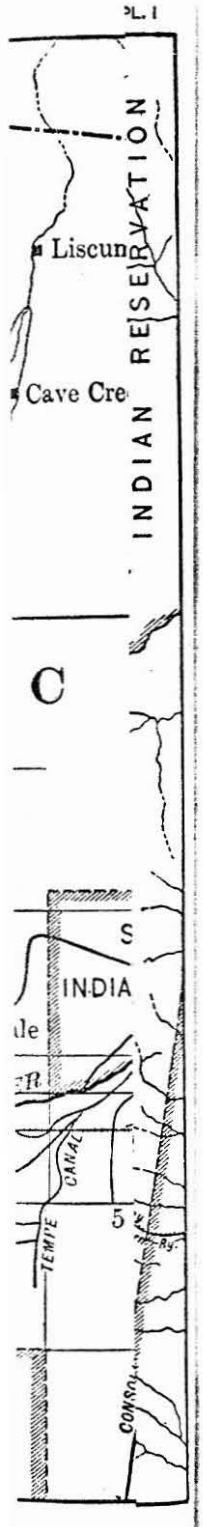




MAP C

UNDERGROUND WATERS OF SALT RIVER VALLEY, ARIZONA.

By Willis T. Lee.

INTRODUCTION.

PURPOSE OF THE INVESTIGATION.

The purpose of this paper is to bring together the facts, so far as known, regarding the underground waters of Salt River Valley, with a view to ascertaining their available quantity, the areas where they occur sufficiently near the surface for economic pumping, and their adaptability for irrigation.

The area of special investigation lies within a line drawn from the junction of Verde and Salt rivers westward a few miles beyond the Agua Fria and southward to Gila River; thence along the northern border of the Pima Indian Reservation to the Superstition Mountains north of Florence, and along the foot of these mountains to the mouth of Verde River—an area, irrespective of the mountains, of about 1,000 square miles. A number of side trips were made beyond this area into the neighboring mountainous districts, but the principal part of the work was done in the lowlands included within the above boundaries. This area is conveniently divided into two districts by a line of buttes that extends across the valley in the vicinity of Tempe, connecting the Phoenix Mountains with the Salt River Mountains. The physical conditions existent east of this line of buttes differ notably from those to the west of it. The division of the valley into two districts is therefore to more purpose than mere convenience of description. The first district, which extends from the mouth of the Verde to Tempe, is known as the Mesa region, and the second, which extends from Tempe to the Agua Fria, is known as the Phoenix region. (See Pl. I.)

CHAPTER I.

WELL RECORDS.

THE MESA REGION.

MURPHY-McQUEEN WELLS (SEC. 34, T. 1 N., R. 5 E.).

The series of deep wells first completed and used for irrigation in Salt River Valley is that on the Murphy-McQueen ranch, near the town of Mesa. This series of wells has been described by W. H. Code in two publications,[a] and his descriptions are here transcribed. In the first he writes:

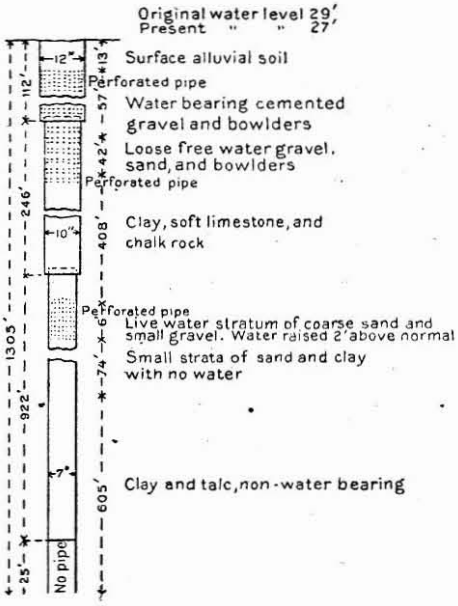


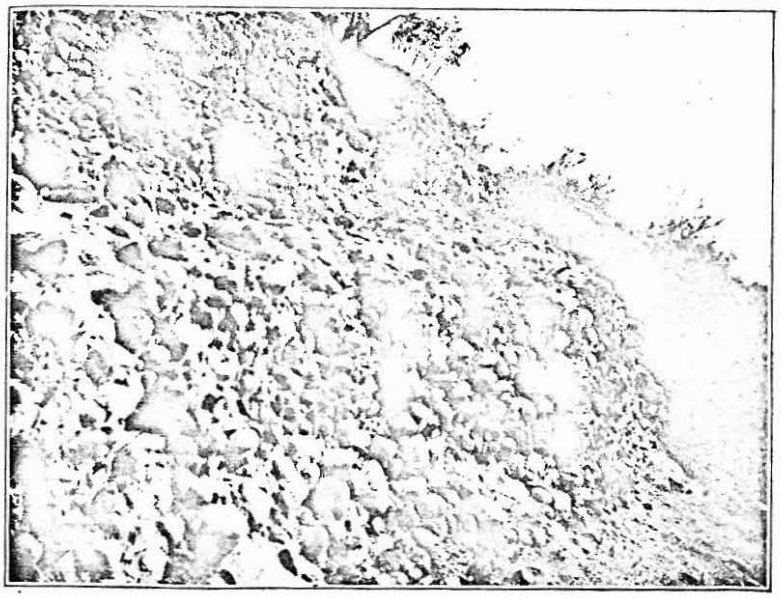
FIG. 1.—Bored well of S. J. Murphy, on Murphy-McQueen ranch, Mesa.

> The Murphy well (fig. 1) was started as a 12-inch double-steel-cased one, but on account of the great difficulties encountered in the way of bowlders and cement strata, together with a peculiar formation of clay known as the swelling variety, it has been necessary to reduce the size of the well three times in the depth of 1,305 feet, ending with a casing 7 inches in diameter.

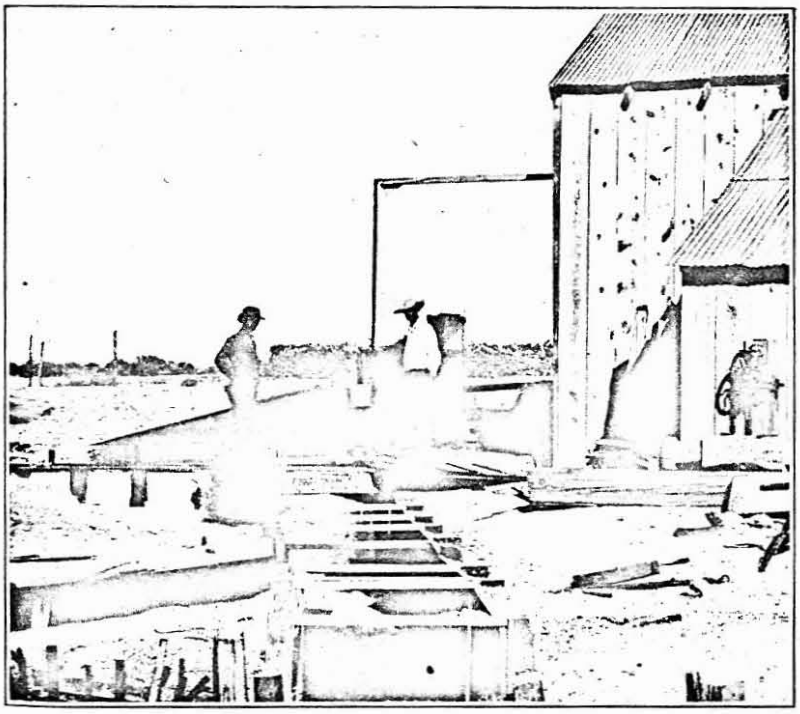
In the later and more complete report Mr. Code writes as follows:

> Four 12-inch bored wells were sunk on a line, with 12½-feet centers. The first one was put down 1,305 feet in the hope that an artesian flow might be obtained. As the drill was still in a nonwater-bearing stratum of clay and talc when this depth was reached it was decided, after having penetrated this stratum 605 feet, to abandon the search for artesian flow and depend upon pumps for raising the water. The remaining three wells, therefore, were drilled to a depth of approximately 212 feet, the formations intercepted being as follows:

[a] Code, W. H., Report of irrigation investigations for 1900. No. 2: U. S. Dept. Agric., Bull. 104, 1901, p. 93; Report of irrigation investigations for 1901. No. 1: U. S. Dept. Agric., Bull. 119, 1902, pp. 65-68.



A. EDGE OF THE MESA NEAR CONSOLIDATED CANAL COMPANY'S POWER PLANT.



B. A. J. HANSEN'S PUMPING PLANT.

Discharging 518 inches of water.

the common salt, although very abundant, could be washed out of the soil with comparative ease should it accumulate in too large quantities. The nitrates, so valuable in irrigation, are abundant. It is possible, as many believe, that the continued use of so saline an irrigation water for a series of years will prove harmful to the land, unless precautions are taken to prevent the accumulation of salts in harmful quantities. The quantity and kind of salt which may be present in irrigation waters depend so largely upon the physical and chemical composition of the land irrigated and upon the manipulation of that land that prediction is useless without a more extended knowledge of facts.

Analysis of water from E. Olsen's well.

Quantitative (parts in 100,000):	
Total solids soluble at 110° C.	381.00
Chlorine in terms of NaCl (common salt)	235.20
Hardness in terms of $CaSO_4$ (sulphate of lime)	59.84
Alkalinity in terms of Na_2CO_3 (black alkali)	.0
Nitrogen in the form of nitrates	2.00
Nitrogen in the form of nitrites	Faint.
Qualitative:	
Sulphates	Very strong.
Magnesia	Strong.
Lime	Very strong.
Bicarbonates	Very strong.

HANSEN WELLS (SEC. 35, T. 1 S., R. 4 E.).

Mr. A. J. Hansen's pumping plant is located about 10 miles south of Tempe. There are four 12-inch drilled wells, double-steel cased, 30 feet apart, and sunk to a depth of 200 feet. A central shaft containing a 12-inch horizontal centrifugal pump is sunk to water level. From this shaft tunnels communicate with the wells as explained for the Murphy-McQueen plant, and the wells are connected by a horizontal suction pipe. The pump is operated at the surface by steam power, connected by belt to the pump.

No satisfactory tests have been made on the capacity of the plant. The best measurements obtainable indicate a yield of about 518 inches (see Pl. IV, *B*), or something over 5,000 gallons of water per minute. Mr. Hansen is preparing to irrigate, in this way, his entire tract of something over 1,100 acres. At the present writing about 500 acres are supplied with pumped water.

When the pump is run at full speed, drawing from the four wells alike, the water level in the wells is lowered 9 feet 3 inches, making the total lift 26 feet 3 inches. When the water is drawn entirely from an end well, the others being shut off, the water level in that well is said to lower 18 feet, while in the well 90 feet distant it lowers 5 feet. The effect on the intervening wells was not determined.

In drilling the wells very little surface water was encountered, but at a depth of 76 feet water-bearing gravels and bowlders were encountered, from which the water rose 53 feet—that is, to 17 feet below the surface of the ground.

Log of A. J. Hansen's wells.

	Feet
Soil, sand, and cement	7
Hard cement	
Coarse sand, gravel, and bowlders, water bearing	1[illegible]

In the course of the drilling two circumstances were noted indicating the looseness of the water-bearing gravels. In drilling the last well it was noted that the water in the first one, 90 feet distant, moved in unison with the plunge of the sand pump. As the sand bucket with its massive attachments, descended, the water surface in the first well was agitated and moved slightly upward. As the sand bucket was withdrawn the water surface was lowered slightly, maintaining a churning motion in unison with the drill. The second circumstance was noted in connection with sinking the casing. The casing is usually forced downward under heavy pressure by means of hydraulic jacks into the hole made by the sand pump. In Mr. Hansen's well the gravels were so loose that the casing settled into them of its own weight and had to be held back to prevent it from settling faster than desired.

Three analyses have been made of water from these wells, the first taken January 2, 1903, and the second March 2, 1903, before any extensive pumping had been done. A third analysis was made May 14, 1904, after the pump had been in constant operation for about five months.

Analyses of water from A. J. Hansen's wells.

	No. 1.	No. 2.	No. 3.
Quantitative (parts in 100,000):			
Total solids soluble at 110° C	509.0	446.8	442.[illegible]
Chlorine in terms of NaCl (common salt)	355.0	307.0	311.[illegible]
Hardness in terms of $CaSO_4$ (sulphate of lime)	60.9	135.4	151.[illegible]
Alkalinity in terms of Na_2CO_3 (black alkali)	.0	.0	.[illegible]
Nitrogen in the form of nitrates	.....	Faint.	Trace
Nitrogen in the form of nitrites	.....	Faint.	.[illegible]
Qualitative:			
Sulphates	Very strong.	Very strong.	Very strong.
Magnesia	Very strong.	Very strong.	Strong.
Lime	Very strong.	Very strong.	Very strong.

water was encountered, but
s and bowlders were encoun
–that is, to 17 feet below the

wells.

	Feet
.....	7
.....	4
.....	12

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onstant operation for about

Hansen's wells.

	No. 2.	No. 3.
9.0	446.8	442.0
5.0	307.0	311.0
0.9	135.4	151.2
.0	.0	.0
....	Faint.	Trace
....	Faint.	.0
ng.	Very strong.	Very strong
ng.	Very strong.	Strong
ng.	Very strong.	Very strong

TEMPE CANAL COMPANY'S WELLS (SEC. 19, T. 1 N., R. 4 E.).

The Tempe Canal Company has undertaken the construction of a large pumping plant, designed to augment the water supply of the Tempe canal. A battery of ten 15-inch wells is planned. Two of these are completed at the present writing. The wells are 50 feet apart, and will be operated from a central station. It is expected that the ten will yield 1,000 inches of water. It is the purpose of the company to increase the output to 3,000 inches, if water is found in sufficient quantity to warrant such expansion.

The pumps will be so placed as to discharge the water into the Tempe canal, thus mixing the pumped water with the river water and distributing it uniformly.

The material encountered in these wells differs notably from that in neighboring wells in the absence of the great number of bowlders. The material is described as sand and gravel rather than as gravel and bowlders, as in other wells, and the lower 33 feet is clay.

Log of Tempe Canal Company's wells.

	Feet.
Soil	10
Sand and gravel	157
Clay	33

VALLEY SEEDLESS GRAPE COMPANY'S WELLS (SEC. 4, T. 1 S., R. 4 E.).

The company's vineyard is situated about 4 miles south of Tempe. There are two 12-inch drilled wells, one at the southern end of the vineyard, 348 feet deep, and one at the northern end, 250 feet deep. In the 250-foot well water-bearing gravels were encountered at a depth of about 190 feet. The water from the gravel bed rose to a level 18 feet below the surface of the ground. The 348-foot well is on higher land and the water level is 30 feet below the surface. No careful driller's record was kept, but the foreman in charge reported that the material passed through was a mixture of sand, clay, and cement to a depth of about 120 feet. At this depth sands and gravels begin and alternate with granitic wash to a depth of about 300 feet. No water worthy of mention was found until a bed of gravel 9 feet thick was encountered at a depth of about 275 feet. Below the 300-foot level the material is granitic wash down to 340 feet, where hard red granite was found. The well penetrates the granite 8 feet.

The 250-foot well is not in use at the present time. The 348-foot well is operated to irrigate the vineyard by a centrifugal pump placed in a shaft sunk to near water level and operated by a 12-horsepower gasoline engine. The water is pumped into a small cement reservoir from which it is distributed for irrigation.

Repeated efforts were made to secure measurements in a test run of this plant for the purpose of computing the cost of water thus obtained. In the meantime Prof. S. M. Woodward, of the Arizona Experiment Station, working independently to the same end, obtained measurements which he has kindly allowed me to use. The test run consumed 1.5 hours, the quantity of water pumped during that time being measured in the cement reservoir and the rate per second computed. The water in the well was lowered 11.5 feet when the pump started and remained constant during the run. The water was lifted 5.5 feet above the level of the ground, making a total lift of 47 feet. The plant is still in an experimental stage and certain easily remedied faults in construction will reduce the cost given below. Owing also to these imperfections, the liability to error in measurements is needlessly great. Those taken by Professor Woodward are probably as accurate as can be obtained at the present time. The original cost of the plant could not be obtained and attendance is not included in the following computations:

Cost of pumping water at the Valley Seedless Grape Company's vineyard.

Rate of discharge in cubic feet per seconds	1.15
Distillate consumed per hour, in gallons	1.6
Time to pump 1 acre-foot, in hours	10.52
Distillate consumed per acre-foot of water pumped, in gallons	16.83
16.83 gallons of distillate, at 22 cents	$3.70
Oil and incidentals	$0.05
Total cost per acre-foot	$3.75
Lift in feet	47
Average cost per foot in raising an acre-foot	$0.08

Analyses of water from the Valley Seedless Grape Company's wells.

	348-foot well.	250-foot well.
Quantitative (parts in 100,000):		
Total solids soluble at 110° C	155.8	115.[illegible]
Chlorine in terms of NaCl (common salt)	105.4	78.[illegible]
Hardness in terms of $CaSO_4$ (sulphate of lime)	21.8	11.[illegible]
Alkalinity in terms of Na_2CO_3 (black alkali)	.0	.0
Qualitative:		
Sulphates	Strong.	Strong
Magnesia	Pronounced.	Pronounced
Lime	Strong.	Strong

TEMPE WATERWORKS WELLS.

The town of Tempe is supplied with water from three 12-inch double-steel-cased wells, 152 feet, 147 feet, and 145 feet deep, respectively. The water-bearing gravels were entered at a depth of 12 feet

easurements in a test run of
cost of water thus obtained.
of the Arizona Experiment
me end, obtained measure-
se. The test run consumed
uring that time being meas-
per second computed. The
hen the pump started and
water was lifted 5.5 feet
total lift of 47 feet. The
nd certain easily remedied
given below. Owing also
r in measurements is need-
Woodward are probably as
time. The original cost of
lance is not included in the

Grape Company's vineyard.

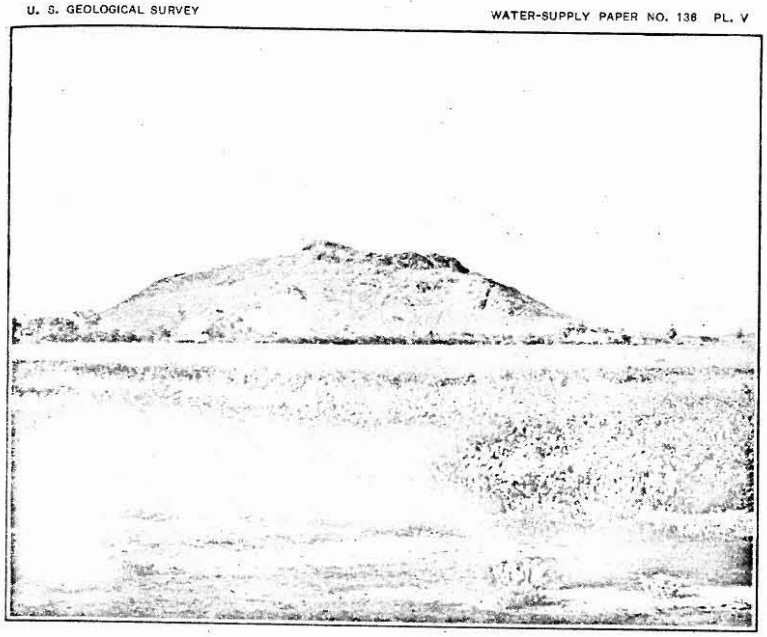
.....	1.15
.....	1.6
.....	10.52
ped, in gallons	16.83
.....	$3.70
.....	$0.05
.....	$3.75
.....	47
.....	$0.08

Grape Company's wells.

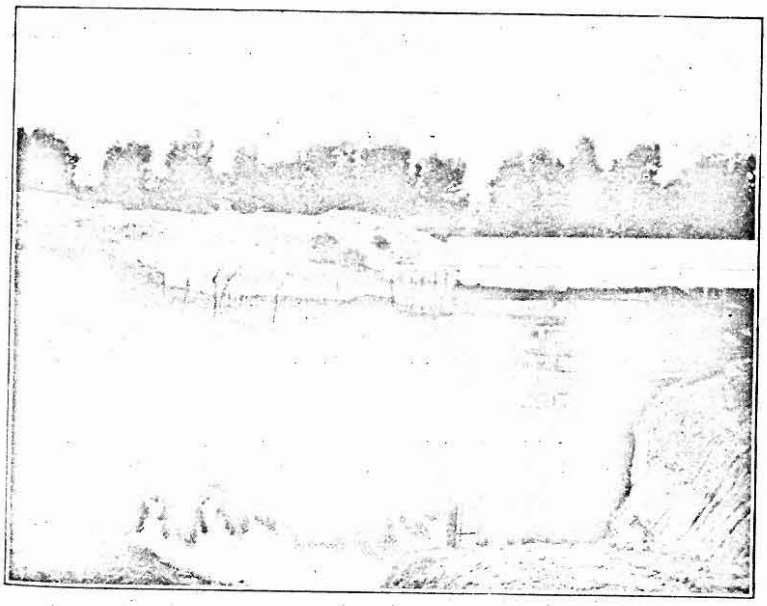
	348-foot well.	250-foot well.
..	155.8	115.2
..	105.4	78.6
..	21.8	11.4
..	.0	.0
..	Strong.	Strong.
..	Pronounced.	Pronounced.
..	Strong.	Strong.

WELLS.

water from three 12-inch
and 145 feet deep, respec-
ntered at a depth of 12 feet



A. TEMPE BUTTE, SHOWING RESERVOIR NEAR THE TOP.



B. COLLINS WELL, NEAR PHOENIX.

and the surface of the water at 23 feet. The water is under no pressure and is not capped by an impervious clay, as it is in most places throughout the valley.

The plant is a well-equipped one, with a shaft 20 by 20 feet, sunk 15 feet, and containing a Goulds triplex single-acting pump and 30-horsepower electric motor. The three wells are connected by a horizontal suction pipe, from which a vertical suction pipe extends into each well, inside the casing. The water is forced to a reservoir near the top of Tempe Butte, making a total lift of 249 feet. (Pl. V, *A*.)

It is especially worthy of note that at Tempe the water-bearing gravels extend practically to the surface, the shallow wells reaching the same water body from which the deep wells draw. This is not the case 1 mile south of Tempe at H. L. Chandler's well, where the surface waters are separated from the waters of the great bowlder bed by impervious clay. Analyses of water from the deep wells and from shallow wells near by indicate the same kinds of salts in both the shallow and deep wells, but show varying amounts. The following analyses are from wells only a few blocks apart. The town well is perforated only below 90 feet, and the water analyzed from this well is presumably from that depth. The others are from wells about 30 feet deep.

Log of Tempe waterworks well.

	Feet.
Surface soil	4
Clay and bowlders	6
Clay, sand, and bowlders, cemented	2
Loose sand, gravel, and bowlders, water bearing	117
Igneous rock	23

Analyses of water from wells at Tempe, Ariz.

	City waterworks; 152 feet.	Casa Loma Hotel.	Normal School; 30 feet.
Quantitative (parts in 100,000):			
Total solids soluble at 110° C	103.0	169.8	219.2
Chlorine in terms of NaCl (common salt)	58.8	105.8	133.6
Hardness in terms of $CaSO_4$ (sulphate of lime)	9.52	12.9	15.78
Alkalinity in terms of Na_2CO_3 (black alkali)	.0	.0	.0
Nitrogen in the form of nitrates	.17	.18	.51
Nitrogen in the form of nitrites	.0	.0027	.0
Qualitative:			
Sulphates	Strong.	Very strong.	Very strong.
Magnesia	Strong.	Pronounced.	Very strong.
Lime	Strong.	Very strong.	Very strong.

At the request of the writer, Mr. P. E. Fuller, the engineer under whose direction the pumping plant was constructed, made a careful test of the quantity of water pumped, power consumed, etc. Mr. Fuller has been kind enough to put the observations in the tabular form given below:

Test of pumping plant of Tempe city waterworks, August 2, 1903.

READINGS.

Time.	Voltage between phases.	Total amperes.	Pressure gage.	Vacuum.	Watt meter, one phase.	Revolutions of pump; 6¼ gallons per revolution.	Velocity watt meters per minute.	Difference between gages.
			Pounds.	*Inches.*				
4.20[a]	175.0	170	99	15.25	1,747,200	810.310	37.00	3.33
4.40	177.5	170	99	15.25	1,747,700	811.221	.....	3.33
4.50	182.5	170	99	15.25	1,748,050	811.623	34.50	3.33
5	172.5	170	99	14.75	1,748,320	812.056	34.50	3.33
5.10	165.0	170	99	14.75	1,748,580	812.487	35.50	3.33
5.20[b]	152.5	172	99	14.50	1,748,830	812.848	33.50	3.33
Total	170.83	170.33	99	14.96	1,630 kw.	2,538 rev.	35.00	3.33

[a] Running start was made; watt meter was 37.3 per cent fast, volt meter was 1 per cent low—for all readings of watts and voltage.
[b] Low readings due to low voltage at power house.

DEDUCTIONS.

Average voltage corrected for error		172.55
Average amperes in both phases		170.33
Apparent energy consumed by motor	kilowatts	29.39
Actual energy consumed	do	23.51
Power factor	per cent	80.00
Horsepower actually consumed by motor		31.51
Average gallons of water pumped per minute		274.95
Total head, in feet, pumped against		248.87
Net water horsepower		18.49
Combined efficiency of motor, pump, suction piping, and ¾-mile 8-inch main	per cent	58.68
Power rate paid per thousand gallons pumped	cents	4
Equivalent cost per horsepower per hour and per kilowatt per hour	do	2.13 2.85

Reducing the figures to the basis of cost per acre-foot of water lifted, we have the following:

Cost of pumping water at the Tempe, Ariz., waterworks.

Cost of plant (not including the reservoir and distributing system)	$3,700.00
Interest on investment at 7 per cent per annum for 19.8 hours	$0.59
Depreciation at 10 per cent per annum for 19.8 hours	$0.84
Hours to pump 1 acre-foot	19.8
Cost of power to raise 1 acre-foot (power furnished at 4 cents per 1,000 gallons of water pumped)	$13.07
Oil and incidentals (estimated)	$0.05

Total cost per acre-foot	$14.55
Total lift in feet	249
Average cost per foot in lifting 1 acre-foot of water	$0.058

CHANDLER WELL (SEC. 21, T. 1 N., R. 4 E.).

Mr. H. L. Chandler proposes to establish a pumping plant for irrigation about 1 mile south of Tempe. Two 12-inch double-steel-cased wells were started, but accidents have caused a discontinuance of the work. One well, however, reached a depth of 186 feet, and the record, furnished by the driller, is given herewith. The well is in water-bearing gravels and bowlders throughout nearly the entire depth. There seem, however, to be two distinct bodies of bowlders separated by 8 feet of clay. The upper or surface water is alkaline, from which the lower water is probably free, as is the case in other wells of the region. The lower water was struck at a depth of 41 feet below the surface. An unusually large number of heavy bowlders were encountered in these wells, making the drilling a matter of some difficulty, but at the same time indicating a comparatively free passage for the underflow. It is in the beds of coarse gravels and bowlders that the greatest available quantity of water is to be expected.

Log of H. L. Chandler's well.

	Feet.
Soil and cement	11
Gravel and bowlders, water bearing	22
Clay	8
Gravel and bowlders, water bearing	145

A sample of the water was taken for analysis from near the bottom of the well, the water being obtained from the sand pump as the bucket was hoisted. The sample is not therefore representative of the water at this locality. The alkali is probably from water of the upper stratum. Samples of water taken in this way from other wells which were afterwards cleared by pumping show a greater proportion of salts than samples taken after pumping. The analysis, however, is here given for the sake of completeness and for the purpose of indicating something of the quantity of salts contained in the waters of this locality.

Analysis of water from H. L. Chandler's well.

Quantitative (parts in 100,000):	
Total solids soluble at 110° C.	224.00
Chlorine in terms of NaCl (common salt)	146.00
Hardness in terms of $CaSO_4$ (sulphate of lime)	.00
Alkalinity in terms of Na_2CO_3 (black alkali)	2.12
Qualitative:	
Sulphates	Very strong.
Magnesia	Very strong.
Lime	Strong.

are 180 feet deep, and penetrate the gravel and bowlders common i that region. It is worthy of note that clay and granitic wash we found beneath the bowlders.

Log of well of B. F. Johnson, near Mesa, Ariz.

	Fe
Soil	1
Sand, gravel, and bowlders	12
Clay	[illegible]
Granitic wash	[illegible]

TEMPE-MESA PRODUCE COMPANY'S WELL (SEC. 23, T. 1 N., R. 4 E.

The company has recently established a pumping plant at it creamery near Tempe. There is one 12-inch double-steel-cased wel 100 feet deep. As indicated in the log it is in loose gravel an bowlders through practically the whole depth.

Log of Tempe-Mesa Produce Company's well.

	Feet
Soil	1
Gravel and bowlders	9

DESERT WELL (SEC. 11, T. 1 S., R. 7 E.).

This well is located about 15 miles southeast of Mesa, on the road leading from Mesa to Florence, and is owned at the present time by Thomas Buchanan. The well, which was dug in 1885, is 212 feet deep and contains 24 feet of water. On a platform near the surface of the water is a pump and small steam engine, supplied by steam generated above ground, which lifts water at the rate of 25 gallons per minute. The surface of the water is lowered 10 feet by the pump, at which stage the inflow equals the demand of the pump.

Log of Desert well.

	Feet.
"Wash" (sand, pebbles, clay, and cement)	150
Sand	[illegible]
Cement	20
Sand and gravel	5
Cement	[illegible]
Water-bearing gravel	[illegible]

The material penetrated in digging the well varies little in the 188 feet exposed above the water. The sides are not cased, except in three places where loose sand was encountered. The material is "wash" from the hills. It is an intimate admixture of clay, sand, and pebbles more or less cemented in places by caliche. The pebbles are angular and give slight indication of the action of water. Although the sides of the well are not protected in any way, they have stood for eighteen years without material change. Little moisture reaches them from the surface, and no water-bearing seams were encountered until near the

bottom. At a depth of 212 feet a cement layer was penetrated and water encountered under sufficient pressure to raise it 24 feet.

Mr. Buchanan reports that the water has been steadily rising in the well for eight years—ever since he has owned the well. Even during the exceptionally dry years of 1901 and 1902, when many of the shallower wells of the valley entirely failed, the water in Desert well steadily increased in volume. This increase is somewhat vividly indicated by the present position of the engine and pump in the well. When placed there the platform upon which they rest was built at a convenient distance above the surface of the water. At the time of my visit the water was 3 feet deep over the platform and the engine and pump were submerged.

The quantity of water does not appear to be such as to warrant the supposition that this well draws from the great gravel beds furnishing the principal flow in the wells farther west. Twenty-five gallons per minute is a small volume compared with that yielded by some of the wells, and yet this yield lowers the water in Desert well about 10 feet. The quality of the water as shown by the following analysis and the elevation of the water 1,260 feet as against 1,134 in the Murphy-McQueen well renders it probable that the stratum from which the desert well draws its supply is connected with what is known as the surface flow of the valley rather than with the deeper and larger flow. In order to strike the level of the water-bearing gravels which supply the water for the large pumping plants of the valley Desert well would have to be lowered about 100 feet.

Analysis of water from Desert well.

Quantitative (parts in 100,000):	
Total solids soluble at 110° C.	32.00
Chlorine in terms of NaCl (common salt)	5.20
Hardness in terms of $CaSO_4$ (sulphate of lime)	.00
Alkalinity in terms of Na_2CO_3 (black alkali)	4.66
Nitrogen in terms of nitrates	.494
Nitrogen in terms of nitrites	Very faint.
Qualitative:	
Sulphates	Faint.
Magnesia	Very faint.
Lime	Faint.
Bicarbonates	None.

KLEINMAN WELL (T. 2 S., R. 9 E.).

Mr. Daniel Kleinman's well is about 10 miles southeast of Desert well and 25 miles southeast of Mesa, on the Mesa-Florence road. It was dug to a depth of 272 feet, and from the bottom a 14-inch pipe was driven 12 feet, making the total depth 284 feet. The log of the well could not be obtained. The quantity of bowlders taken from the well, however, indicates that bowlder and gravel beds make up a large

Throughout the Mesa region, wherever special inquiry was m it was found that the surface of the underground water has been tinually lowering for years. Wells which were formerly produ throughout the year are now dry for a part or all of the year. W few exceptions the wells have been lowered in order to obtain cient water. This lowering of the water has been progressive wells have been deepened repeatedly. In the vicinity of Tempe water has lowered about 7 feet. Near Mesa it has lowered m more. According to Code's[a] measurement in 1901, the normal w level at the Murphy-McQueen pumping plant was 22.5 feet below land surface (see fig. 2, p. 14). On January 19, 1904, this level found at the same place to be 34 feet below the land surface. certain places the lowering is reported as 20 feet or even more.

While the underground water supply of the valley has been decr ing for a number of years, there are yearly variations depending m or less directly upon the abundance of surface waters. Certain w are dry during the dry seasons and contain water during the sea of more abundant supply. The term "rainy season" is purpo avoided, the seasons of more abundant surface waters being thos which an increased supply enters the valley in streams. The rain the valley itself are so slight that they have no effect that can detected in the wells.

THE PHOENIX REGION.

PHOENIX WATER COMPANY'S WELLS.

Previous to 1902 the city of Phoenix was supplied with water fr two dug wells, 42 feet deep, which had, when measured, 10 feet water. During the exceptionally dry season of 1902 the water in th wells failed and three 12-inch double-steel-cased wells were drille a depth of 208 feet. An abundant water supply was found at a de of 55 feet, and thence downward to 208 feet were continuous wa bearing gravels and bowlders. The water from the open wells co from the upper gravels indicated in the log, and that from the dri wells comes from the lower gravels. At the time of my visit to plant water from one open well and one drilled well was supplying city at the rate of about 1,750 gallons per minute. It is said that of the drilled wells alone has yielded water at this rate.

Log of well of Phoenix Water Company, near Phoenix.

Soil .....
Gravel and bowlders, water bearing .....
Clay and cement .....
Gravel and bowlders, water bearing .....

[a] Code, W. H., Report of irrigation investigations for 1901, No. 1: U. S. Dept. Agric., Bull. 11 p. 67.

Unfortunately there was no opportunity of obtaining satisfactory pumping tests at this plant. The amount named, 1,750 gallons per minute, is estimated from the time it takes to fill the standpipe.

As in the case of the well at the asylum and other wells to be described later there is no marked difference between the upper and lower water bodies, although the two are separated by 7 feet of clay and cement. No. 3, in the table below, is an analysis of water from the upper water body and No. 4 from the lower body. The samples were taken directly from the wells at a time when the pumps were in operation.

Much interest is taken by the water users of the valley in the supposed improvement in the quality of the water as the wells are used. Reference has been made to such an improvement in case of the Chandler wells and others. Four analyses of the Phoenix city supply have been made, as indicated below. The three analyses representing the shallow wells extend over a period of about 5.5 years. Since this water supplies the city the draft on the wells is constant, and if use will materially improve the quality of wells, this water should show an improvement. On the contrary, the latest analyses indicate a marked increase in the quantity of soluble salts.

Analyses of water from the Phoenix Water Company's wells.

	1. Dug well, Sept. 18, 1898.	2. Dug well, May 9, 1902.	3. Dug well, May 14, 1903.	4. Drilled well, May 14, 1903.
Quantitative (parts in 100,000):				
Total solids soluble at 110° C	116.8	102.4	136.00	132.00
Chlorine in terms of NaCl (common salt)	72.5	54.6	80.80	77.60
Hardness in terms of $CaSO_4$ (sulphate of lime)	Strong.	8.98	6.53	5.44
Alkalinity in terms of Na_2CO_3 (black alkali)	.....	.....	.00	.00
Nitrogen in the form of nitrates	.10	.16	.25	.25
Nitrogen in the form of nitrites	.0007	.0045	.02	Very faint.
Qualitative:				
Sulphates	.....	Very strong.	Pronounced.	Pronounced.
Magnesia	.....	Very strong.	Pronounced.	Pronounced.
Lime	.....	Very strong.	Strong.	Strong.
Bicarbonates	.....	.....	Strong.	Very strong.

PHOENIX LIGHT AND FUEL COMPANY'S WELL.

This company has a single 12-inch double-steel-cased well at t power house in Phoenix. The well is 194 feet deep, with water at depth of 31 feet. Below a depth of 46 feet, 16 feet of clay and ceme occur. Otherwise, throughout the entire depth of the water-beari portion, the material is coarse and wholly unconsolidated.

Log of Phoenix Light and Fuel Company's well.

	F.
Soil	
Gravel, water in the lower part	
Cement	
Clay	
Cement	
Quicksand	
Sand, gravel, and bowlders, water bearing	1

A shaft has been sunk to near water level and cemented to exclu any moisture from without. At the bottom of this shaft is placed t centrifugal pump and 50-horsepower electric motor. The water used for condensing steam in the power house, after which it is us for irrigation.

A careful pumping test was made at this plant under the directi of Mr. D. W. Beldon, the engineer in charge, with results given belo It will be noted that in this case a single 12-inch well is yielding 1,9 gallons of water per minute continuously, with a local depression the water table of little more than 16 feet.

Report of test on electrically driven centrifugal pump for irrigation.[a]

[Test made January 10, 1904, by D. W. Beldon, electrical engineer.]

Motor (3 phase; 350 volt; 60 cycle) speed	r. p. m.	7
Pump (direct-connected centrifugal; 10-inch suction; 8-inch discharge) r. p. m		7
Height; pump center above water (still)	feet	
Vacuum; pump running	inches	
Water lowered by pump running (22 feet − 5⅓ feet)	feet	1
Head above vacuum gauge	do	
Total head (less friction and velocity of discharge)	do	
Water pumped per minute	cubic feet	2
Total power absorbed by motor	kilowatts	3
Kilowatt hours required per acre-foot		10
Cost of power per acre-foot (2 cents per kilowatt hour)		$2.
Cost of power per acre-foot (per foot of lift)		$0.0

PERKINS WELL (SEC. 23, T. 2 N., R. 3 E.).

Mr. C. W. Perkins has a 10-inch drilled well 155 feet deep. T water surface is 83 feet below the surface of the ground. The well

[a] This report did not reach the writer in time to be included in the computations of cost deser in the following chapters. The cost does not differ materially from that of other well-equi pumping plants.

L COMPANY'S WELL.

double-steel-cased well at th
194 feet deep, with water at
feet, 16 feet of clay and cem
tire depth of the water-bearin
olly unconsolidated.

uel Company's well.

	Fe
.....	1
.....	2
.....	.
.....	1
.....	
.....	
.....	12

level and cemented to exclud
ottom of this shaft is placed th
electric motor. The water i
er house, after which it is use

t this plant under the directio
harge, with results given below
le 12-inch well is yielding 1,99
usly, with a local depression o
eet.

trifugal pump for irrigation.[a]

Beldon, electrical engineer.]

.....r. p. m..	72
suction; 8-inch discharge)	
.....	72
.....feet..	5
.....inches..	2
feet) .....feet..	16
.....do....	.1
rge) .....do....	4
.....cubic feet..	2
.....kilowatts..	38.
.....	105
tt hour).....	$2.1
.....	$0.051

, T. 2 N., R. 3 E.).

illed well 155 feet deep. Th
ace of the ground. The well

luded in the computations of cost descril-
naterially from that of other well-equip

tuated at Mr. Perkins's olive-oil factory, and the water is used for rigating his olive and orange orchards during dry times when ditch ater can not be obtained. The distance through which the water st be raised (a minimum of 83 feet) prohibits its economic use cept as a last resort. Before the well was put down the lack of ter in the irrigation canals at critical times caused serious damage the fruit and even the death of a large number of trees. Costly as is to pump from such a depth, water at a critical time is worth much re than it costs in saving valuable crops that might otherwise be jured or wholly destroyed. The well yields about 200 gallons per inute. The water is lifted by means of a deep-well pump, operated a gasoline engine.

Analysis of water from C. W. Perkins's well.

antitative (parts in 100,000):	
Total solids soluble at 110° C.	83.60
Chlorine in terms of NaCl (common salt)	30.80
Hardness in terms of $CaSO_4$	8.30
Alkalinity in terms of Na_2CO_3	.00
Nitrogen in the form of nitrates	.53
Nitrogen in the form of nitrites	.871
alitative:	
Sulphates	Very strong.
Magnesia	Strong.
Lime	Strong.

PHOENIX MACHINE AND COLD STORAGE COMPANY'S WELL.

The well is located at the company's factory in Phoenix, and was t down in December, 1903. It is a 12-inch double-steel-cased well 25 feet deep. Only 5 feet of fine material was encountered at the rface, all below this being entirely loose sand, gravel, and bowlders. Water is raised by means of a deep-well cylinder pump, but since no reat supply is required the capacity of the well is not known.

Log of Phoenix Machine and Cold Storage Company's well.

	Feet.
l	5
l and bowlders slightly cemented	12
l, gravel, and bowlders, water bearing	118

BARTLETT-HEARD LAND AND CATTLE COMPANY'S WELLS (SEC. 30, T. 1 N., R. 4 E.).

An extensive pumping plant has been planned for this company for purpose of obtaining an auxiliary water supply for a large tract of l lying south of Phoenix. A battery of six 15-inch double-steel-d wells has been established, but the machinery is not installed at writing. A depth of 28 feet of soil was penetrated, and water-ring bowlders were encountered to a depth of 90 feet. The bowl-

of which was penetrat
consolidated. Numer
were taken from the w
and its surface does
at a depth of 32.5 f
avel bed drilling was
l and a preliminary pu
. Fuller, the engineer
ailable quantity of wa
at this place.

pany's well No. 3.

.....
.....
.....

in the proportion of
n area was tested, on
it proved satisfact
question regarding th
forations. A shaft
and a small centrif
bottom and belted t
ion engine at the surf
rated 2.5 hours and r
ery ten minutes. It
of 78.8 miner's inche
per minute) and low
well 19 feet and 8 in
er in the second well.
tested, was lowered
ty seconds after the p
rose to the normal l
akes correspondingly
ater table and therefo
by better perforatio
n probably be mater
can be still obtain
lls.

nd Cattle Company's well.

bruary 4, 1904.]

.....
.....
.....
.....
.....

ative:

Sulphates	Strong.
Magnesia	Strong.
Lime	Strong.
Bicarbonates	Very strong.

WELL AT THE TERRITORIAL ASYLUM FOR THE INSANE (SEC. 2, T. 1 N., R. 3 E.).

The asylum is situated about 3 miles east of Phoenix on the Phoenix-ape road. A shaft 12 by 14 feet and 22.5 feet deep is tightly cked and cemented to shut out any surface water which might seep

From the bottom of this shaft a 12-inch well was sunk 87.5 t. or 110 feet below the surface of the ground. At a depth of 57 t the water-bearing gravel was struck, but the supply of water is t as great as in other wells entering what is presumably the same avel bed. This may possibly be due to imperfections of construction; y the lower 24 feet of the pipe are perforated, and these perforations re made before the casing was forced into the well. After the pipe in place the well was "shot." This increased the available supply a quantity sufficient for the present needs of the asylum, but the d is not yet as great as might reasonably be expected.

Log of asylum well, near Phoenix.

	Feet.
.....	12
avel, water bearing	16
y and cement	9
vel and bowlders, water bearing	53

A steam pump is located at the bottom of the shaft and a suction e 24 feet long extends into the well. The engine is usually run at rate which lifts 95 gallons per minute, and depresses the water sur-e 5 feet. This has been found to be practically the capacity of the ell.

There are two water-bearing horizons in this well separated by 9 feet clay and cement. Since the casing is perforated only near the ttom, the upper water is shut off, and analysis 1 of the following le is from water of the lower gravels. Analysis 2 is from water of ell 42 feet deep and therefore from the upper body. The great larity of the analyses indicates that the two water bodies are bably connected.

Analyses of water from the asylum well, near Phoenix.

	No. 1.	No. 2.
Quantitative (parts in 100,000):		
Total solids soluble at 110° C	126.40	120.4
Chlorine in terms of NaCl (common salt)	78.80	79.2
Hardness in terms of $CaSO_4$ (sulphate of lime)	13.60	8.2
Alkalinity in terms of Na_2CO_3 (black alkali)	None.	None.
Nitrogen in the form of nitrates	Faint.	Faint.
Nitrogen in the form of nitrites	Faint.	Faint.
Qualitative:		
Sulphates	Very strong.	Very strong.
Magnesia	Strong.	Very strong.
Lime	Strong.	Very strong.
Bicarbonates		

PHOENIX INDIAN SCHOOL WELLS (SEC. 20, T. 1 N., R. 3 E.).

There are three deep wells at the Indian School, one at the power house and two, designed for irrigation, some distance from the school buildings. The well at the power house is 193 feet deep and 6 inches in diameter. The water is used to supply the school buildings and lawns and is pumped at the rate of about 60 gallons per minute.

The first irrigation well is dug to a depth of 56 feet. From the bottom of this pit two 6-inch holes have been drilled, the first 145 feet and the second 338 feet in depth. The water stands 36 feet beneath the surface. It was the original plan to cut the well casing at the bottom of the open part and allow the water to flow from the drilled wells into the open well, from which it was to be lifted by a bucket pump.

Log of Phoenix Indian School irrigation well No. 1.

	Feet.
Soil and cement	40
Sand, cemented in places	40
Hard, white cement	15
Quicksand	6
Sandy clay	66
Sand, water bearing	26
Alternating beds of sand, clay, and cement (no definite record)	62
Cement	20
Cemented sand	24
Granite wash, water bearing	12
Sand and gravel	12
Cemented sand	8
Sand and gravel, water bearing	9
Gravel and bowlders, water bearing	3

The material passed through gave promise of comparatively little water. A gravel bed was encountered at the depth of 335 feet, but

um well, near Phoenix.

	No. 1.	No. 2.
.....	126.40	120.[illegible]
.....	78.80	79.[illegible]
me) ..	13.60	8.[illegible]
)	None.	None
.....	Faint.	Faint
.....	Faint.	Faint
.....	Very strong.	Very strong
.....	Strong.	Very strong
.....	Strong.	Very strong
.....	.....	.....

LS (SEC. 20, T. 1 N., R. 3 E.).

ndian School, one at the power tion, some distance from the er house is 193 feet deep and to supply the school buildings about 60 gallons per minute. epth of 56 feet. From the bot been drilled, the first 145 feet e water stands 36 feet beneath o cut the well casing at the bot r to flow from the drilled wells be lifted by a bucket pump.

irrigation well No. 1.

	Feet
.....	40
.....	40
.....	15
.....	[illegible]
.....	6[illegible]
.....	2[illegible]
definite record)	6[illegible]
.....	2[illegible]
.....	2[illegible]
.....	1[illegible]
.....	1[illegible]
.....	[illegible]
.....	[illegible]
.....	[illegible]

romise of comparatively little at the depth of 335 feet, but

since the casing was not extended to the bottom no headway could be made in the loose gravels, and the drilling was abandoned for a time. The gravel bed at the bottom is promising, but its thickness and character are unknown. At a preliminary pumping test only 10 inches of water was obtained.

The well is supplied temporarily with a bucket pump operated by an electric motor. When running at ordinary speed, the pump discharges about 200 gallons of water per minute and soon drains the open well. A discharge of about 100 gallons per minute maintains the water level at 52 feet, a depression of 16 feet, thus indicating the practical capacity of the well. During the time that the water surface was held at a depth of 52 feet the water flowed from the top of the drilled wells into the open part, but without any great force. The rate of discharge is slow, and the outlook for an underground supply is not encouraging.

A good example of the depression of the water table is found at this place. In the year 1895 a well at the Indian School encountered water at a depth of 16 feet. The same well, deepened as the water surface lowered, in January, 1904, contained water at a depth of 38 feet—a depression of 22 feet in about eight years.

Log of Phoenix Indian School irrigation well No. 2.

	Feet.
Soil, sand, and cement	85
Sand, water bearing	14
Cemented sand	40
Putty clay	30
Sand	10
Putty clay	16
Sand and gravel	30
Red sandstone	3

A third well has been put down on the Indian School farm 1 mile east of the school. It is a 6-inch drilled well 228 feet deep. An incident occurred in drilling this well which has an important bearing on the quantity of water to be expected in this vicinity. Water was found at a depth of about 51 feet and rose 15 feet, keeping the well filled until a sand stratum was encountered at a depth of about 170 feet. The water from above entered this sand and lowered the surface of the water in the well to about 100 feet—a depression of about 64 feet. This level was maintained, the sand absorbing the entire flow from the higher water horizons until the leakage was stopped by clay pounded into the loose sand by the action of the drill.

This well is slightly more promising than No. 1, but no test has been made. The red sandstone at the bottom is probably the breccia exposed at the surface farther to the east and north.

Analyses of water from wells at the Phoenix Indian School.

	No. 1 (45 feet).	No. 2 (145 feet).	No. 3 (15 feet).	No. 4 (60 feet).
Quantitative (parts in 100,000):				
Total solids soluble at 110° C	245.20	250.00	222.00	362.30
Chlorine in terms of NaCl (common salt)	160.80	145.00	141.00	258.00
Hardness in terms of $CaSO_4$ (sulphate of lime)	21.80	65.80	None.	Strong.
Alkalinity in terms of Na_2CO_3 (black alkali)	None.	None.	33.36	None.
Nitrogen in the form of nitrates	.40	.25	Faint.	.30
Nitrogen in the form of nitrites	Faint traces.	.00	.0008	.0028
Qualitative:				
Sulphates			Very strong.	Very strong.
Magnesia			Very strong.	Very strong.
Lime			Very strong.	Very strong.
Bicarbonates			Strong.	Strong.

G. W. SMITH'S WELL (SEC. 10, T. 1 N., R. 3 E.).

This well is dug 20 by 40 feet, 38 feet deep, and has 8 feet of water. The lower half of the well is in coarse sand, gravel, and bowlders, and required careful timbering to keep the sides from caving in. It was the material from this well which was used in the experiment described later under the caption of "practical porosity." The water is raised by means of a 12-horsepower gasoline engine and 6-inch horizontal centrifugal pump, at the rate of about 50 inches (564 gallons) per minute. The water is used for irrigation.

THE KUNZ WELL (SEC. 18, T. 1 N., R. 3 E.).

The well of Dr. R. E. Kuntze and L. Kunz & Sons is 6 by 6 feet, 24 feet deep, and has 6 feet of water. It was begun in 1899 and has since been lowered, but the water is now gradually rising. It is used for irrigating a botanical garden containing various kinds of shrubs, trees, and flowers. Since 1899 the garden has been irrigated with no other water.

The pump is a novel invention of one of the owners of the place and has comparatively high efficiency. The essential part of the mechanism is a light walking beam about 12 feet long hinged at the center.

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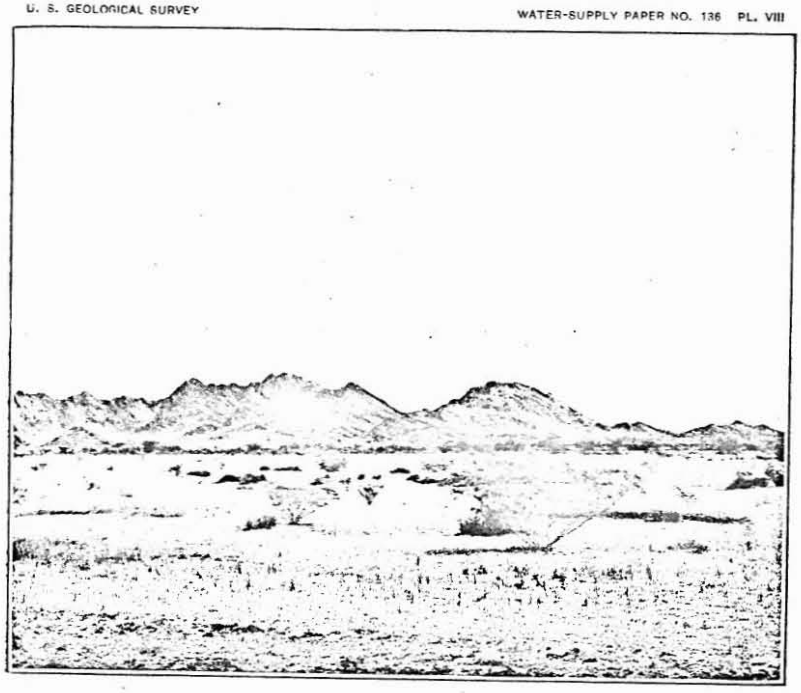
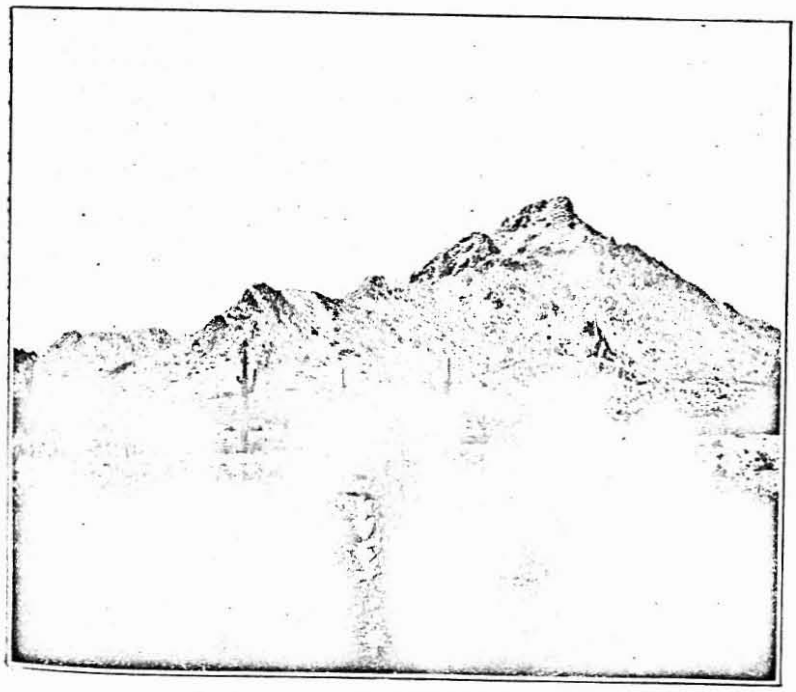
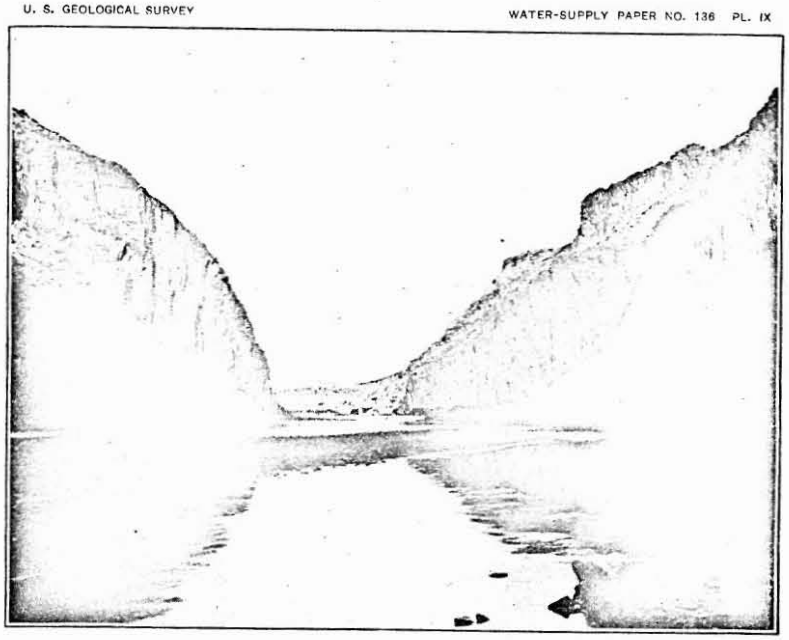


A. TILTED PRE-CAMBRIAN QUARTZITES AND ARGILLITES IN THE PHOENIX MOUNTAINS.

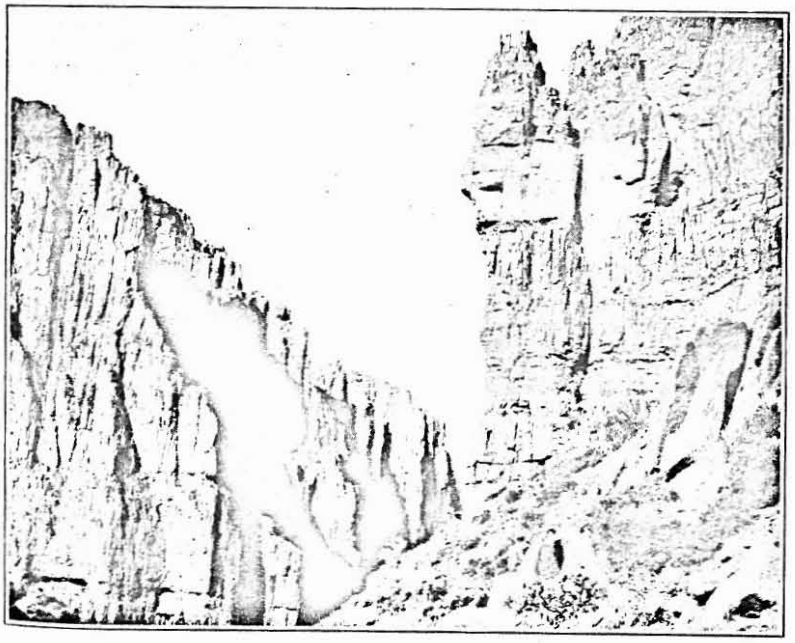


B. PHOENIX PEAK, NORTH OF PHOENIX.



A. SALT RIVER DAM SITE, LOOKING UPSTREAM INTO TONTO BASIN.

The rock is Algonkian quartzites and argillites dipping upstream. Photograph by Walter Lubkin.



B. SIDE CANYON IN TONTO BASIN.

Showing the nature of the quartzites and argillites of the Algonkian strata of the Sierra Ancha.

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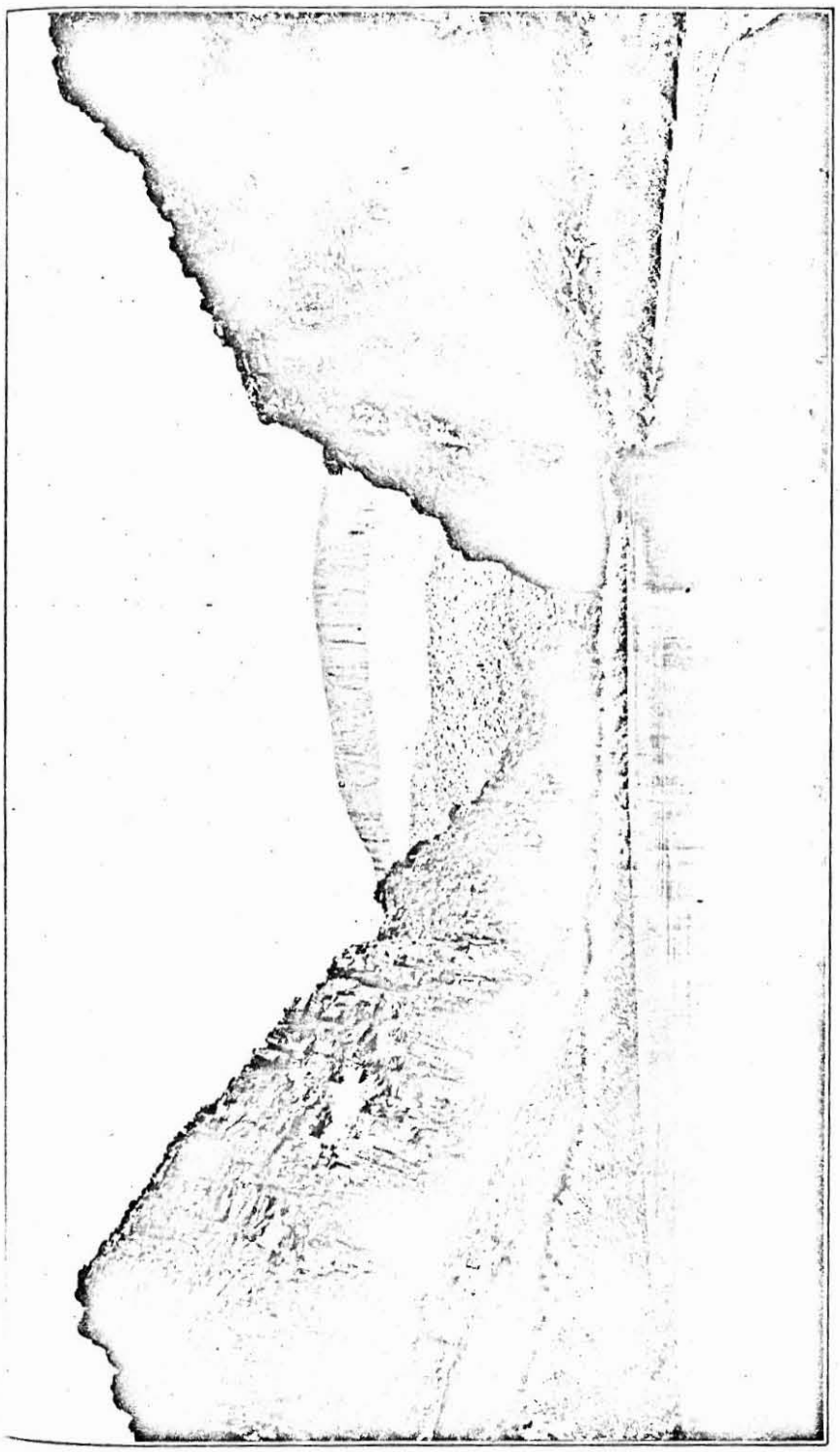
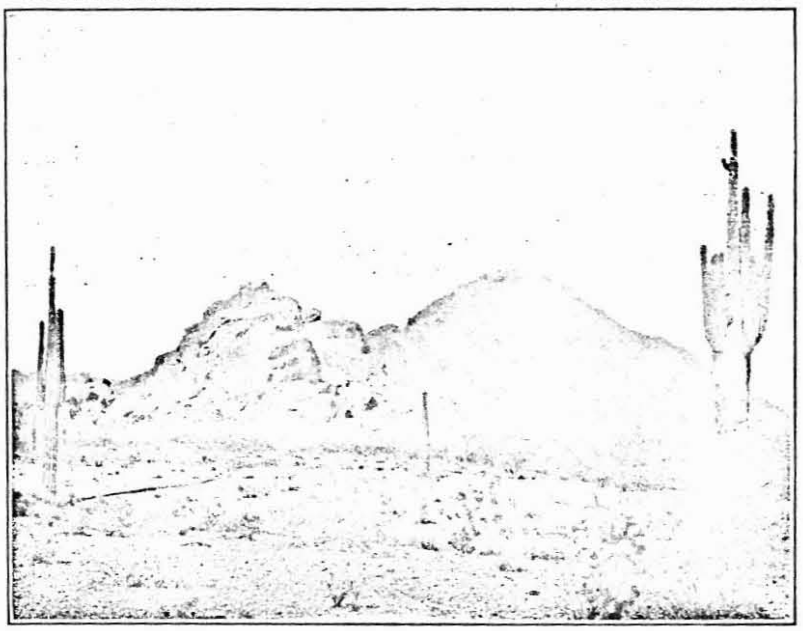
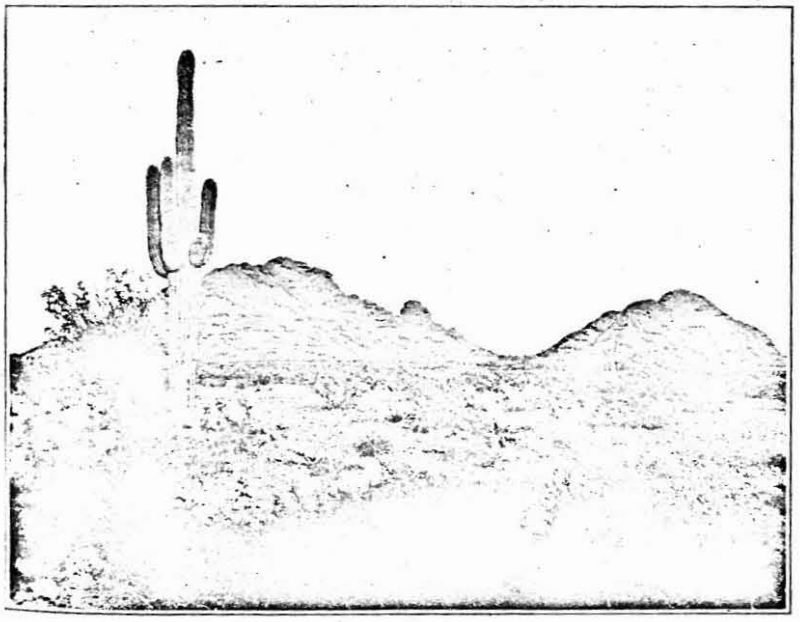


TILTED FORMATIONS AT UPPER END OF TONTO BASIN.
Looking up Salt River from dam site of power canal.



A. CAMELBACK MOUNTAIN, NEAR PHOENIX.

Showing breccia at the left, resting on the flank of a granite mountain.



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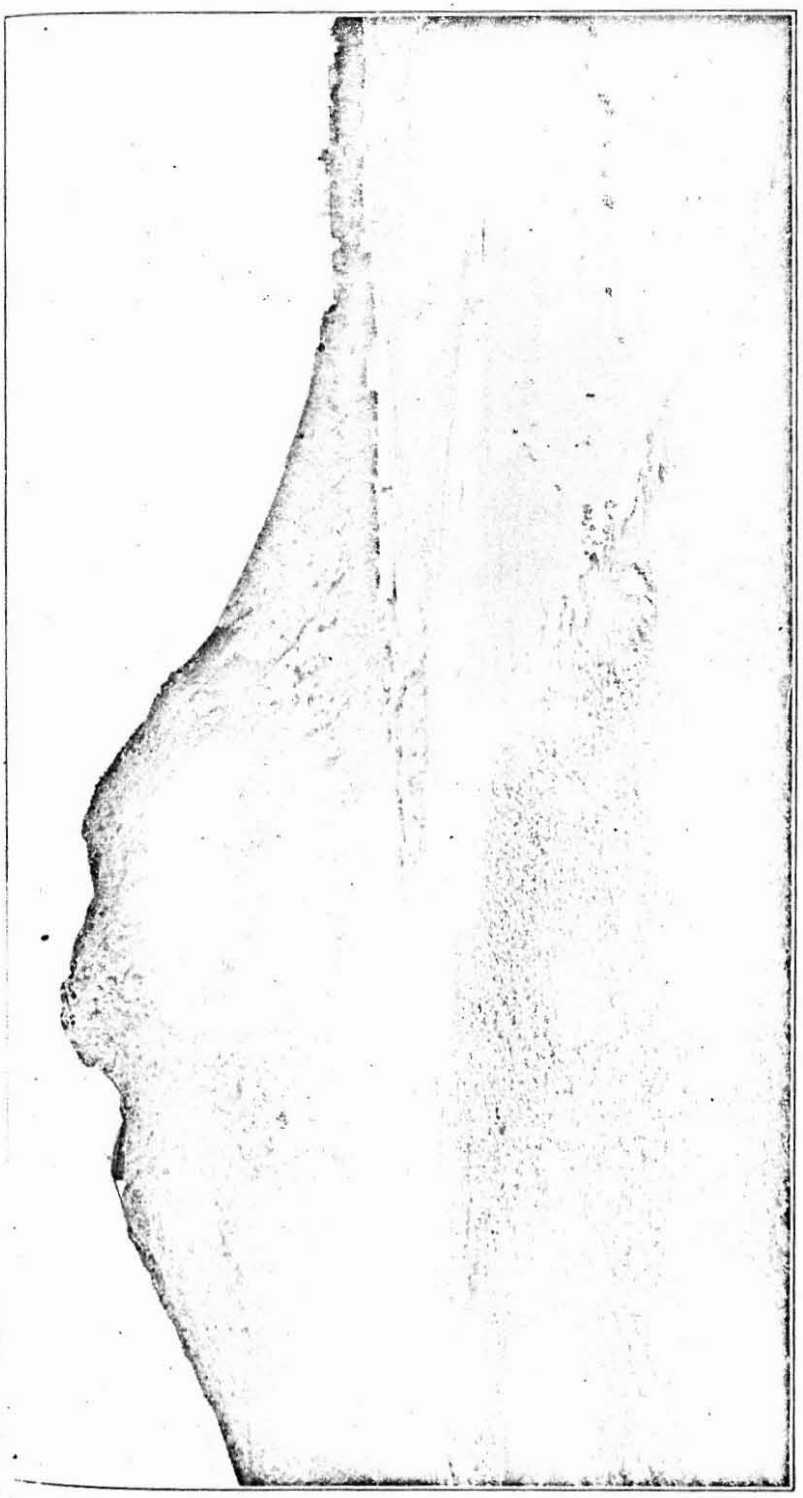
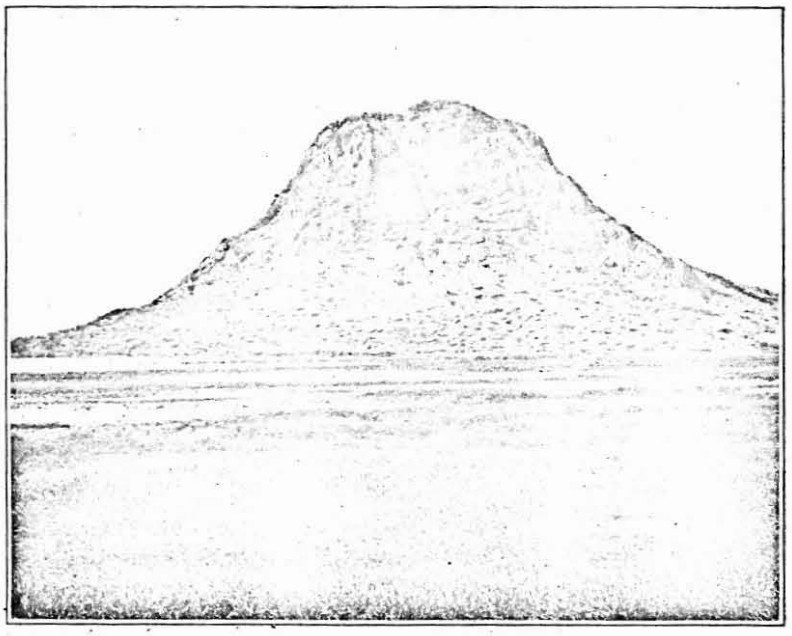
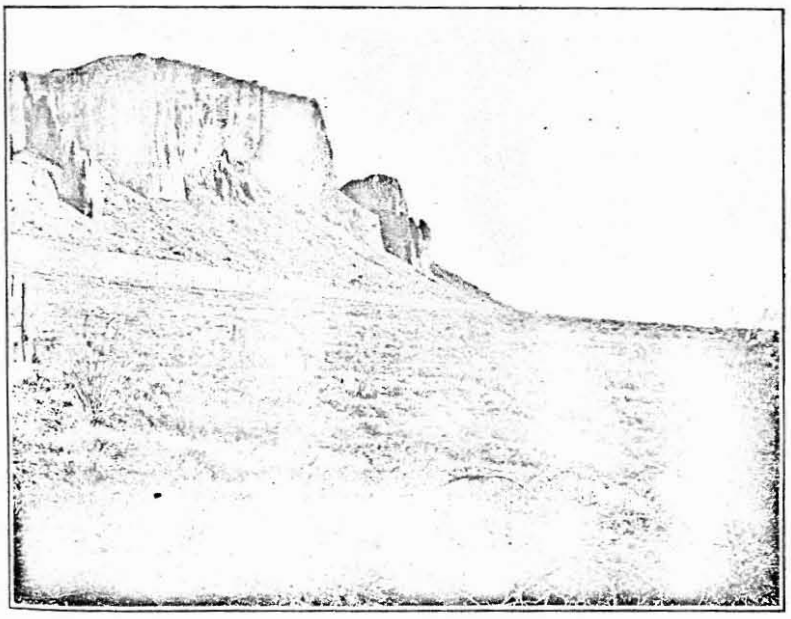


TEMPE BUTTE, SHOWING TILTED SANDSTONE AT THE RIGHT, OVERLAIN BY ANDESITE.



A. BELL BUTTE, NEAR TEMPE.

A lava butte partly buried by valley fill.



B. NORTH END OF SUPERSTITION MOUNTAINS.

A lava promontory rising above the detrital plain of Salt River Valley.

VALLEY FILL.

At Mount McDowell Salt River emerges from the narrow canyon by which it passes through the Superstition Mountains and enters the broad bottom lands known as Salt River Valley. (Mount McDowell stands at the head of what is termed the "valley" in this paper.) Some time ago it was proposed to construct a dam across the Verde River near its junction with Salt River at Mount McDowell, and a series of borings was made across the canyon to ascertain the depth to bed rock. From the records of these borings a cross section of the

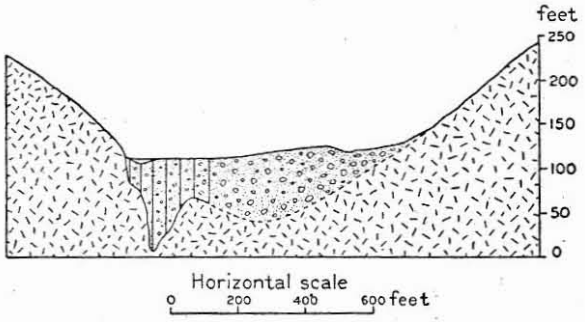


FIG. 12.—Cross section of Verde Valley near Mount McDowell, Arizona.

ancient or filled canyon of the Verde is constructed (fig. 12), showing that the valley has been filled to a depth of at least 90 feet. This valley fill is composed of waterworn material, similar to that found in the river bed and throughout the valley at the present time. This section may be taken as illustrative of the general structure of Salt River Valley. The valley, very much deeper in past ages than it is now, has been filled to its present level by fragmentary material.

STRUCTURE.

The region known as the Mesa is at the eastern extremity of the valley, ing about 25 feet higher than the bed of the river. The bluffs forming the edge of the Mesa are composed of river gravels and bowlders similar to those found in the present river bed (see Pl. IV, *A*). It is ident that the Mesa gravels were deposited by Salt River, and that cause of some subsequent change in the abrasive force of the river, used perhaps by a slight elevation of the surface, the river has cut to its former deposit to a depth of at least 25 feet near Mesa. How ch deeper it cut remains unknown. The well at the creamery near mpe, described in the former chapter, seems to be entirely in the ent material, though this can not be confidently stated. This degration occurred over a strip 1 to 2 miles wide. The degraded area was in covered with débris forming the lowlands found along the river the Mesa region. No deep wells have penetrated the more recent

deposits of the lowlands in the Mesa region in localities suitable to indicate the depth of these deposits. Shallow wells dug to a depth of about 50 feet seem to be wholly in the recent deposits, indicating that the erosion which formed the Mesa bluffs must have lowered the river bed at least 50 feet beneath its present elevation.

The two gravel terranes differ but slightly. Their constituents are the same, but the younger accumulations are notably less cemented. Wells sunk in them are the most productive wells in the region because of the readiness of movement of their ground waters. In the Mesa region the younger gravels are easily distinguished from the older on account of the former being confined between bluffs of the older material. But at Tempe and throughout the Phoenix region the younger gravels cover the older and their distribution can be judged only from the well records. The relations of the two series of accumulations are shown in sections AB and CD of Pl. XIX, and in the cross-section near Phoenix (Pl. XXI).

MATERIAL.

The valley fill is composed of more or less irregular lenses of clay, silt, sand, gravel, wash, and bowlders. These are arranged in a most erratic manner, the character of the beds changing rapidly both vertically and horizontally, as indicated by the well records.

This material may be divided for convenience of description into (1) river débris, (2) sheet wash, and (3) chemical precipitate.

RIVER DÉBRIS.

In the present river bed are found bowlders and gravel of quartzite, quartz, chert, granite, gneiss, and various kinds of eruptive rock. The quartzose materials greatly predominate, owing, no doubt, to their enduring character. Bowlders occur with a maximum diameter of about 2 feet. A comparison of the material found in the river bed at the present time with the older material found in the exposed bluffs along the river and in the numerous wells throughout the valley indicates that for the most part the valley fill was derived from the same sources from which the present river gravels are derived, namely, the formations along the upper reaches of Salt River.

SHEET WASH.

The term wash is used in this region with at least four meanings, more or less separate and distinct:

(1) The stream courses occupied by water only in times of heavy rainfall, called arroyos in other parts of the West, are here called washes.

(2) Many of the dry stream courses having their origin in the mountains are well defined for a greater or less distance after emer-

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ging from the mountains, but finally disappear on the plain, leaving no trace of a definite course. During times of flood the waters spread in a broad, thin sheet over the plain. The largest floods gradually find their way to the rivers, not by way of channels, for there are none, but by a broad wash over the even surface of the gently sloping plain. In most cases, however, the waters never reach the river, but are absorbed by the sands and gravels of the valley floor and disappear completely from the surface. The broad sheet of water thus sweeping over the surface is called a sheet wash.

(3) The material brought from the hills by the streams, many of them of considerable size—as, for example, Queen Creek and Cave Creek—is deposited as a broad fan, so broad and low, in fact, that it is scarcely separable from the general valley floor. Queen Creek has a well-defined course for about 50 miles, and Cave Creek one somewhat longer. During floods a large amount of débris is deposited along these stream courses and is locally known as wash. The material in which wells have been sunk is sometimes described as "Queen wash" or "Cave wash," etc.

(4) A fourth meaning of the term is closely allied with the third, and yet distinct enough to demand separate mention. The sudden heavy showers so characteristic of Arizona are too well known to require explanation. If a so-called cloud-burst occurs in the hills near the edge of the valley the small stream courses, flooded to overflowing, discharge their débris-charged waters upon the gentler slope of the valley floor, where all definite stream courses disappear. Should a channel by chance become established, the checked velocity of the water on the gentler slopes of the valley floor soon causes it to become choked and to be deflected and join that of the neighboring streams. The result is that flood waters from the hills move more or less in a sheet over the valley floor until they disappear beneath the surface. The loose material from the hillsides is thus brought to the valley and distributed somewhat evenly over the surface. Cloud-bursts which take place over the valley produce the sheet floods on a smaller scale. The material thus brought from the hills and distributed over the valley is called also sheet wash.

The term wash, therefore, applies (1) to a dry stream course, (2) to water moving in the form of a thin sheet over the plain, (3) to the material deposited by an intermittent stream near the base of the mountains in the form of a fan or dry delta, and (4) to the accumulations of detrital material working slowly from the hillsides, as a more or less evenly distributed sheet.

It is not difficult to understand how the washes can cause large quantities of débris to accumulate near the hills. But in the midst of the plain, miles from the hills, the sheet flood, as a geologic agent, might seem so unimportant as to be negligible. The heavy showers

occur but seldom and affect a very limited area at any one time. It is probable that scores of years may intervene between two showers sufficiently heavy to produce sheet floods at any given point, and yet the writer is of the opinion that the sheet flood is a factor which can not be neglected in the adequate explanation either of the valley fill or of the underground water contained in this fill.

As the arkose works its way down the mountain slopes and spreads over the surface of the plain, the coarse material naturally accumulates near the foot of the parent mountain, while the finer material is carried farther out. The sorting, however, is not carried on to anything like the extent observed in the case of regular streams. In many cases, indeed, the floods are so tumultuous that coarse and fine materials alike are carried forward and piled in confusion. In the less violent floods the coarse material accumulates near the hills. This fact is of the utmost importance in furnishing an explanation of certain phenomena connected with the underground waters of the valley.

The sheet wash is apt to differ from the stream-carried débris in bearing less evidence of the recognized action of running water. The water wear and sorting are at a minimum. When there is water enough to move any of the material of the wash, there is likely to be enough to move coarse and fine alike. The result is an accumulation of silt, clay, sand, and gravel commingled in every conceivable proportion. The gravels are usually angular, although some are slightly water worn. Near the granite hills the wash is composed of the coarse, angular products of the partial decomposition of the granite, previously described. When the feldspars are decomposed to such an extent that they do not easily retain their original form, the material is locally known as "talc" or "soapstone" (not to be confused with true talc and soapstone).

At Desert well the wash covering the surface is at least 180 feet thick, and no other material except a few feet of sand is found throughout that thickness. The 348-foot well of the Valley Seedless Grape Company, near the eastern end of the Salt River Mountains, is in granitic wash throughout most of its depth and at the bottom penetrates solid granite. In many places the wash from the hills gives character to the topography over wide areas. Southwest of the Superstition Mountains the surface of the desert over an area of something like 300 square miles is composed of wash from these mountains. The small stream courses from the mountains soon disappear in a regularly inclined desert surface which is practically wanting in even the smallest stream courses.

Queen Creek, which may be taken as a type of the streams that enter the valley from the neighboring mountains and disappear on the valley floor, illustrates the manner of accumulation of wash. It has a drainage area of about 143 square miles in the mountainous

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strict northeast of Florence, and its course is traceable in a distinct channel for a distance of over 40 miles, but on entering the valley the waters soon sink from view into the sands and gravels of the floor, leaving the bed dry except in times of flood. A few miles below the dam site at Whitlow's ranch the creek emerges from the hills upon the sloping plain of the valley, and thence to the end of its course follows no well-defined depression or valley. From Whitlow's ranch to the end of the course near Andrada well the creek bed has a fall of about 665 feet, making an average gradient of 28 feet to the mile, which above the ranch is still higher. With such a gradient it is evident that during times of flood great quantities of débris must be swept from the hills. The floods are in part checked as they enter the plain and in part lost by sinking into the gravels, and the débris is deposited, building up the course of the stream. The result is that numerous channels occur side by side, more or less connected by crosscuts forming a network of interlacing courses. A second result is that along the lower reaches of its course, Queen Creek has built up a fan or dry delta above the surface of the surrounding plain. A similar fan has been built by Cave Creek, the lower reaches of which are within the area covered by the detailed topographic map of Salt River Valley. The deflection of the contours south of Cave Creek, as shown on this map, is due to the general elevation of the land surface in that region caused by the Cave Creek fan. North of Sacaton Mountains Queen Creek branches into numerous forks or distributaries and is eventually lost in the general surface of the plain. From this point to the Gila River, a distance of about 15 miles, there is no stream channel. Floods large enough and lasting enough to reach the Gila pass over this last 15 miles as sheet washes. These washes are said to vary from a few inches to 2 feet in depth and the water is so loaded with silt and floating vegetation that it works its way slowly over the plain without excavating channels even where the slope is comparatively steep.

It is seldom, however, that floods occur of sufficient size and duration to reach the Gila, being more often lost in the valley fill long before reaching that river. The amount of water which thus sinks beneath the surface, together with the intermittent character of the flow, is well shown in the accompanying table and diagram (fig. 13) taken from the paper on Irrigation near Phoenix, Ariz., by A. P. Davis.[a]

[a] Davis, A. P., Irrigation near Phoenix, Ariz.: Water-Sup. and Irr. Paper No. 2, U. S. Geol. Survey, 1897.

Estimated monthly discharge of Queen Creek, Whitlow's ranch, Arizona, in 1896.

[Drainage area, 143 square miles.]

Month.	Discharge.			Total for month in acre-feet
	Maximum in second-feet.	Minimum in second-feet.	Mean in second-feet.	
January	2	2.0	2.0	12
February	2	2.0	2.0	11
March	2	2.0	2.0	12
April	2	1.0	1.5	8
May	1	1.0	1.0	6
June	1	1.0	1.0	6
July	9,000	.....	121.6	7,48
August	1,433	.6	13.1	80
September	3,428	.5	17.1	1,01
October	1,188	.5	13.3	82
November	80	.6	1.3	8
December	207	.6	2.0	12
Total	9,000	.....	15.0	10,89

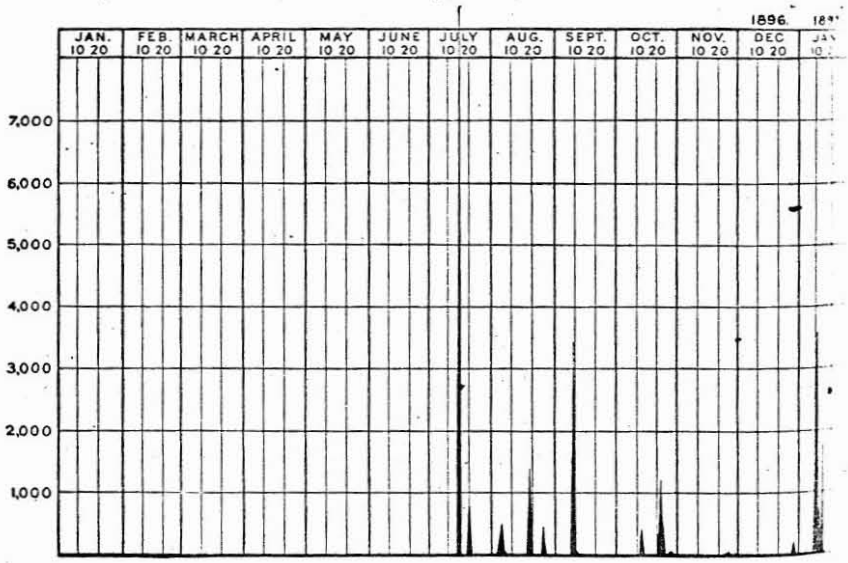
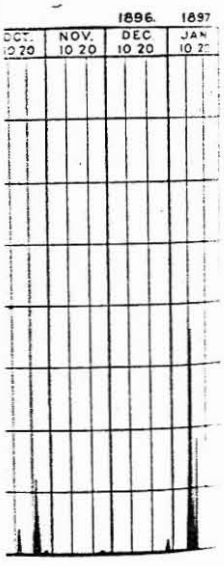


FIG. 13.—Daily discharge of Queen Creek.

Robert Bowen, who owns a ranch about 6 miles east of Harringt well, on Queen Creek, pointed out to me certain fields which w flooded a few months previous to my visit. There are 6 channels this point, varying from a few feet to about 100 feet in width. order to flood the fields in question the water in these channels m

Arizona, in 1896.

Mean in second-feet.	Total for month in acre-feet.
2.0	123
2.0	115
2.0	123
1.5	87
1.0	61
1.0	60
121.6	7,48[illegible]
13.1	80[illegible]
17.1	1,01[illegible]
13.3	82[illegible]
1.3	80
2.0	12[illegible]
15.0	10,89[illegible]



east of Harringt[illegible]
fields which we[illegible]
are 6 channels [illegible]
feet in width. [illegible]
hese channels m[illegible]

have had a depth of at least 5 feet. Mr. Bowen states that at the Harrington ranch, 6 miles downstream, there was not enough water to fill certain irrigation ditches which had been prepared for the diversion of flood waters. Here then is a specific case of a flood of somewhat notable volume that sank into the sands and gravels of the valley fill within a distance of about 6 miles.

CHEMICAL PRECIPITATES.

Caliche.—In nearly every well of the valley a substance is encountered, in greater or less quantity, which is commonly known as cement or hardpan. This material is also known, though less generally, as caliche, and has been described by Prof. W. P. Blake,[a] of the University of Arizona, who says:

In southern Arizona and in Mexico the word caliche is in general use to denote a calcareous formation of considerable thickness and volume found a few inches, or a few feet, beneath the surface soil, upon the broad, dry, gravelly plains and mesas. * * *

Caliche has a wide distribution in the regions of Arizona and Mexico. It is usually hidden from view by a slight covering of soil, but it is easily found by digging, and is often revealed by a flow of water during heavy rains. It is practically a continuous sheet, from 3 to 15 feet thick, of earthy limestone or travertine, through which the smaller plant roots find their way with difficulty. * * *

The top of the caliche is more dense and solid than the lower portions. The surface of this crust, or layer, is comparatively smooth, though undulating, while the lower portions, under the crust, are irregular, cavernous, earthy, and very porous, blending gradually with the materials of the sandy and gravelly beds, from which they are divided by no sharply defined plane of stratification or separation. The caliche invests, surrounds, and includes sand grains, gravels, and more or less earthy material, but seems to have had the power, especially in its upper crust, of extruding the coarse materials of the soil to a great extent.

The deposit does not form a regular horizontal bed conformable with the rude stratification of the gravels and sands, but conforms roughly with the general surface, rising and falling with the undulations of the mesa. There are, in places, repetitions of the compact layers, separated by a few inches of the amorphous and more earthy deposit. * * *

Close observation detects, in some places, small perforations, like pin holes, at the top, which enlarge gradually below and penetrate the entire compact crust, becoming lost in the irregular amorphous granular mass. * * *

The caliche is an example of deposition independent of the influence of organic agencies. * * *

In chemical composition the caliche is essentially a lime carbonate, but contains some calcium, magnesium, and aluminum silicates, as more fully shown by the result of an analysis made by my assistant, Mr. J. S. Mann, in the laboratory of the Arizona School of Mines:

[a] Blake, William P., The caliche of southern Arizona: Trans. Am. Inst. Min. Eng., vol. 31, 1901, p. 220.

Analysis of Arizona caliche.

Calcium carbonate ($CaCO_3$)	72.[illegible]
Magnesium carbonate ($MgCO_3$)	2.[illegible]
Calcium silicate ($CaSiO_3$)	5.[illegible]
Aluminum silicate ($AlSiO_5$)	7.[illegible]
Ferric oxide (Fe_2O_3)	1.[illegible]
Moisture (H_2O)	1.[illegible]
Total	96.4[illegible]

This caliche, unlike the deposits of travertine formed in the open air, is not sufficiently compact and solid to be useful in construction, as was the travertine of ancient Rome. When calcined it yields good caustic lime, which, tempered with sand, makes a strong, quick-setting mortar or cement. It is quarried and used for this purpose in some places. Occurring as it does in mixture with gravel and sand, it has the appearance of an artificial mixture. * * *

After describing local conditions and giving the analyses of water from 7 wells near Tucson, which indicate that the underground waters contain the principal elements found in caliche, Professor Blake adds:

There has been much speculation in regard to the origin of the caliche. It has been generally assumed to be a deposition from some ancient lake, or body of water, once covering the area in which it is found. But such a theory is untenable when all the phenomena are considered. The formation is clearly the result of the upward capillary flow of calcareous water, induced by constant and rapid evaporation at the surface in a comparatively rainless region.

With a constant supply of phreatic calcareous water, the second great essential factor in the formation of caliche is the continued desiccating atmosphere—a condition which prevails, with only short and temporary exceptions, through the year. The desert and semidesert regions of Arizona are characterized meteorologically by the unusual dryness of the air and its capacity for the absorption of moisture and by the maintenance of continued evaporation from the soil, which determines a constant upward movement of the phreatic water. The occasional rains in midsummer and midwinter do not penetrate to great depths, but are sufficient to leach out the soil to the depth of a few inches or feet, turning the calcareous solution back and downward and producing the denser upper crust, where it meets the upward flow.

Such I conceive to be the origin of the caliche. It may be called a subterranean deposit of travertine; but it is not the result of a flow from springs or from any source at the surface, or from the lateral movement of water. Unlike ordinary travertine, it is the result not of descending but of ascending currents. The ordinary conditions of vadose circulation are reversed. The caliche is a fine example of the formation of extensive calcareous strata in the midst of preexistent beds, not by metasomatic processes, but by precipitaton from sources below.

To Professor Blake's description I would add that caliche occurs in varying degrees of purity and that any consolidated layer is locally known as cement. When caliche is not mixed with a considerable amount of foreign material it may become very compact, resembling a fine-grained limestone, and sometimes causes much difficulty in sinking wells through it. Several cases are on record where wells were abandoned because the casing caught on a cement layer and could be forced no farther.

caliche.

	72.28
	2.13
	5.57
	7.37
	1.88
	1.20
	96.43

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A sand or gravel bed cemented with this material often becomes impervious to water. The confining strata above the water in nearly all the wells of Salt River Valley, where water is found under pressure, contain more or less caliche in the form of a cementing material.

It will be noted that according to Professor Blake's interpretation the caliche is due to the deposition of compounds gathered from some outside source and brought in solution, through underground passages, to the region where they are deposited through the agency of surface evaporation. Applying this explanation to the origin of the caliche layers in the valley fill of Salt River Valley, it is evident from the analyses of waters already given and from the rocks previously described, which furnish by their decomposition the elements brought into the valley by the waters, that all elements necessary for the formation of caliche are present. The prevalence of caliche at or near the surface strengthens the postulate that the surface is its natural place of formation. Since the valley fill, as explained elsewhere, is due to the gradual filling of the valley by débris shed from the hills, each horizon throughout its depth has at some former time been the surface. Hence the presence of caliche bands at all horizons.

It should be noted, however, that bicarbonates are present in nearly all the waters of the valley. A relief of pressure alone is sufficient under certain conditions for the escape of carbon dioxide, which causes the bicarbonates to change to the comparatively insoluble carbonates, which are then readily deposited. It is entirely possible, therefore, that the deposition of caliche may take place at some depth beneath the surface, in fact at any depth where the pressure upon water containing bicarbonates in solution is sufficiently relieved and opportunity given for the escape of the gas.

The postulate that caliche is in some cases at least deposited without the influence of surface evaporation, is strengthened by the observation of uneven porous structures on the under side of caliche layers. This strongly suggests the deposition of caliche beneath, after the impervious layer had been formed. A lowering of the water table during dry cycles, such as are known to occur, would naturally leave beneath a caliche layer which had been formed near the surface a space occupied by loose gravels, no longer filled with water as before. The caliche layer would prevent any great amount of evaporation, but probably would not prevent relief of pressure upon the water in the gravels beneath. A relief of pressure might cause a loss of carbon dioxide and result in deposition of the insoluble carbonates.

A case in hand is found at the Murphy-McQueen pumping plant (see p. 12). Beneath the 13 feet of soil at the surface coarse gravels and bowlders occur to a depth of 34 feet. The material in the upper 13 feet is free from any notable amount of caliche, while the loose

face movements have been somewhat general over a large portion of western Arizona.

The Colorado River probably furnishes the best index available of the general surface movements of the Southwest. In an examination of northwestern Arizona, described elsewhere, the author noted at numerous points a series of tilted and partly consolidated conglomerates and breccias, overlain by more recent and unconsolidated sands and gravels, which were in turn dissected and overlain by a third series now accumulating to form the present lowlands along the Colorado River. The older series is extensive both in thickness and areal distribution. Its original thickness must have been at least 2,500 feet, remnants being now found 2,300 feet above the river, and it extends downward to some unknown depth beneath its bed. The next younger deposits are less extensive, and the youngest form the present flood plain.

The succession of events recorded in these deposits as well as in those of Salt River Valley and elsewhere is indicated in fig. 14. The original valley (A) was filled with the oldest débris (B), and this in turn was eroded (C) and again filled with the second accumulation (D). A third stage of erosion excavated the present valley (E), and the deposits now accumulating are represented in stage F.

A similar succession of events has been noted at several points in Arizona, notably along San Pedro, Santa Cruz, and upper Gila rivers, and in Tonto basin, as well as in a number of places in northwestern Arizona. Near Benson, in San Pedro Valley, wells have penetrated the valley fill to a depth of about 800 feet without reaching bed rock.

In the Tonto basin upland deposits of at least two periods of accumulation are exposed. The older is a coarse breccia, moderately well consolidated and more or less tilted in places (Pl. XIV, *B*). This breccia rests upon the eroded surface of the older formations and is deeply dissected in places. Against this tilted breccia rest nearly horizontal beds of more recent sediments, which are in turn dissected, large portions of them having been carried away by the more recent action of the river (Pl. XIV, *A*). Nothing was found to indicate the geologic age of either deposit, but the older is regarded as probably representing the base of the Quaternary.[a]

There have been, then, since the original formation of Tonto basin at least 5 separate stages: (1) The period of erosion, which, in part at least, formed the basin, corresponding with stage A of fig. 14; (2) a period of accumulation, during which the breccia just described was deposited, this period corresponding to stage B; (3) a period of

[a] Gilbert, G. K., Report on the geology of portions of New Mexico and Arizona: U. S. Geog. Surv. W. 100th Mer., vol. 3, 1875, p. 540.

Ransome, F. L., Geology of the Globe copper district, Arizona: Prof. Paper U. S. Geol. Survey, No. 12, 1903, p. 57.

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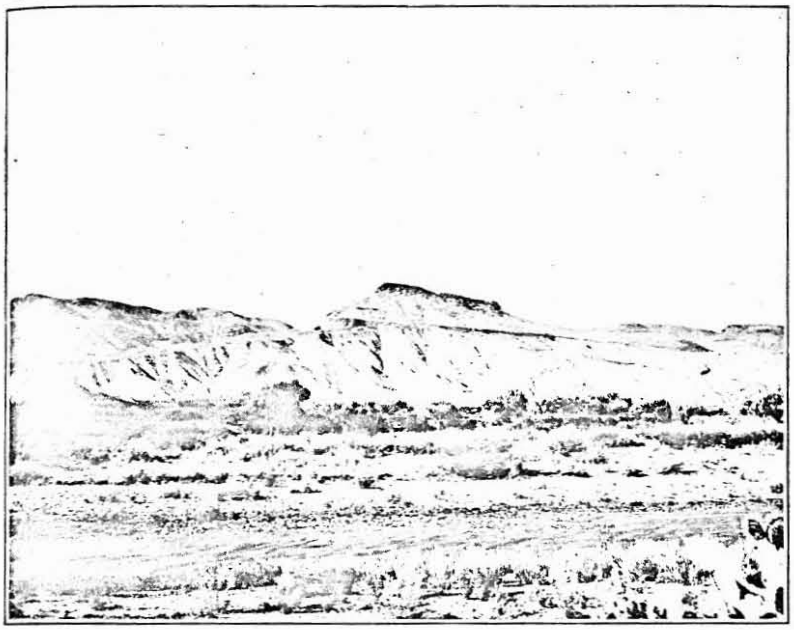
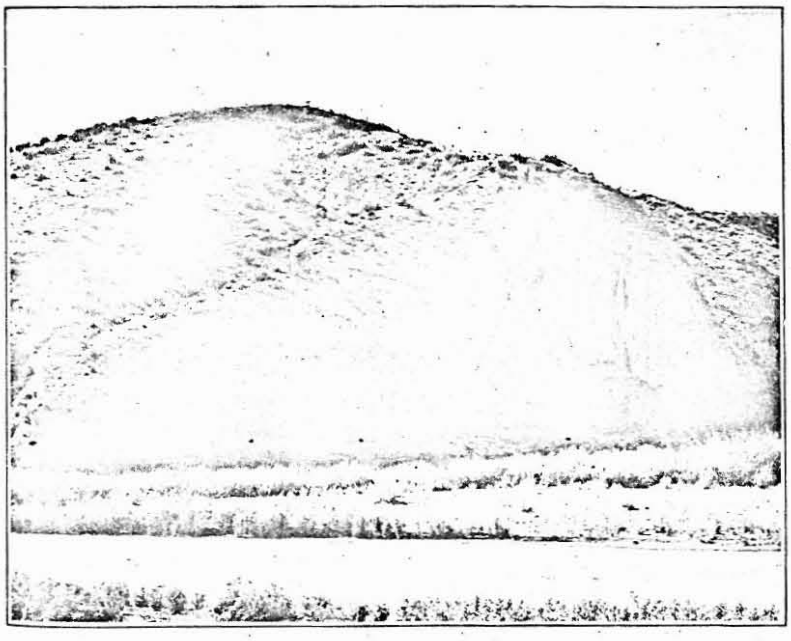


A. CLAY BANK IN TONTO BASIN, FROM WHICH CLAY WILL BE OBTAINED FOR CEMENT IN THE CONSTRUCTION OF SALT RIVER DAM.



B. TILTED BRECCIA IN TONTO BASIN.

Accumulation represented by stage B.

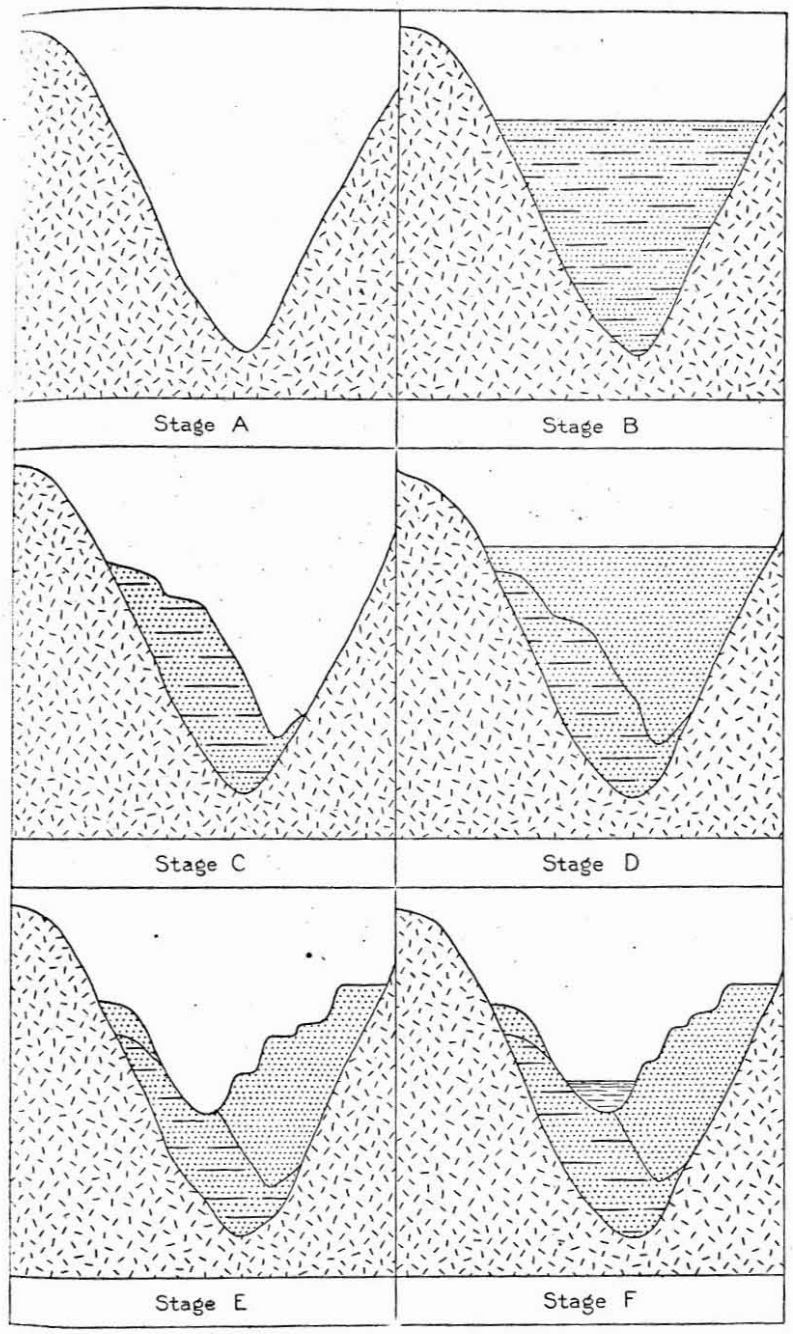


FIG. 14.—Diagrammatic illustration of valley filling and erosion in central and western Arizona.

erosion, probably inaugurated by uplift and tilting, in which the b cia was dissected, this period corresponding to stage C; (4) a pe of accumulation, in which the younger sediments of the basin w deposited on or against the dissected breccia—stage D; (5) a pe of erosion, the present stage of the river, during which the pre valley has been excavated—stage E.

Since the same succession of events is shown to the west of S River Valley along the Colorado, to the east in Tonto basin, to southeast in San Pedro Valley, etc., it is possible that the vari stages are due to far-reaching causes affecting Salt River Valley common with the other localities named.

The older mesa gravels of Salt River Valley may represent stage while the younger gravels represent stage D and the present ri channel, stage E. There are no accumulations in Salt River Vall except the gravels of the broad bed of the river, which can be co pared to the accumulation of stage F. The similar succession events in widely separated localities is suggestive of common caus but no definite correlation is possible at the present time. This mu however, can be stated with reasonable confidence—the valley fill not the result of continuous aggradation. Periods of erosion ha alternated with periods of accumulation.

It is worthy of note that in the three deepest wells of the valley the Murphy-McQueen well, 1,305 feet; the Chandler well, 705 fe and the Thomas Murphy well, 865 feet—a considerable thickness clay or other fine material occurs beneath the coarse detritus. In t Murphy-McQueen well this material is described as "chalk rock" a "talc." The writer has seen a small portion of the material tak from the 1,305-foot level. It consisted of clay containing a few quar pebbles. The clay from the bottom of the Thomas Murphy well very plastic and contains no fragments of foreign material. The cl apparently lies underneath the breccia. Little more is known of t lower horizons of the valley fill. The material of the upper horizon so far as known, is evidently due to upland accumulation. For th reason, and because of the want of definite information concerning t lower horizons, the whole thickness of the valley fill has been assum to originate in the same way. What little is known of the low horizons suggests the possibility of lacustrine origin. The occurren of the clay underneath the breccia near Phoenix suggests that the cl beds encountered in the Mesa region may be notably older than t detrital material above. In that case the lower part of the valley f may be of Tertiary age, and a thickness of only a few hundred feet the top may belong to the Quaternary.

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SURFACE MOVEMENTS.

There is abundant evidence that changes in surface elevation have taken place in and about Salt River Valley in comparatively recent times.

(1) The immense deposits of upland accumulation in this region are best explained as due to subsidence of the surface. The general occurrence of upland accumulations of débris throughout western Arizona and southern California suggests that the same cause affected wide areas. It is probable that these accumulations are in part due to desiccation of the climate. There is abundant evidence that in former ages streams of considerable size occupied valleys which are now dry. However much desiccation of the climate may have caused a diminution of streams and consequent deposition of débris in valleys which were formerly swept clear by these streams, it can not wholly account for this accumulation.

The present surface elevation at Mesa is about 1,200 feet. The deep well at Mesa—1,305 feet—extends about 100 feet below sea level and does not reach bed rock. It is obvious that at this point the surface must have been at a greater elevation when the valley was formed, since the river could not excavate the valley below sea level. Similar thicknesses of the upland débris occur elsewhere—800 feet in San Pedro Valley; 1,000 feet in Sacramento Valley at Yucca, Ariz., and about 2,400 feet exposed in the bluffs of the Colorado River. In none of these places, however, is bed rock reached. The evidence points to a general subsidence as the initial cause of the upland deposits.

(2) Local movements. The sandstones and the breccia near Tempe and at Mount McDowell, near the head of the valley, are highly inclined. The attitude of the sediments in Tonto basin indicates faulting and tilting to a notable extent, and Ransome[a] describes an area of intense faulting and movement east of Salt River Valley. Faulting and block tilting are not easily recognized in crystalline formations such as those immediately surrounding the valley, and the covering of detrital matter renders the location of possible fault lines doubtful. Reasoning, however, from analogy it is probable that faulting and block tilting have played a considerable part in bringing about present relations in and near Salt River Valley.

The most conspicuous example of a tilted block within the valley is found in Tempe Butte, where the sandstone and its overlying sheet of andesite are tilted steeply to the south. The movement which brought this butte to its present position was very recent. Waterworn bowl-

[a] Ransome, F. L., Geology of the Globe copper district, Arizona: Prof. Paper U. S. Geol. Survey No. 12, 1903.

ders, such as compose a large part of the valley fill, are found on the sides of the butte above the level of the valley floor, and although they

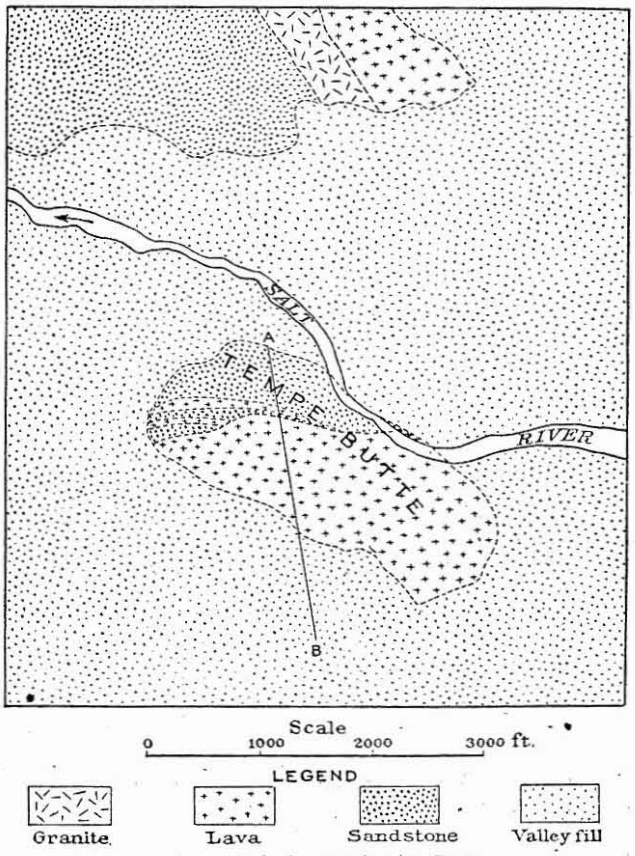

FIG. 15.—Geologic map of Tempe Butte.

lie loose on the steep sides, sufficient time has not elapsed since their elevation to allow of their finding their way back to the river which

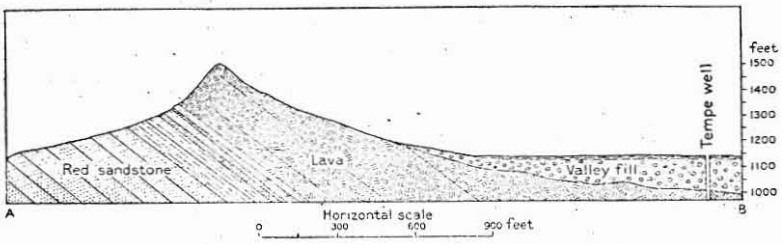

FIG. 16.—Section through Tempe Butte and Tempe well.

flows at the foot of the butte. The attitude of the formations and their relations to each other are indicated in figs. 15 and 16.

CHAPTER III.

PHYSIOGRAPHY.

MOUNTAIN AND PLAIN.

The so-called valleys of Salt and Gila rivers are but parts of a broad plain occupying a large portion of southwestern Arizona. The valleys are in part surrounded by mountainous areas, and they themselves in turn surround isolated peaks and groups of mountains which rise abruptly from their surface. To the north and east the country becomes more and more mountainous to the edge of the high plateau, which within a distance of something like 80 miles rises to an elevation of about 7,500 feet, as indicated in the sketch profile fig. 17. The escarpment bordering the great western plateau passes through this region. The surface of the plateau slopes northward, while the drainage from its face—the edge of the Mogollon Mesa—together with that from the broken country to the southwest of the escarpment forms Salt and Verde rivers, thus furnishing the water which supplies Salt River Valley. In a general way the aggraded

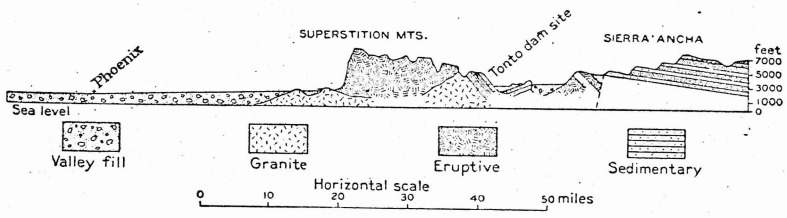

Fig. 17.—Sketch profile from the Agua Fria, through Tonto basin and the Sierra Ancha.

plain of which Salt River Valley is a part lies at the foot of the escarpment bordering the plateau, and has been filled and graded principally by material shed from the edge of this plateau. Between the escarpment proper and the aggraded plain there is much broken country of which little is known. Toward the south and west of the escarpment the mountain masses stand out as more or less isolated groups, separated by stretches of fairly level plains, as, for example, the Salt River and Sacaton mountains.

The plain from which these comparatively small mountain groups rise has a regular and moderately uniform slope corresponding to the gradients of the streams. In some cases the transition from mountain to plain is marked by a series of partly buried hills, which were

originally outlying remnants of erosion and which have since been surrounded by débris shed from the mountain slope. This is illustrated in a small way south of the Phoenix Mountains (Pl. XV). In a larger way the groups of mountains, such as Salt River Mountains, Sacaton Mountains, etc., are also remnants of erosion partly buried by débris. In other cases the mountains rise from the graded plain or valley floor with the utmost abruptness, as in the case of Bell Butte (Pl. XIII, *A*), and Camelback Mountain (Pl. XVI, *A*). Probably the most notable physiographic feature of the region is the abrupt transition from mountain to plain.

In the views, previously referred to, of Tempe Butte, Bell Butte, etc., the aggraded plain shown in the foreground extends to the abrupt rocky slopes with little or no transition. Irrigable lands extend to the foot of the slopes, as indicated in Pl. XVII, which is a view from the top of Tempe Butte. The explanation of these relations is found in the study of the material and structure of the valley floor. The old valley has been flooded with débris and the outlying peaks and spurs partly or wholly submerged.

THE MESA REGION.

The Mesa gravels, or older gravel accumulations, were deposited to an elevation 25 feet or more above the present river bed. Later these gravels were cut by the river to a depth of at least 75 feet, and this

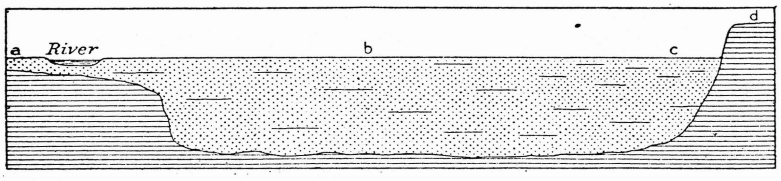

FIG. 18.—Sketch section illustrating the restricted area of water-bearing gravels due to underground structure. The older accumulation (stage B) was dissected (stage C) and the valley filled (stage D).

depression widened several miles. Later still this degraded area was partly filled. There is, then, an old valley filled with débris in which a younger valley was excavated, to be, in turn, itself filled with débris. It may be best explained, in this connection, why certain wells are productive while others in seemingly as good positions fail. If the old valley fill—the Mesa gravels—had become impervious by the deposit of silt or caliche, or from any other cause, and the present river gravels had remained unconsolidated, a water-bearing stratum of restricted distribution would occur, corresponding in extent to the recent gravels. If the recent gravels had filled the secondary valley and spread over the older accumulations, wells sunk in the strip covered by the recent gravels would be productive while wells outside of this strip would be unproductive. This is illustrated graphically in fig. 18.

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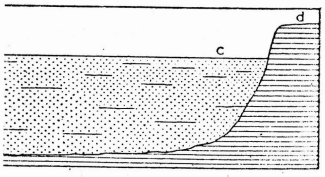

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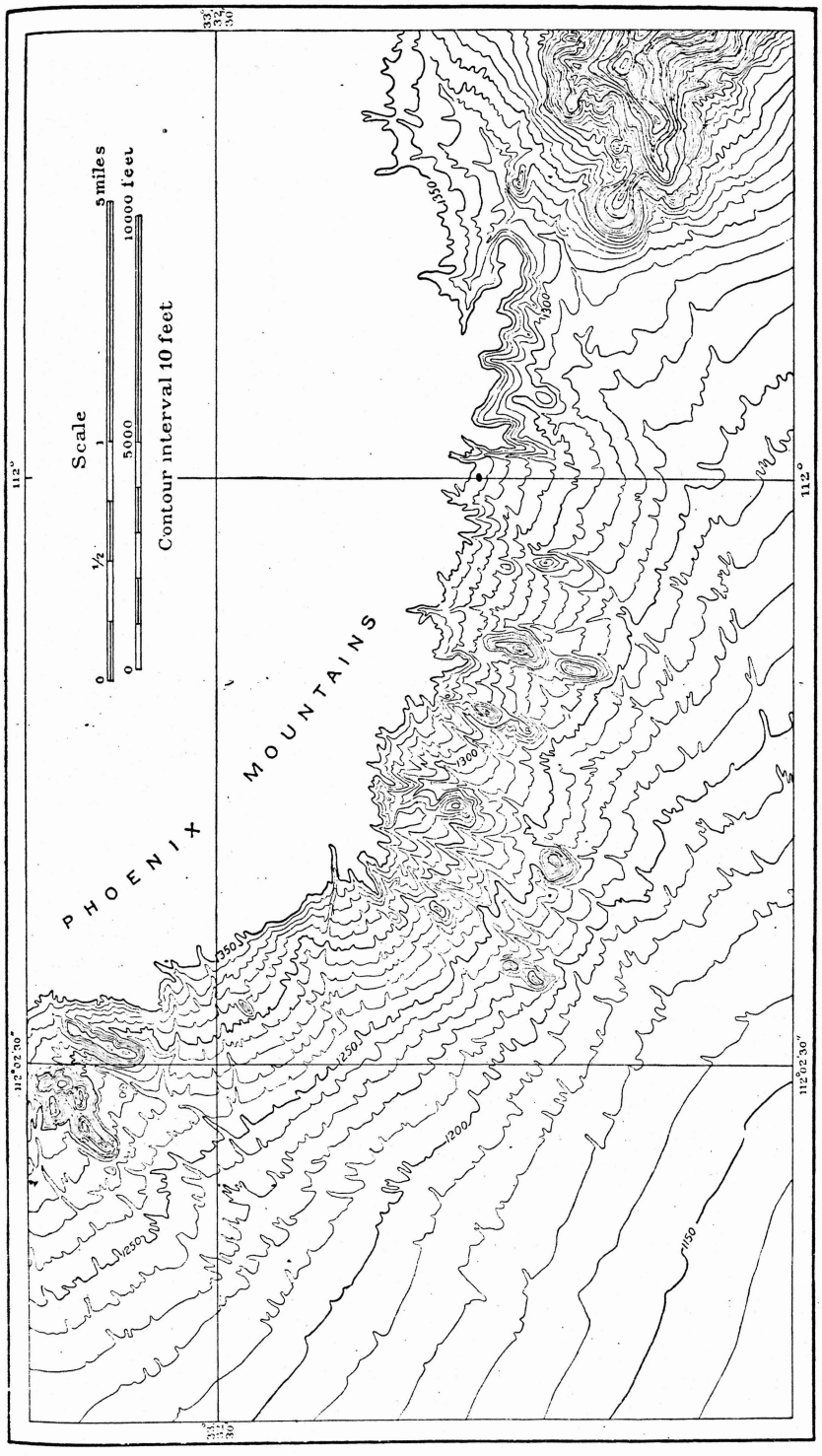
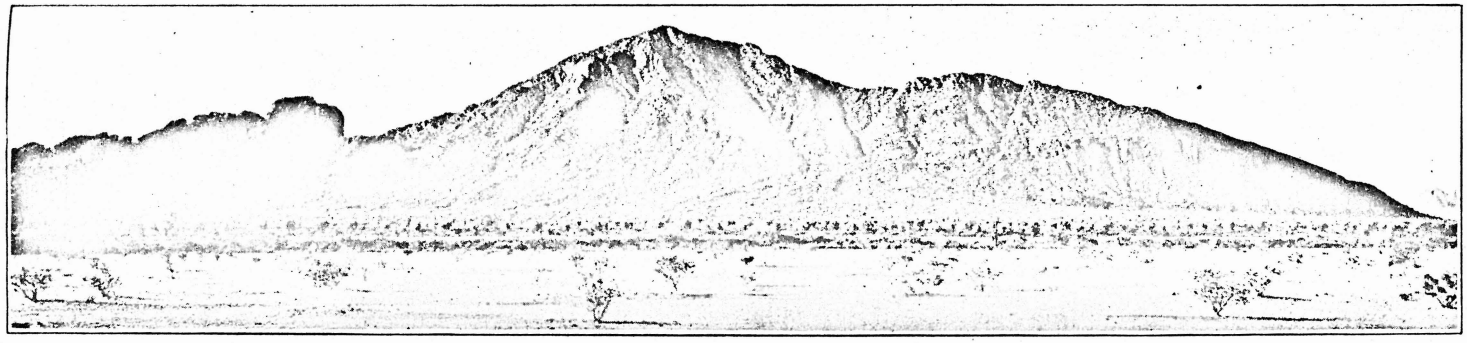
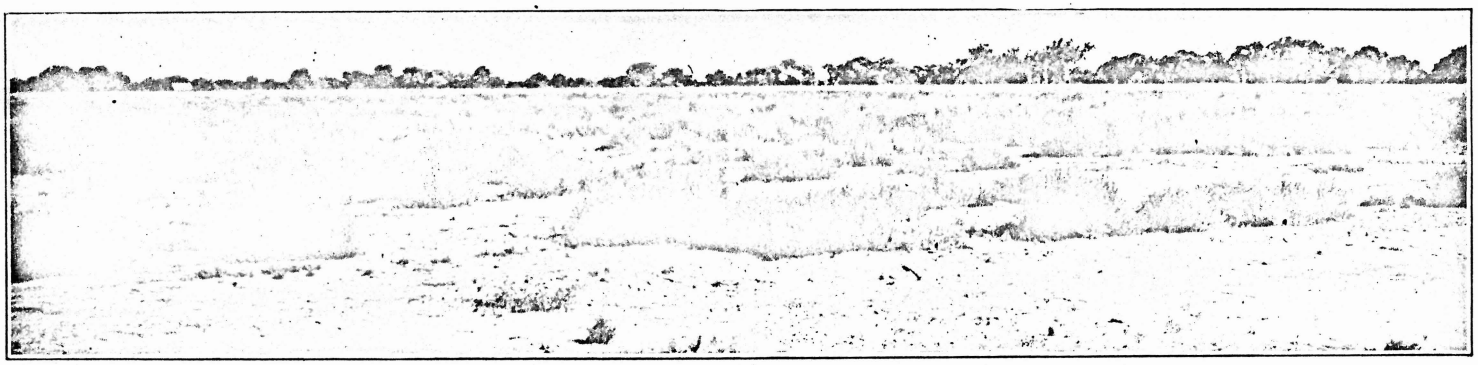


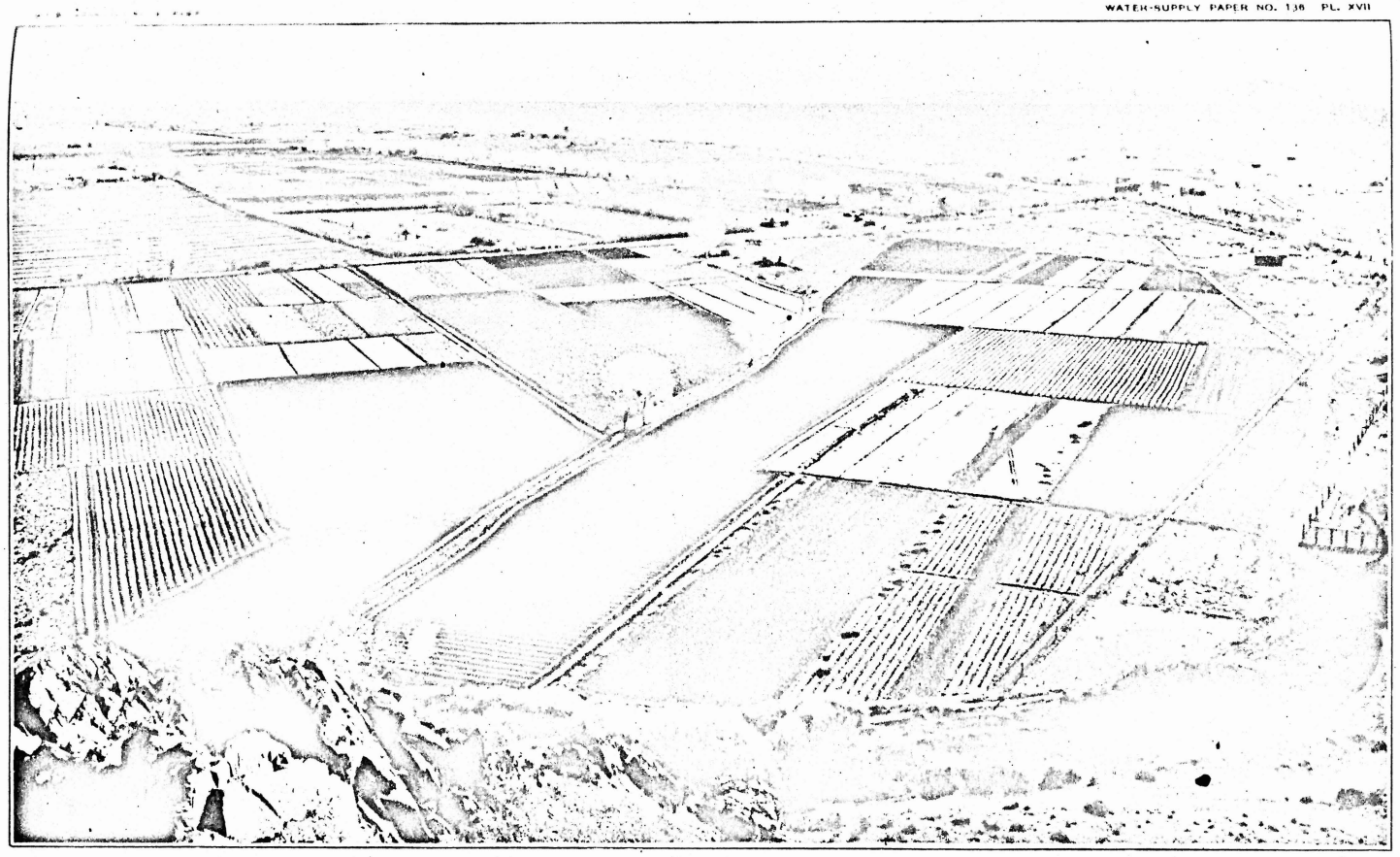
MAP OF BASE OF PHOENIX MOUNTAINS, SHOWING SMALL OUTLYING POINTS PARTLY SUBMERGED IN DÉBRIS.



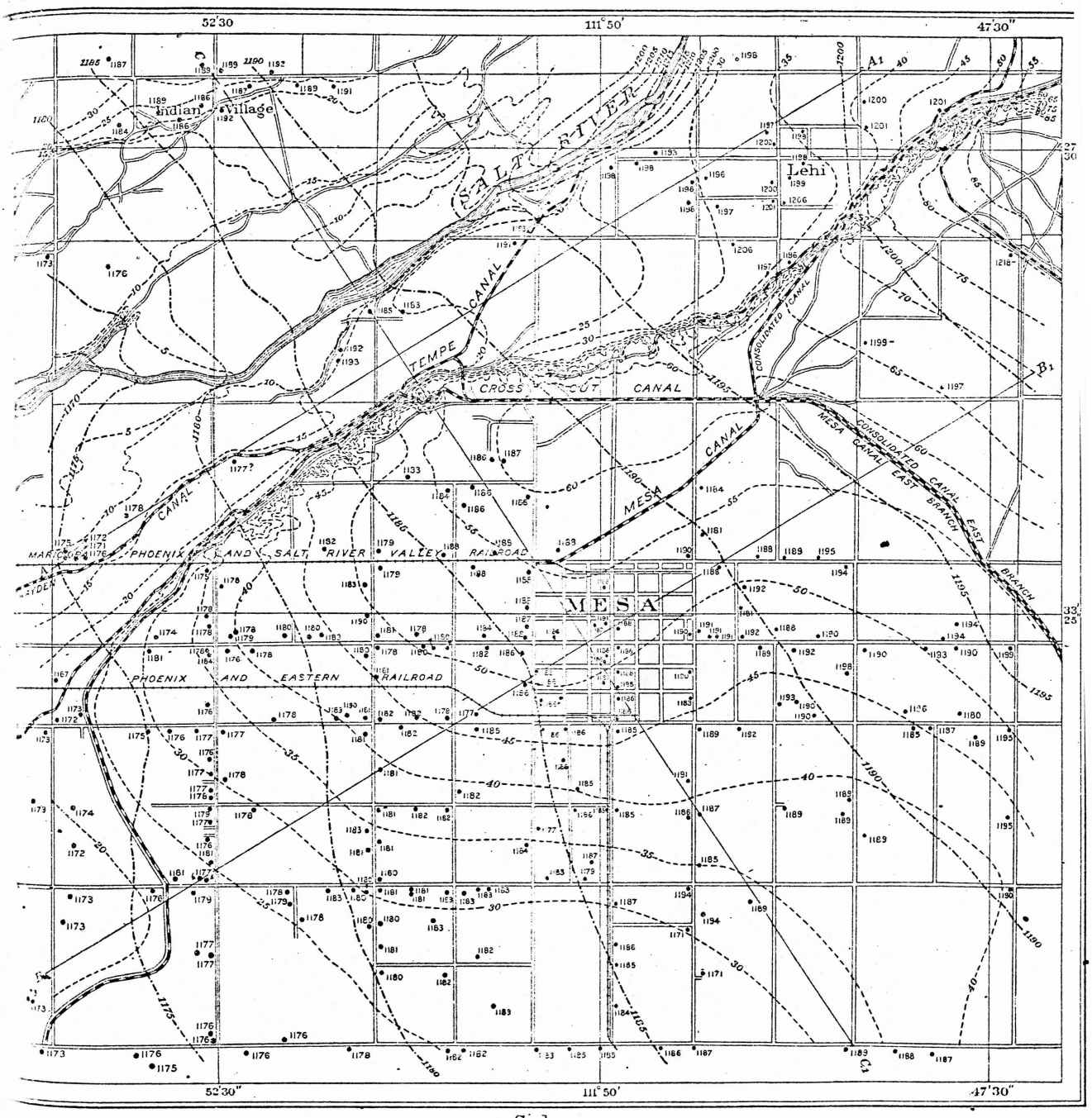
A. CAMELBACK MOUNTAIN FROM NEAR POWER HOUSE ON ARIZONA CANAL, RISING ABRUPTLY FROM DETRITAL PLAIN.



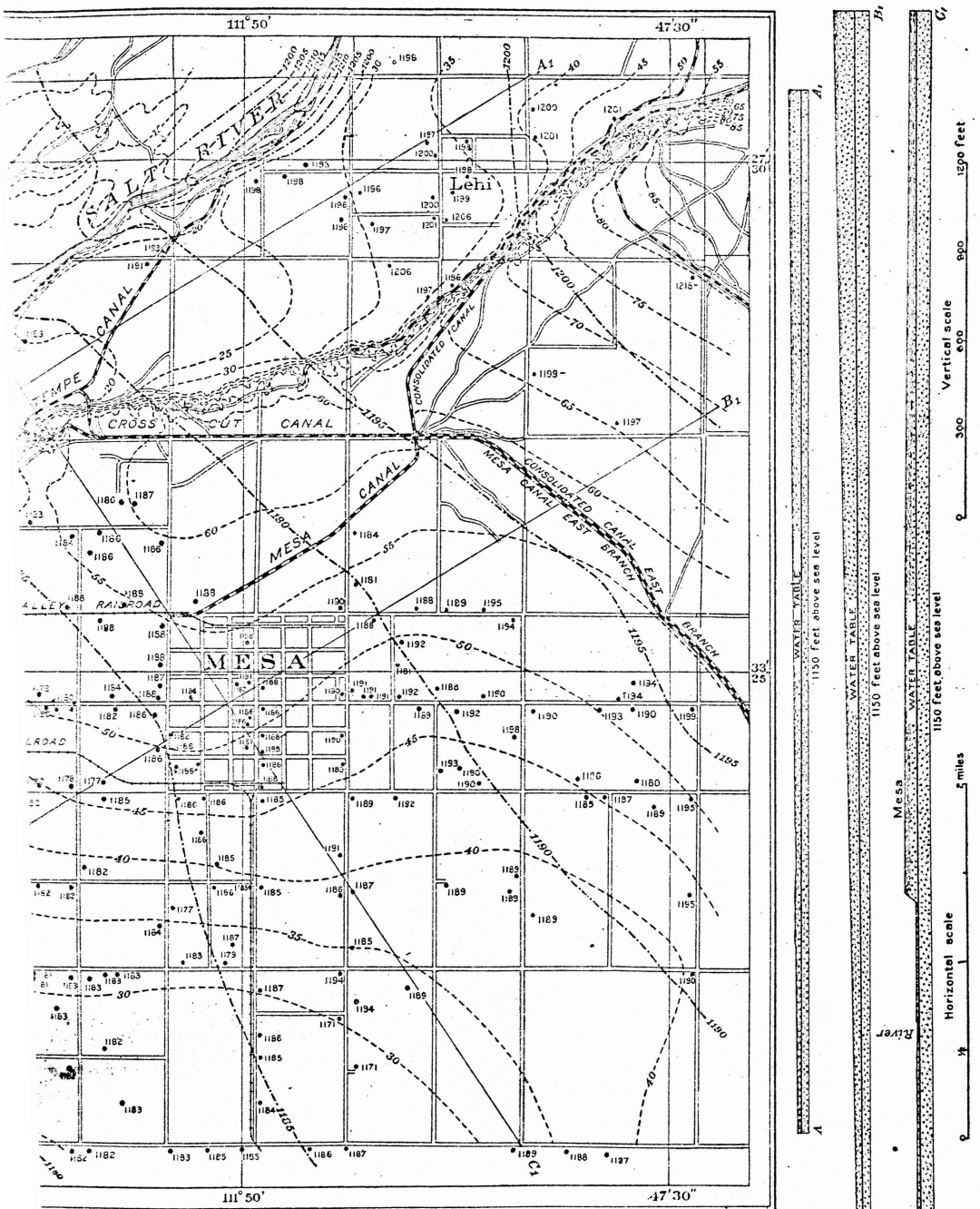
B. SEEPAGE LAND NEAR TEMPE.



VIEW EASTWARD FROM TEMPE BUTTE.



MAP AND SECTIONS OF MESA TOWNSHIP, SALT RIVER VALLEY, SHOWING POSITION OF WATER TABLE.



WNSHIP, SALT RIVER VALLEY, SHOWING POSITION OF WATER TABLE.

river, the rate of fall averaging about 10 feet per mile. The cro sections of Mesa Township (Pl. XVIII), where the wells are numero indicate that a line projected across the water surfaces in the we in any direction is practically a straight line, and furthermore th the water level in any well is practically the level of the river b at the point nearest that well. This is modified in certain cas near the river, which are described later. So regular is the surfa of the underground water that the depth to water at any point known elevation can usually be foreseen with considerable accurac

The water table as here described is not necessarily the same as t water-bearing stratum. For example, the water table at some partic lar point may be 30 feet beneath the surface. Water may or may n be found at that depth, but if found at a depth of 40 feet it will rise feet in the well, and if found at 100 feet it will rise 70 feet in the we

The shallow wells have an annual and a cyclic variation. Durin the dry summer season the water lowers more or less, and the sha lower wells become dry. During seasons of more abundant rainfa the water level rises again. There are several facts connected with th annual variation which are worthy of note:

(1) The stage of lowest water is not coincident with the driest sea son, but is reached some time after the rains begin.

(2) The water in the wells seems to stand at its maximum heigh far into the dry season.

(3) The variations in water level can not be due to rainfall in th valley for the obvious reason that not enough rain falls to supply th quantity of water represented by the variations, even if it all join the underground water.

As a matter of fact very little of the water falling as rain in th valley can enter the wells, except in certain localities where wells a obviously fed by surface water. The impervious layers of calic common throughout the valley would prevent a great amount o surface water from joining the underflow, even if evaporation allow an appreciable amount to remain permanently in the soil.

The only supply of water that is quantitatively adequate to expla the phenomena is that from the river and from the flood waters ente ing the valley from the surrounding hills. Waters move throu sand and gravel very slowly, and a greater or less time, differi according to circumstances, must elapse after the floods enter t valley before their influence can be felt in the wells. Theoretical there should be a retardation, or lagging of effect, and such is fou to be the case in the variations of the water level.

The cyclic variations may be explained in the same way, but le accurate knowledge is obtainable than in the case of the annual vari tions. During the past few years the shallow wells throughout t valley have been lowered repeatedly. South of Tempe, where t

water level is said to have been formerly within 2 feet of the surface, it is now 8 feet. At Mesa it has lowered 12 feet in four years; at the Phoenix Indian School it has lowered 20 feet in ten years. This is commonly attributed to the drought which has prevailed during the past few years. It may be partly due also to the increasing number of wells in use. The quantity of ground water is not unlimited and the operation of a large number of pumps must in time affect the supply.

The deep wells which draw their water from the lower water horizons vary to some extent, but little is yet known of them. The water level in Mr. Olsen's well rose 2 feet in less than three months, February 1 to April 14, 1903. The water in Desert well has been rising for the past eight years—during the time when the shallower wells of the valley were being repeatedly lowered to obtain water. The deeper water-bearing beds naturally draw their supply from points farther out toward the borders of the valley and the waters may have a greater distance to travel through the valley fill than those of the surface flow. It is possible also that the zigzag course which the water may follow in the valley fill is a matter of much importance. If the ideal section given in fig. 3 represents actual conditions, water from the river would pass laterally six times partly across the valley before reaching the lowest gravels. At the rate of flow as described later on it might take many years for water to make such a journey. The waters of any particular flood may not reach the deep wells until several years after the flood occurs.

It is likely, however, that the water level in a particular well would be affected by a flood long before the waters of that flood actually arrived at the well. Much as a wave may travel faster than the water composing the wave, so there may be waves or pulsations in the underflow due to the entrance of flood waters. The smaller pulsations—the annual ones—might and probably do appear in the shallow wells. These smaller pulsations may become imperceptible where they travel far, and may merge into cyclic pulsations, which alone affect wells far from the source of supply—for example, the Desert well.

On account of these variations of the water table certain allowances must be made in applying the accompanying maps which indicate by contours the elevation of the water table and the depth of this table beneath the surface. At a certain point, for example, the depth to water was 20 feet when the map was constructed. At some future time the depth may be greater or less than 20 feet according as the volume of underground water may have increased or diminished.

THE RIVER AND THE UNDERFLOW.

The river is considered the most important source of the underflow. There is a permanent water supply in it from the head of the valley to

the Tempe canal, north of Mesa. Below the head-gates of the Tempe canal a short space occurs in which the river is practically dry for the greater part of the year. Farther downstream underground water returns to the river bed; that is, the river cuts beneath the water table and the underflow returns in part, making a surface flow of something like 35 second-feet. It is evident, therefore, that from the head of the valley to the Tempe canal the surface flow of the river is at a higher level than the general surface of the underground water on either side. Wells sunk near the river indicate that the depression

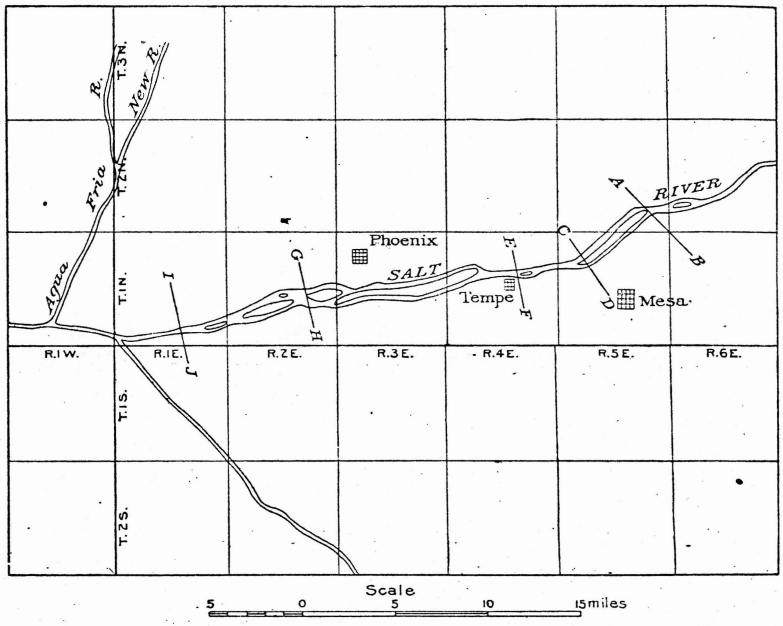


FIG. 19.—Index map of Salt River Valley, locating the sections shown in Pl. XIX.

of the water table from the river laterally is very abrupt. This is indicated by the contours of the water table as given on the map, Pl. XX, and in the sections of Pl. XIX. The fact that a permanent flow of water exists in the river at the upper end of the valley at an elevation higher than the surface of the underground water of the valley in general is of prime importance in understanding how the water enters the valley fill.

North of Mesa the river bed is at the same elevation as the water table, while at Tempe the river bed is below the water table. This explains the return of the underflow to the surface, making a perennial stream at Tempe, while the river bed both east and west of Tempe is dry. The reason for the approach of the water table to the surface near Tempe requires further explanation.

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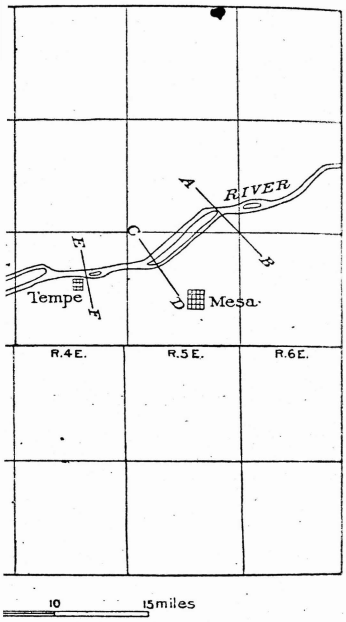

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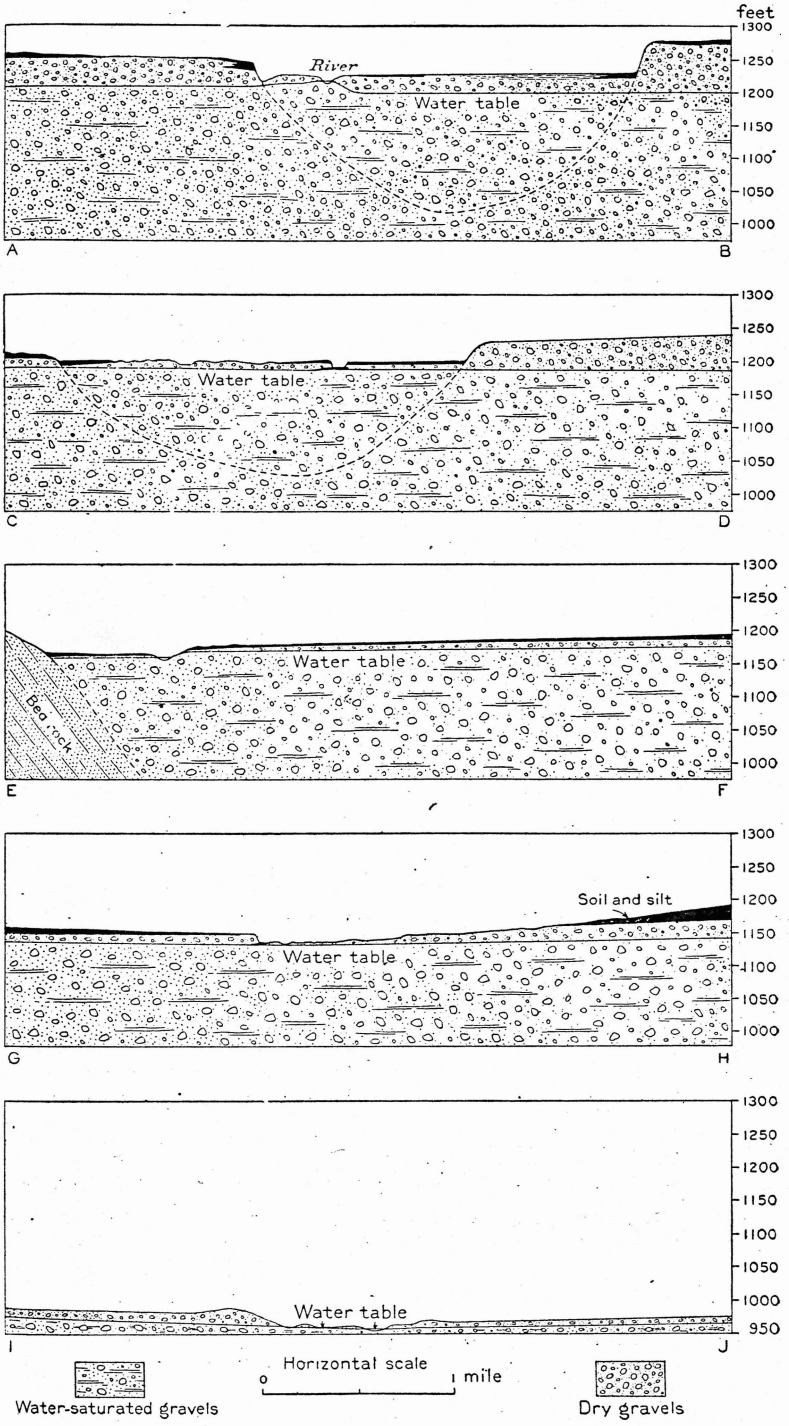

SECTIONS INDICATING RELATION OF WATER TABLE TO RIVER AND LAND SURFACES.

COURSES OF THE UNDERFLOW.

At Tempe the river flows practically on bed rock. The andesite and the red sandstones of the butte are exposed down to the water's edge. The river passes through a narrow channel between Tempe Butte and the conglomerate hills to the north. From Tempe northward to the Phoenix Mountains bed rock appears at the surface for the greater part of the distance. Where it is not exposed it is encountered in wells at no great depth. A glance at the contours of the water table of the township north of Tempe (T. 2 N., R. 4 E.) will reveal the fact that this table is 90 feet higher east of the buttes than it is about 2 miles farther west. There is then no free passage for the underflow north of Tempe except through the gravels in the immediate channel of the river.

Southwest of Tempe, Bell Butte rises from the level valley floor about midway between Tempe Butte and the Salt River Mountains. No deep wells have been drilled between Tempe and Bell Butte to indicate the underground conditions, the nearest being that of H. L. Chandler, one mile south of Tempe. This well indicates that loose gravels and bowlders extend to a depth of at least 186 feet. This would seem to indicate a free passage for the underflow between Tempe and Bell buttes. On the other hand, there is a sharp decline of the water table to the west in this region. North of Bell Butte a depression of the water table of 16 feet within half a mile was observed. South of Bell Butte a still sharper decline occurs, depressing the water table 10 feet in less than a quarter of a mile. The line along which this depression of the water table takes place is one passing from Tempe Butte through Bell Butte to Salt River Mountains.

As previously described in D. B. Heard's well, situated at the southwest corner of section 30, bowlders were encountered to a depth of 90 feet, beneath which granite wash occurs, probably from the mountains to the south. The wells at the Valley Seedless Grape Company's vineyard, 4 miles south of Tempe, and the two wells drilled in the same region by Mr. Heard indicate that the water-bearing bowlder bed hardly reaches that point. It is evident, all things considered, that the underflow so voluminous and extensive in the Mesa region does not find free passage to the Phoenix region past Tempe.

In explanation of this, there is a belief somewhat widespread in the valley that the passage is obstructed by a subterranean dam formed either by volcanic activity or by the formation of a cement reef across the valley. After what has been said of the formation of caliche, or cement, it seems evident that the continuous passage of the underflow would prevent any cement from forming across the valley which could in any sense act as a dam, and this postulate may be dismissed without further comment. The suggestion of a volcanic dam finds some con-

firmation in the presence of the andesite of Tempe and Bell butt. As previously described, the uplift of Tempe Butte occurred in co paratively recent time, but whether the formations of the lava of Tem and Bell buttes and the subsequent local movements occurred after t excavation of the valley or had anything to do with the obstruction the underflow remains a matter of conjecture. In the mind of t writer, the phenomena about Tempe find most rational explanation the change of the course of the river described below.

In order to place pumping plants where they will be most productiv it is a matter of prime importance to know the nature and course o

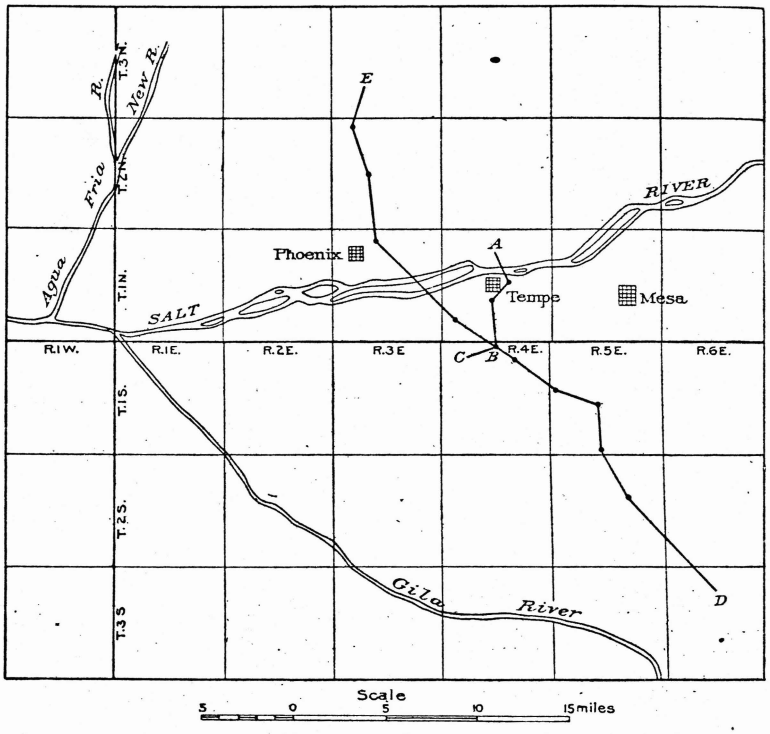

FIG. 20.—Index map of Salt River Valley, locating the sections shown in Pl. XXI.

the underflow. It is believed by some that the water is virtually stagnant and held in the gravels as water is held in a sponge. The "underground lake" is a familiar expression in the valley. A still more common expression is "the underground river." It is scarcely necessary, after what has been written, to explain that no underground lake and no underground river, taken in the popular sense, exist. There is, however, a slow movement of the underground water down the valley, which is designated as the underflow. Whether the underflow is as wide and as deep as the valley fill, or whether there are certain restrictions both laterally and vertically, directing the flow in certain courses, depends entirely upon the structure of the valley fill.

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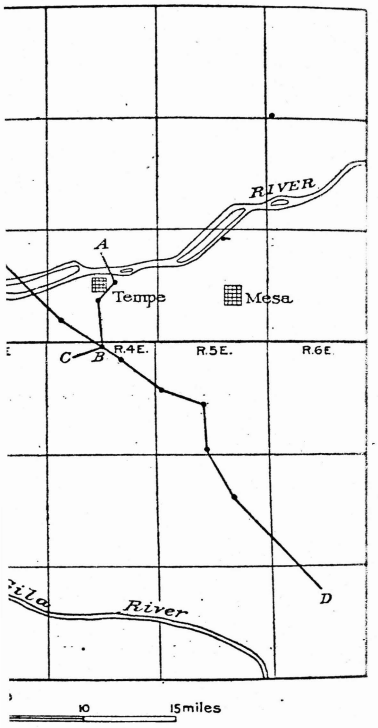

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There is also to be considered the possibility that the ancient course f the river was not the same as the present course. Enough has been ritten to indicate that there are restrictions, and that the great volume f the underflow passes through a comparatively narrow space. The lley, filled as it has been both by wash from the hills and by sands d gravels brought down the river, would naturally yield abundant ater only where the valley fill is sufficiently open to allow a free pas-ge of water. The wash from the hills along the outer portions of e valley, while coarse enough to allow free passage of water in places, very frequently cemented to a practically impervious mass. Some ells obtain a good supply from this wash, but there are many that ave failed because they were in the wash. The most productive wells re in the beds of river gravel and bowlders.

ANCIENT RIVER CHANNELS.

Since it is always the river that is making the deposits of gravel and owlders through which water passes most readily, it naturally follows at the bowlder beds mark the ancient courses of the river. It further-ore follows that the present course of the underflow is in general the ourse of the ancient river that deposited the gravels and bowlders in hich the underflow occurs. It remains, then, to determine the old ourses as accurately as possible in order to place the pumping plants the most advantageous localities. At first thought this course ould be in general down the valley, parallel to the river. But a little flection indicates that this is not necessarily the case. As the floor f the valley was raised by the deposition of débris, the river shifted om side to side of the valley. When the level of the rising valley oor reached the saddle of some spur or divide the river might pass er this divide, leaving its former course at one side. This is proba-y what Salt River has done in comparatively recent times. On this oint the following facts are to be noted:

(1) In the Mesa region water-bearing gravels occur to a depth of at ast 620 feet (Murphy-McQueen well) and extend at least as far south the Chandler well No. 5, 12 miles south of Mesa.

(2) It is in these gravels that some of the best producing wells of e valley are located.

(3) There is an obstruction of some kind, as previously described, eventing a free passage of the underflow downstream at Tempe. ch well records as are available indicate that the gravel-filled valley ar Tempe may be comparatively shallow.

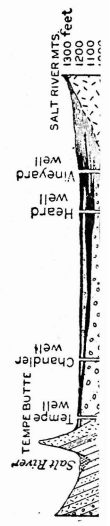
(4) Between Salt River Mountains and Sacaton Mountains is a broad nearly level plain extending without interruption from the Mesa gion to Gila River. It is an aggraded plain underlain by water-aring gravels and connecting with the water-bearing gravels of the la, described in a previous paper by the writer.[a]

[a] Lee, W. T., Underground waters of Gila Valley, Arizona: Water-Sup. and Irr. Paper No. 104, U. S. Geol. Survey, 1904.

(5) At a point in Gila Valley where the waters passing as underflow through the gravels between the two groups of mountains just mentioned would naturally be expected to appear underground water returns to the surface in considerable quantity. At this point there is the somewhat novel phenomenon of a perpetual lake in the midst of a desert where evaporation is about ten times greater than the rainfall. This lake is not fed by Gila River, as is evident from the fact that the river is dry for a distance of about 50 miles above the lake during the greater part of the year. It is not fed from flood waters, since floods are seldom of sufficient volume to enter it. There is furthermore a constant and regular discharge of water from the lake. The only obvious source of supply is the underflow of Gila and Salt rivers.

An attempt has been made to show graphically the underground conditions across the valley at Tempe (Pl. XXI, *A*) and across the space between the Salt River Mountains and the Sacaton Mountains (Pl. XXI, *C*), so far as those conditions are known or can be reasonably inferred from the data at hand. It should be explained in this connection that these sections are so chosen as to pass through such deep wells as are known, thus making a section along a broken line. The depth of water-bearing gravels there indicated should not be interpreted as the depth of the passage open to the underflow. The crest of the subterranean ridge which is thought to exist is probably about a mile west of the line represented in section A, as indicated by the shallowness of the gravels at Heard's well and the sharp depression of the water table already described.

The evidence at hand leads clearly to the inference that in former ages Salt River joined the Gila east of the Salt River Mountains instead of occupying its present course north of those mountains. It has been argued with some degree of plausibility that the chemical character of the water throws doubt upon this hypothesis. The waters of the Salt River underflow as represented in the Olsen and Hansen wells, contain much greater quantities of salts than do the waters of the Gila underflow. It has been argued that waters so saline could not feed in any great measure an underflow such as that of Gila Valley. It should be noted, however, that the water from the Chandler wells farther to the east is less saline. For convenience of comparison there are placed, below, the analyses of four samples of the Gila underflow. (All water in this part of Gila Valley at ordinary times comes from the underflow.) In the same table are included the analyses of waters from the Salt River underflow, so selected as to give as wide a range as possible within the region which presumably feeds the Gila underflow. It appears from a comparison of these analyses that although the waters from the Hansen and Olsen wells are much more saline than the Gila underflow, those from the Chandler wells are



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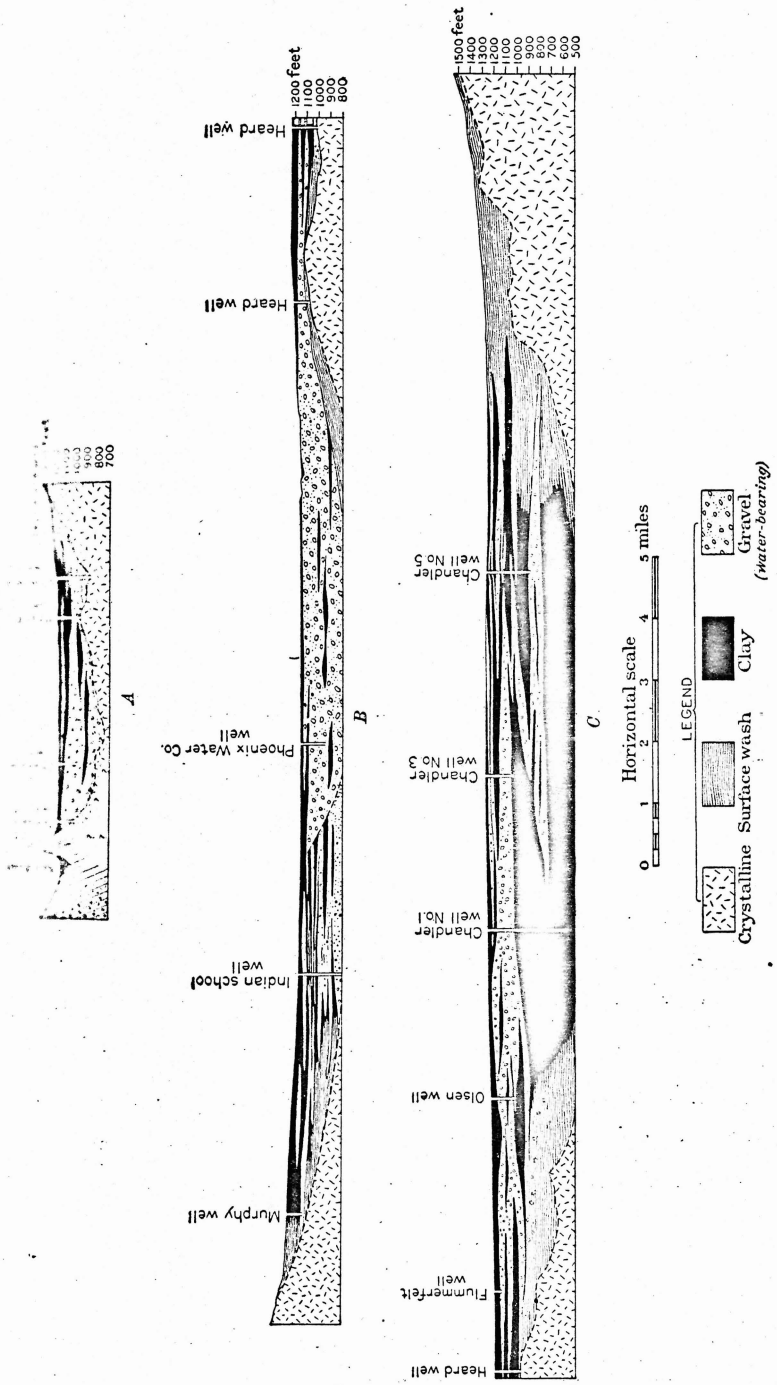

A. SECTION THROUGH TEMPE BUTTE TO SALT RIVER MOUNTAINS, ALONG THE BROKEN LINE A-B-C, FIG. 20.
B. SECTION ACROSS SALT RIVER VALLEY NEAR PHOENIX, LINE B-E, FIG. 20.
C. SECTION FROM SALT RIVER MOUNTAINS TO SACATON MOUNTAINS, LINE B-D, FIG. 20.

practically the same as the Gila underflow. It is entirely possible that the Chandler wells are in or near the course of freest flow where salts have either failed to find lodgment or if deposited in former times have been carried away by the comparatively free sweep of the waters, while the Olsen and Hansen wells may draw from water which, for some reason, is comparatively sluggish and therefore more saline, since the gravels in which it is held are not freely washed by a constant inflow of water.

Analysis of water from the underflow of Salt and Gila rivers, Arizona.

FROM GILA VALLEY.

	Lake in Gila Valley.	Cooperative Co.'s ditch, Gila Valley.	Gila River seepage.	Well at Presbyterian mission, Gila crossing.
Quantitative (parts in 100,000):				
Total solids soluble at 110° C	107.0	106.0	127.0	160.0
Chlorine in terms of NaCl (common salt)	61.2	62.8	76.4	110.8
Hardness in terms of $CaSO_4$ (sulphate of lime)	2.72	13.1	12.5	28.4
Alkalinity in terms of Na_2CO_3 (black alkali)	.....	.....	.....	.....
Nitrogen in the form of nitrates	.....	.....	.....	.....
Nitrogen in the form of nitrites	.....	.....	.....	.....
Qualitative:				
Sulphates	Very strong.	Strong.	Very strong.	Very strong.
Magnesia	Strong.	Strong.	Strong.	Strong.
Lime	Strong.	Strong.	Strong.	Strong.
Bicarbonates	Strong.	Strong.	Pronounced.	Strong.

FROM SALT RIVER VALLEY.

	Chandler well No. 1 (after 15 months' pumping).	Chandler well No. 1 (after 24 months' pumping).	Chandler well No. 3 (after thorough pumping).	Olsen well.	Hansen well (after several months of constant pumping).
Quantitative (parts in 100,000):					
Total solids soluble at 110° C	127.4	179.0	84.8	381.0	442.0
Chlorine in terms of NaCl (common salt)	75.6	116.8	44.6	235.2	311.0
Hardness in terms of $CaSO_4$ (sulphate of lime)	23.1	53.3	18.5	59.84	151.2
Alkalinity in terms of Na_2CO_3 (black alkali)	None.	None.	None.	None.	None.
Nitrogen in the form of nitrates	.07	Trace.	.266	2.0	Trace.
Nitrogen in the form of nitrites	Traces.	None.	Traces.	Faint.	.01
Qualitative:					
Sulphates	Strong.	Very strong.	Strong.	Very strong.	Very strong.
Magnesia	Distinct.	Strong.	Distinct.	Strong.	Strong.
Lime	Pronounced.	Strong.	Strong.	Very strong.	Very strong.
Bicarbonates	Strong.	Strong.	Very strong.	Very strong.	Distinct.

PRINCIPAL COURSES OF UNDERFLOW.

While it is not probable that the underflow in this region follows a channel that is in any sense well defined, there are without doubt courses along which the flow has a maximum velocity, and others along which it has a minimum velocity. It is entirely conceivable, also, that there are places where the water is virtually stagnant. The underflow may be compared with the water of a swamp. It is one body of water, but communications between various localities are not equally free as in the case of a lake. Nor is the flow conceived to be as nearly uniform as in the case of a river. The water finds its way through the gravels along paths of least resistance, sometimes straight and sometimes circuitous. It should not be inferred, therefore, from reference to the principal course of the underflow, that anything like a definite channel is meant.

From a consideration of all available data it seems clear that the ancient course of the river and the present course of a large part of the underflow are east of the Salt River Mountains. It is probable that at a comparatively late stage in the course of the accumulation of the valley fill the gradually rising floor of the valley reached the level of the saddle between the Salt River Mountains and the Phoenix Mountains and found a shorter and easier passage than the circuitous route around the former. As the valley floor was still farther raised by the deposition of débris, and as the river passed its aggrading and degrading stages previously described, its course may have changed repeatedly, sometimes north of the Salt River Mountains and sometimes east and south of them. While the débris accumulating along its course is deemed the chief cause of the lateral migrations of the river, certain changes may have been caused by volcanic action and local movements in the vicinity of Tempe, as previously suggested.

This postulate explains in a rational and natural way the peculiarities near Tempe already described. There is probably a subterranean dam across the present valley at Tempe, which prevents the passage of the principal part of the underflow. It is not a dam thrown across a previously existing valley, but one which was formerly a ridge at the side of the valley and which was buried by débris as the valley was filled. It is probable that only the waters from the upper horizons of the gravels of the Mesa region find their way over the top of this submerged ridge into the underflow of the Phoenix region.

SOURCES OF THE UNDERFLOW.

One of the most notable features about the valley fill in the Mesa region is the thick bowlder bed covered with impervious clay. It occurs in the center of the valley, while toward the sides the bowlders

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give place to the finer material. The water in the bowlder bed is under considerable pressure, while above the clay which confines it occur water bodies of limited extent, forming what is locally known as the surface flow. In certain places the surface flow is under slight pressure, while in others it is under no pressure, but the underflow and the surface flow form a single water body, as evidenced by the definite water table. The questions naturally arise: How are the waters connected? whence do they come? and how do they get into the ground?

There are several possible sources—(1) rainfall soaking into the ground; (2) underground water in the form of springs or artesian flow entering the valley from foreign regions; (3) streams and sheet washes entering the valley from the surrounding hills during times of abnormal precipitation.

(1) The rainfall is so slight—an average of little over 7 inches per year in the valley—that it could supply but a very small part of the underground water known to exist, even if it did not evaporate before entering the soil to any great depth. It is probable, however, that little if any of the water from rains in the valley finds its way to the underflow. At best it could only join the surface waters owing to impervious clay and cement layers separating these waters from those beneath.

(2) The hills surrounding the valley are composed principally of crystalline rock. There is no known possibility of water entering the valley in any form of artesian flow, and springs from the hillsides are so small that they may be disregarded.

(3) The only source which is quantitatively adequate to supply the known amount consists of the streams, chief among which is the Salt River system. There seems to be little doubt that the underflow is connected directly with the river.

In order to understand clearly how the waters enter the underflow it is necessary to know how the valley fill was deposited. In former ages Salt River Valley was a broad, deep valley of erosion, at least 1,305 feet deeper than it is at present. How much deeper, is impossible to say, for no well has penetrated beyond that depth. By some change in the altitude of the land or change of climate, perhaps both, the streams were changed from degrading to aggrading streams. The water could no longer carry all of its load. River débris accumulated as it is still accumulating. The coarser material was dropped in the channel, while the clay and silt accumulated on the floodplain, and cement formed near its surface. As the channel became choked with gravels and bowlders the stream shifted gradually, covering the clay and cement already deposited, while these materials in turn slowly accumulated over the gravels and bowlders of the abandoned stream

courses. As the river swung from side to side of the valley, gravel and bowlder beds were always left in its wake; furthermore—and this is the key to the problem—wherever a bowlder bed was formed a bowlder train filling the old channel connected and probably still connects this bed with the mouth of Salt River Canyon, whence the water, together with its débris, issued then as it does now.

While Salt River was the main factor in the formation of the valley fill the tributary streams and sheet washes played some part. Each stream, no matter how small, left a train of gravel leading into the valley fill, and in a small way migrated from side to side, as did the river. Permanent streams, no matter how small, kept a constant connection with the river, and their ancient gravel trains probably still form comparatively free subterranean passages for water into the general underflow. But nowadays the small stream courses, even streams as large as Queen and Cave creeks, do not reach the river but are lost in the valley fill. Judging the past by the present, similar relations may have obtained then. Such streams as Queen and Cave creeks might form their valley trains from the hills into the main valley for a considerable distance, and perhaps form a considerable bed of loose material through which water would flow readily, but the connection with the bowlder beds of the main stream might be cut off by impervious beds of clay or cement. Such beds might form water pockets in the valley fill, and under certain conditions yield flowing wells. However, no water pockets have been found in Salt River Valley yielding flowing water.

At the present time, while the streams are depositing their débris in the bottoms of the valleys, the granitic hills about the valley are forming granitic sand which slowly works its way down to meet the advancing accumulation of the river fill. Judging the past by the present, the outer edge of the valley fill is composed largely of granitic sand or arkose. This material is more or less pervious, and the waters shed from the hillsides sometimes sink quickly into it. Since it is only on the old flood plains that impervious clay layers were formed, these layers, so potent in the middle of the valley, where they are penetrated by the wells, do not exist near the edges of the valley, where both clays and gravel beds pass laterally into the accumulations of arkose. Thus the water, whether from the river, or from a tributary stream, or from a sheet wash from the hillside, finds its way always downstream into and through the valley fill underneath the impervious layers or wherever the trains or sheets of gravel lead.

The gravel trains thus form a network through the valley fill, connecting the principal bowlder beds, and leading back in every case to the stream which formed them. It is evident, therefore, that the underflow, although seemingly divided by impervious layers, is one

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body of water, although the avenues of communication may be extremely tortuous and complicated. It thus results that the water of the underflow, whether from an upper or an under stratum, rises to a definite level which forms a comparatively uniform "water table," the gradient and local variations of the table being due to the varying resistance offered by the gravels to the passage of the water.

THE PHOENIX REGION.

The physical features of the Phoenix region differ in but few important respects from those of the Mesa region, and need be described only in so far as they differ in some essential manner. The principal part of this area consists of a broad plain, sloping gently southward to Salt River. Cave Creek enters the region from the north, and is lost upon the plain in a manner resembling that of Queen Creek in the Mesa region. At the western border of the region the Agua Fria and New River have definite channels extending over the plain to join the Gila.

DISTRIBUTION OF MATERIAL.

At the eastern border of the region granites, lavas, and the older sediments occur, as described in Chapter II. From Tempe westward to the Crosscut canal and thence northward and westward the valley fill abuts more or less abruptly against the older formations. The asylum well penetrates gravels to the depth of 110 feet without reaching bed rock, while 2 miles to the east bed rock appears at the surface. In the Murphy well, 325 feet deep, 115 feet of valley fill is penetrated, below which the breccia is encountered. Two miles to the east the breccia emerges from the surface to form the buttes north of Tempe.

In the southern portions of the region near the river the valley fill, as indicated by the well records, is composed mainly of river gravels and bowlders. It appears, from the occurrence of gravels in the Heard and McCallum wells, that the bowlder bed continues well southward toward the mountains. This southward extension is in harmony with the southward trend of the streams at the present time, as well as the southward trend of the ancient river, as indicated by the bowlder beds and the underflow of the Mesa region. While it is always unsafe to make predictions in matters so uncertain as underground conditions, the indications so far as known point to more favorable conditions for pumping south of Salt River than north of it.

A study of the well records in the light of what has already been said respecting surface oscillations, and the resulting stages of degradation and aggradation, leads to the belief that the bowlder bed underlying Phoenix is somewhat abruptly terminated at the north, as indicated in the section, Pl. XXI, *B*. The several wells in the vicinity of Phoenix enter bowlder beds differing in no essential manner from

those in the Mesa region except that they are, so far as known, comparatively free from cement. Three miles north of the Phoenix waterworks, the Indian School wells penetrate no bowlder beds nor any material that could not rationally be attributed to the action of small streams from the north and to wash from the hills. At some point, therefore, in the 3 miles intervening between the Phoenix well and the Indian School there is a transition from the bowlder bed to comparatively fine material. This transition has been shown in the section as abrupt, since the bowlder bed is regarded as equivalent to the younger beds of the Mesa region, while the finer material corresponds in age to the older Mesa gravels. During the stage of degradation intervening between the two periods of accumulation it is thought that a broad valley was cut in the older deposits similar to that described in the Mesa region, and that during the later accumulation this valley was not only filled, but the bordering bluffs were buried by the younger accumulation.

North and west of Phoenix gravel beds are few, and sand, cement, and wash make up the principal part of the valley fill. While there are a great many drilled wells in this region, there are few for which definite records were kept. The meager data obtainable are noted in Chapter I. Several wells reach gravel beds, but the extent of such gravels is unknown. Since, with few exceptions, the wells are small, being intended only for domestic use, they do not penetrate through the gravel beds. A few wells, such as the Bartlett well, the Kellner well, and the Indian School wells, have been sunk deep enough to indicate that the bowlder beds of the southern part of the Phoenix region do not extend far to the north. No accurate record of either the Bartlett well or the Kellner well is obtainable. It is thought, however, that had bowlder beds been encountered, their presence would be known, if for no other reason, because drilling machinery such as was employed in constructing these wells has proved inadequate to go through bowlders such as are found in the southern part of the region. It is probable that gravel beds of considerable volume occur, but they seem to be more or less separated. If water pockets are to be found in Salt River Valley with water under pressure sufficient to produce flowing wells, it would appear from theoretical considerations that the northern part of the Phoenix region is the place where they might reasonably be expected; but while many shallow wells have been sunk in this region, no well has yet penetrated to a sufficient depth to test this possibility. The Bartlett well, 311 feet deep, is the deepest well put down, and, according to the best account to be obtained, water under considerable pressure was encountered.

GEOGRAPHIC CHANGES.

On account of the great importance of this subject to those who may consider the construction of wells for irrigation purposes, emphasis is put on it at the risk of repetition. During stage B (see fig. 14) a thickness of more than 1,300 feet of débris was deposited in the Mesa region, closing with the great bowlder beds. During the greater part of this time, and perhaps until the close of stage B, Salt River flowed east of Salt River Mountains. The Phoenix region in the meantime was without the controlling influences of Salt River. Its aggradation was due to wash from the hills and to the débris of comparatively small streams. The material thus brought into the valley was comparatively fine; some of the larger streams formed gravel beds, but no great accumulation of bowlders took place. During stage C Salt River was flowing in or near its present course north of Salt River Mountains, and was cutting away the deposits previously laid down, and at the same time was deepening a passage through the rock ridge near Tempe. This passage is narrow, as would naturally be expected, on account of the hardness of the rock.

During the second period of accumulation (D) the new channel, or secondary valley, was filled, as was the case in the Mesa region, and since this secondary valley in the Phoenix region was now the course of the river, it was filled principally with coarse material, and to an extent sufficient to bury the bluffs, obliterating from the surface all evidence of such a valley. The recent river accumulations of the Mesa region and the bowlder beds of the Phoenix region are regarded as equivalent and directly connected through the comparatively narrow passage at Tempe.

WATER TABLE.

From what has been written it appears that the water table of the Phoenix region assumes neither the definiteness nor the importance of the water table in the Mesa region, where there is free communication between the water-bearing formations. At certain points in the Phoenix region communication seems to be wanting, as is shown in the Indian School well; at other places communication is poor. The water supply in the northern part of the Phoenix region is comparatively limited, and yet there is an inclination of the water table in places of 20 feet or more to the mile. Such a gradient could scarcely be maintained unless the passages through which the water finds exit presented formidable obstructions.

EXTENT OF BOWLDER BEDS.

The northern boundary of the bowlder bed west of Phoenix is not known. The Harris well is 7 miles west of Phoenix and 5 miles north of the river; the ostrich-farm well is 9 miles west of Phoenix and 5 miles north of the river; and the Kellner well is 14 miles west of Phoenix. The bowlder bed of the southern part of the Phoenix region was not encountered in either of these wells. It is probable that the bowlder bed will not be found much, if any, north of the Salt River canal. Thence northward the chances of finding water sufficient for successful pumping plants grow progressively less, (1) because of the increasing depth to water; (2) because of the scarcity of water-bearing material; (3) because of the limited supply of water; and (4) because of the evident want of easy communication between the various beds of water-bearing material. So far as known the underground water throughout the Phoenix region is amply sufficient for domestic use. Certain wells would probably yield a moderate supply for irrigation for a time. It is evident, however, that a pumping plant to be permanently successful must be in such a position as to draw freely from the underflow of the river, the only permanent and adequate supply. Extensive pumping would soon exhaust the limited supply from the north. If my interpretation of the underground conditions, as indicated in the history of the valley fill and presented graphically in the section across the valley (Pl. XXI), be correct, it is probable that pumping on an extensive scale would not be permanently successful anywhere north of an east-west line passing 1 or 2 miles north of Phoenix.

South of this line, however, there is every indication that pumping plants could be successfully operated. The known volume of the bowlder bed near Phoenix indicates that a similar volume is to be expected downstream. The great productiveness of the pumping plants now in operation near Phoenix, described in Chapter I, indicates an abundant water supply wherever the bowlder bed is found. The readiness of movement evidenced by the large output, and the rapidity with which the water regains its normal level in the wells when the pumps stop, indicate conditions most favorable for profitable pumping. The return of the underflow to the surface a few miles west of Phoenix and thence westward, making a surface flow of considerable volume in the Buckeye region, indicates a volume of underflow which promises permanency of supply.

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CHAPTER IV.

ECONOMICS.

It remains to inquire into the practical application of the information presented in the preceding chapters. The end in view is the determination of the quantity of underground water available for irrigation, its adaptability for use in irrigation, and the best means of obtaining it. To this end I shall consider the area in which the underflow occurs, the chemical character of the waters, the volume of the underflow, the cost of pumping, and the location of pumping stations.

AREA OF PROFITABLE PUMPING.

The utility of pumping plants is determined largely by two considerations: First, the lift; and, second, the freedom of movement of the

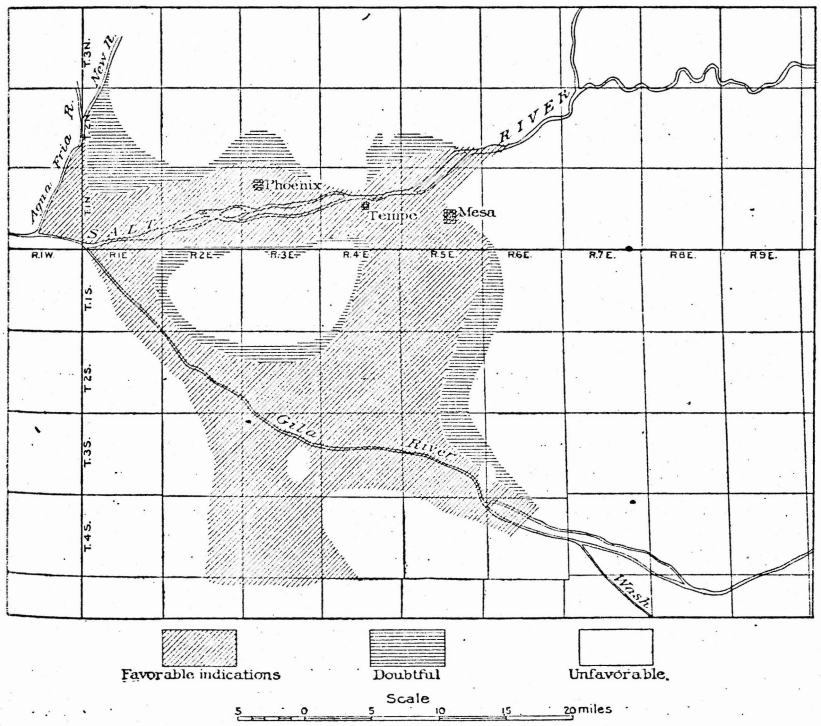

Fig. 21.—Map of Salt River Valley, showing area beneath which water is 50 feet or less below surface.

underground waters. The limit of lift, or total height to which the water may be profitably raised, can only be determined by the cost of pumping and the value of the water obtained. With certain crops

water yields larger returns than with others. On the other hand, there are localities in the valley, as shown in the last chapter, where pumping plants can not secure water from the gravels rapidly enough to make their operation profitable. The underground conditions are so variable that the selection of sites for pumping plants must depend largely on experiment in each case. In fig. 21 is indicated the area where pumping plants would probably be profitable and the area where their success would be doubtful. The line of demarcation can not be accurately drawn at present and the map should not be interpreted in this regard too literally.

The delimitations dependent on the lift can be drawn with more accuracy. Assuming a lift of 65 feet as the maximum for economic pumping, and assuming 15 feet as the average local depression of the water table in the wells through the action of the pumps, it follows that the boundary of the area thus denoted is the contour indicating a depth of 50 feet to water. The contour maps now available do not cover the southern portion of the area indicated. The boundaries are taken from the contour maps as far south as the base line; south of that line the boundaries are approximately correct. The outline of the area in Gila Valley indicating an approximate depth of 50 feet to water is also appended. This outline is taken from a map included in a former paper by the writer on the underground waters of Gila Valley.[a]

CHEMICAL CHARACTER OF GROUND WATER.

The water analyses quoted in this paper were made for the most part at the chemical laboratory of the Arizona Experiment Station at Tucson, by Prof. R. H. Forbes and W. W. Skinner. In addition Mr. Thos. H. Means, formerly of the United States Department of Agriculture, has kindly furnished a table of analyses made by himself some years ago. In so far as the analyses apply to the waters of Salt River Valley they are gathered into the following tables, arranged according to the methods of analysis:

[a] Lee, W. T., Underground waters of Gila Valley, Arizona: Water-Sup. and Irr. Paper No. 104, U. S. Geol. Survey, 1904.

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Chemical analyses of waters in or near Salt River Valley, Arizona.[a]

[Parts in 100,000.]

Number.	Owner.	Location. Township.	Range.	Section.	Date.	Depth of well.	Total solids soluble at 110° C.	Chlorine, NaCl (common salt).	Hardness, $CaSO_4$ (sulphate of lime).	Alkalinity, Na_2CO_3 (black alkali).	Nitrogen in the form of nitrites.	Nitrogen in the form of nitrates.	Qualitative. Sulphates.	Magnesia.	Lime.
						Feet.									
2815	Perry Williams, Maricopa				Mar. 19, 1902	35	100.9	50.0	24.48	.....	Faint.	0.20	Very strong.	Very strong.	Strong.
2816	Railroad Co., 1¾ miles west Maricopa				.....do	.....	39.8	6.4	5.41	.....	Very faint.	.104	Strong.	Strong.	Faint.
2082	Alhambra town well	2 N.	2 E.	26	Sept. 16, 1898	50	116.3	56.0	.....	34.13	.....	.05	.....	.....	.....
2083	A. H. Smith	2 N.	2 E.	21	.....do	95	130.5	40.0	Strong.	.....	0.012	10.0	.....	.....	.....
2084	Frank Alkire	2 N.	2 E.	21	.....do	96	41.1	10.0	Strong.	.....	.0004	1.5	.....	.....	.....
2085	—— Barkley	2 N.	2 E.	17	.....do	90	340.8	68.0	Strong.	.....	.0084	16.0	.....	.....	.....
2086	—— Boyer	.....	.....	.....	.....do	80	234.5	149.0	Strong.	.....	.....	.60	.....	.....	.....
2087	W. S. McClain	2 N.	2 E.	18	.....do	80	117.6	29.0	Strong.	.....	.016	7.0	.....	.....	.....
2088	Town well, Glendale	2 N.	2 E.	5	.....do	90	79.2	39.0	Strong.	.....	.0003	.....	.....	.....	.....
2089	—— Bartlett	3 N.	2 E.	30	.....do	140	53.1	17.0	Strong.	.....	.....	.80	.....	.....	.....
2090	—— Mosher	2 N.	2 E.	9	.....do	70	346.4	112.0	Very strong.	.....	.....	1.0	.....	.....	.....
2091	G. B. Morgan	2 N.	1 E.	5	.....do	40	46.2	10.0	Strong.	.....	.0028	.40	.....	.....	.....
2150	B. A. Fowler	3 N.	2 E.	33	June 30, 1899	.....	80.9	13.2	36.5	.....	.....	.....	.....	.....	.....
2619	W. J. Murphy	.....	.....	.....	June 8, 1901	.....	115.8	35.6	46.11	.....	.....	.....	Very strong.	Very strong.	.....
2620	J. B. Doner	.....	.....	.....	.....do	.....	143.6	44.8	53.2	.....	.....	.....	Very strong.	Very strong.	Very strong.
2621	H. B. Lehman	2 N.	2 E.	6	.....do	.....	91.2	30.8	35.8	.....	.....	.....	Strong.	Very strong.	Strong.
2622	A. J. Straw	3 N.	1 E.	25	.....do	.....	188.6	81.0	.....	.....	.....	.....	.....	.....	.....
2623	A. W. Bennet	.....	.....	.....	.....do	.....	31.0	5.6	.....	.32	.....	.....	Faint.	Faint.	Faint.
2624	E. E. Jack	.....	.....	.....	.....do	.....	57.9	9.6	.....	4.35	.....	.....	Pronounced.	Faint.	Pronounced.
	MESA.														
1506	H. L. Chandler	.....	.....	.....	Nov. 24, 1896	.....	103.6	Very strong.	.....	.....	.....	.....	Strong.	.....	.....
1515	A. J. Chandler	.....	.....	.....	Feb. 1, 1897	.....	166.6	Very strong.	.....	.....	.....	.....	Faint.	.....	Faint.
1517	.....do	.....	.....	.....	.....do	.....	179.4	Very strong.	.....	.....	.....	.....	Strong.	.....	Strong.

[a] Taken from tables in The Underground Waters of Arizona, by W. W. Skinner, Ariz. Agric. Exp. Sta. Bull. 46.

Chemical analyses of waters in or near Salt River Valley, Arizona—Continued.

Number.	Owner.	Location.			Date.	Depth of well.	Total solids soluble at 110° C.	Chlorine, NaCl (common salt).	Hardness, $CaSO_4$ (sulphate of lime).	Alkalinity, Na_2CO_3 (black alkali).	Nitrogen in the form of nitrites.	Nitrogen in the form of nitrates.	Qualitative.		
		Township.	Range.	Section.									Sulphates.	Magnesia.	Lime.
	MESA—Continued.					*Feet.*									
2615	Murphy-McQueen	1 N.	5 E.	34	May 17, 1901	1,305	133.2	82.0	11.15	.....	0.0067	0.43	Very strong.	Very strong.	Very strong.
2724	A. J. Chandler	1 S.	5 E.	22	Aug. 27, 1901	150	174.2	110.7	47.02	.....	Slight trace.	.07	Strong.	Very strong.	Strong.
2775	.....do	1 S.	5 E.	22	Dec. 5, 1901	.....	176.2	111.1	42.6	.....	None.	.02	Very strong.	Very strong.	Very strong.
2804	.....do	1 S.	5 E.	23	Jan. 28, 1902	54	103.2	48.8	.....	7.63	.0094	.21	Strong.	Faint.	Faint.
2818	.....do	1 S.	5 E.	22	Mar. 9, 1902	705	157.4	104.0	39.3	.....	Very faint.	.12	Very strong.	Very strong.	Very strong.
2819	.....do	1 S.	5 E.	22	.....do	146	172.2	110.0	45.3	.....	Very faint.	.12	Very strong.	Very strong.	Very strong.
2820	.....do	1 S.	5 E.	22	.....do	236	163.8	104.4	44.5	.....	Very faint.	.12	Very strong.	Very strong.	Very strong.
2977	.....do	1 S.	5 E.	22	Feb. 6, 1903	240	299.6	154.8	20.9	.....	.0105	.29	Very strong.	Strong.	Strong.
2983	.....do	1 S.	5 E.	34	Mar. 7, 1903	260	162.4	80.4	52.2	.....	.0061	.27	Very strong.	Strong.	Very strong.
3157	.....do	1 S.	5 E.	22	June 13, 1903	236	127.4	75.6	23.1	.....	Faint.	.17	Strong.	Faint.	Pronounced.
3158	.....do	1 S.	5 E.	34	.....do	.....	84.8	44.6	18.5	.....	Faint.	.26	Strong.	Faint.	Strong.
3138	Desert well	1 S.	7 E.	11	May 14, 1903	212	32.0	5.2	.....	4.66	Very faint.	.49	Faint.	Very faint.	Faint.
3141	E. Olsen	1 S.	5 E.	18	.....do	212	381.0	235.2	59.8	.....	Faint.	2.0	Very strong.	Strong.	Very strong.
3144	P. Mets	1 N.	5 E.	22	.....do	56	167.8	108.0	.....	9.33	Very faint.	.38	Strong.	Faint.	Strong.
3145	Alhambra Hotel	1 N.	5 E.	22	.....do	51	152.0	89.6	.....	5.51	Very faint.	.33	Strong.	Faint.	Strong.
3146	Dorman Bros	1 N.	6 E.	33	.....do	100	114.0	74.0	.....	.....	.....	.....	Strong.	Very faint.	Strong.
	PHOENIX.														
1819	Fowler Bros	1 N.	1 E.	1	Apr. 30, 1897	.....	399.3	Very strong.	.....	.....	.....	.....	Very strong.	Strong.	Faint.
2017	Mrs. W. J. Murphy	.....	.....	.....	Aug. 15, 1898	.....	334.3	107.0	.....	.....	.05	10.0	34.3	3.64	10.5
2067	North Central Avenue	.....	.....	.....	Sept. 15, 1898	.....	117.7	66.5	.....	.....	None.	.20	.....	.....	.....
2068	School, Central Avenue	1 N.	3 E.	5	.....do	.....	216.1	150.0	.....	.....	.....	.20	.....	.....	.....
2069	Indian School	2 N.	3 E.	20	.....do	15	222.0	141.0	.....	33.36	.0008	Faint.	.....	.....	.....
2070	.....do	2 N.	3 E.	20	.....do	60	362.3	258.0	Strong.	.....	.0028	.30	.....	.....	.....
2981	.....do	2 N.	3 E.	20	Mar. 7, 1903	45	245.2	160.8	21.8	.....	Faint.	.40	Very strong.	Very strong.	Very strong.
2982	.....do	2 N.	3 E.	20	.....do	145	250.0	145.6	65.9	.....	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

3158	.....do.....	1 S.	5 E.	34	.....do.....	.....	84.8	44.6	18.5	.....	Faint.	.26	Strong.	Faint.	Strong.
3138	Desert well.....	1 S.	7 E.	11	May 14, 1903	212	32.0	5.2	.....	4.66	Very faint.	.49	Faint.	Very faint.	Faint.
3141	E. Olsen.....	1 S.	5 E.	18	.....do.....	212	381.0	235.2	59.8	.....	Faint.	2.0	Very strong.	Strong.	Very strong.
3144	P. Mets.....	1 N.	5 E.	22	.....do.....	56	167.8	108.0	.....	9.33	Very faint.	.38	Strong.	Faint.	Strong.
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3146	Dorman Bros.....	1 N.	6 E.	33	.....do.....	100	114.0	74.0	.....	.....	.....	.....	Strong.	Very faint.	Strong.
	PHOENIX.														
1819	Fowler Bros.....	1 N.	1 E.	1	Apr. 30, 1897	.....	399.3	Very strong.	.....	.....	.....	.....	Very strong.	Strong.	Faint.
2017	Mrs. W. J. Murphy.	.....	.....	.....	Aug. 15, 1898	.....	334.3	107.0	.....	.....	.05	10.0	34.3	3.64	10.5
2067	North Central Avenue.....	.....	.....	.....	Sept. 15, 1898	.....	117.7	66.5	.....	.....	None.	.20	.....	.....	.....
2068	School, Central Avenue.....	1 N.	3 E.	5	.....do.....	.....	216.1	150.0	.....	.....	.....	.20	.....	.....	.....
[illegible]	Indian school.....	2 N.	3 E.	20	.....do.....	15	222.0	141.0	.....	23.36	.0008	Faint.	.....	.....	.....
[illegible]	[illegible]	2 N.	3 E.	20	.....do.....	60	262.3	258.0	Strong.	.....	[illegible]	[illegible]	.....	.....	.....
2082	.....do.....	2 N.	3 E.	20	.....do.....	145	250.0	145.6	65.8	.....	.004	.25	Very strong.	Very strong.	Very strong.
2071	Ida E. Lawrence...	2 N.	3 E.	20	Sept. 15, 1898	30	413.1	285.0	Strong.	.....	.....	.60	.....	.....	.....
2073	—— Cawthorn....	2 N.	3 E.	29(?)	.....do.....	65	97.6	61.0	Strong.	.....	.0006	.40	.....	.....	.....
2074	Orangewood.....	2 N.	3 E.	4(?)	.....do.....	105	44.9	16.0	Strong.	.....	.0016	.80	.....	.....	.....
2075	J. A. Wieder.....	3 N.	3 E.	32	.....do.....	146	76.1	31.5	Strong.	.....	.0078	.70	.....	.....	.....
2076	W. R. Beshier.....	2 N.	3 E.	20(?)	.....do.....	36	126.9	43.0	.....	39.2	.....	.10	.....	.....	.....
2077	—— Churchill....	2 N.	3 E.	20(?)	.....do.....	92	284.6	103.0	Strong.	.....	.0004	.80	.....	.....	.....
2078	.....do.....	2 N.	3 E.	20(?)	.....do.....	70	531.8	179.5	Strong.	.....	.043	2.10	.....	.....	.....
2079	M. Morrison.....	2 N.	3 E.	32(?)	.....do.....	28	287.5	203.0	Strong.	.....	.0002	.80	.....	.....	.....
2080	Wm. Christy.....	1 N.	2 E.	1	.....do.....	22	150.6	84.0	Strong.	.....	.....	.05	.....	.....	.....
2081	G. R. Brewster.....	2 N.	2 E.	36	.....do.....	35	122.5	44.5	.....	33.63	.0004	.40	.....	.....	.....
2095	Phoenix city supply.....	1 N.	3 E.	4	Sept. 18, 1898	42	116.8	72.5	Strong.	.....	.0007	.10	.....	.....	.....
2840	.....do.....	1 N.	3 E.	4	May 9, 1902	42	102.4	54.6	8.98	.....	.0045	.16	Very strong.	Very strong.	Very strong.
3139	.....do.....	1 N.	3 E.	4	May 14, 1903	208	132.0	77.6	5.4	.....	Very faint.	.25	Pronounced.	Pronounced.	Strong.
3140	.....do.....	1 N.	3 E.	4	.....do.....	42	136.0	80.8	6.5	.....	.021	.25	Pronounced.	Pronounced.	Strong.
2143	G. R. Brewster.....	2 N.	2 E.	36(?)	June 30, 1899	.....	103.4	36.5	.....	34.87	.0006	.02	.....	.....	.....
2215	Dr. Duffield.....	.....	.....	.....	Oct. 24, 1899	.....	75.3	35.0	.....	2.3	.....	.....	Strong.	None.	Faint.
2216	.....do.....	.....	.....	.....	.....do.....	.....	68.8	32.0	.....	4.0	.....	.....	.....	.....	.....
1612	C. W. Perkins.....	2 N.	3 E.	23	May 10, 1901	155	83.6	30.8	8.3	.....	.0871	.53	Very strong.	Strong.	Strong.
2625	W. J. Murphy.....	.....	.....	.....	June 8, 1901	.....	28.2	3.1	.....	2.12	.....	.....	Faint.	Pronounced.	Faint.
2696	.....do.....	.....	.....	.....	July 3, 1901	.....	27.6	3.1	.....	2.42	Faint.	.47	Very faint.	Faint.	Faint.
2774	B. Smith.....	.....	.....	.....	Oct. 14, 1901	25	235.8	153.5	12.10	.....	.0029	.31	Very strong.	Very strong.	Very strong.
2837	Thomas Murphy...	2 N.	4 E.	30	Apr. 22, 1902	187	380.4	140.0	10.88	.....	.40	2.33	Very strong.	Very strong.	Very strong.
2838	.....do.....	2 N.	4 E.	30	.....do.....	168	303.2	136.0	26.65	.....	.80	2.70	Very strong.	Very strong.	Very strong.
2839	.....do.....	2 N.	4 E.	30	.....do.....	78	388.0	105.0	.....	45.16	.0666	1.43	Very strong.	Very strong.	Very strong.
2842	.....do.....	2 N.	4 E.	30	May 9, 1902	325	325.8	123.4	32.1	.....	.0073	.66	Very strong.	Very strong.	Very strong.
2845	J. Miller.....	2 N.	2 E.	33	May 27, 1902	.....	239.0	89.8	.....	.....	.....	.....	Very strong.	Very strong.	Very strong.
2849	Asylum.....	1 N.	3 E.	2	June 12, 1902	42	120.4	79.2	8.2	.....	Faint.	Faint.	Very strong.	Very strong.	Very strong.
2949	.....do.....	1 N.	3 E.	2	Oct. 31, 1902	90	126.4	78.8	13.6	.....	Very faint.	Very faint.	Very strong.	Strong.	Strong
2960	Soap Springs, 50 miles north.....	.....	.....	.....	Jan. 5, 1903	.....	272.2	52.4	.....	144.6	.....	.....	Strong.	Faint.	Faint.
2970	A. C. Bartlett.....	2 N.	3 E.	32	Jan. 2, 1903	60	164.0	102.8	6.8	.....	Faint.	.66	Very strong.	Very strong.	Strong.
2342	J. J. Harris.....	1 N.	2 E.	6	May 14, 1903	103	268.0	185.0	34.8	.....	Very faint.	2.0	Strong.	Strong.	Very strong.

Chemical analyses of waters in or near Salt River Valley, Arizona—Continued.

Number.	Owner.	Location.			Date.	Depth of well.	Total solids soluble at 110° C.	Chlorine, NaCl (common salt).	Hardness, $CaSO_4$ (sulphate of lime).	Alkalinity. Na_2CO_3 (black alkali).	Nitrogen in the form of nitrites.	Nitrogen in the form of nitrates.	Qualitative.		
		Township.	Range.	Section.									Sulphates.	Magnesia.	Lime.
	PHOENIX—Cont'd.					*Feet.*									
3143	H. Thompson	2 N.	3 E.	8	May 14, 1903	104	26.0	4.0	.....	4.88	0.126	0.33	Faint.	Very faint.	Very faint.
3187	Mission (Presbyterian), Gila Crossing	.....	.....	.....	Aug. 25, 1903	.....	160.0	110.8	28.4	.0	.....	.....	Very strong.	Strong.	Strong.
3184	Lake near Gila Crossing	.....	.....	.....	do	.....	107.0	61.2	2.72	.0	.....	.....	Very strong.	Strong.	Strong.
3185	Cooperative ditch, Gila Crossing	.....	.....	.....	do	.....	106.0	62.8	13.1	.0	.....	.....	Strong.	Strong.	Strong.
3186	Gila River at Gila Crossing (seepage)	.....	.....	.....	do	.....	127.0	76.4	12.5	.0	.....	.....	Very strong.	Strong.	Strong.
3204	S. W. Nigh	2 N.	4 E.	36	Sept. 19, 1903	.....	110.0	60.0	.....	.....	.....	.....	Pronounced.	Very faint.	Pronounced.
3203	N. J. Murphy	2 N.	4 E.	30	do	.....	193.0	74.0	.....	.....	.....	.....	Very strong.	Very faint.	Very faint.
3202	—— Underhill	2 N.	4 E.	22	do	.....	189.4	93.0	.....	.....	.....	.....	Very strong.	Pronounced.	Strong.
3201	—— Warner	2 N.	4 E.	8	do	120	52.0	17.0	.....	.....	.....	.....	Pronounced.	Very faint.	Pronounced.
	Geo. U. Collins	1 N.	2 E.	15	Aug. 25, 1903	29	150.0	94.8	17.40	.0	.....	.....	Strong.	Strong.	Strong.
	L. Kunz	1 N.	3 E.	18	do	24	223.0	146.8	53.7	.0	.....	.....	Very strong.	Strong.	Very strong.
	J. Heaton	1 N.	1 W.	15	do	45	28.0	5.2	1.09	.0	.....	.....	Pronounced.	Pronounced.	Pronounced.
2092	H. L. Underhill	2 N.	4 E.	22	Sept. 17, 1898	61	84.4	50.0	Strong.	.....	.....	.15	.....	.....	.....
2093	Geo. Blont	2 N.	4 E.	26	do	40	159.4	90.0	.....	.....	.....	.40	.....	.....	.....
2795	Winfield Scott	2 N.	4 E.	23	Jan. 9, 1902	67	167.4	100.8	42.7	.....	.001	.50	Very strong.	Very strong.	Very strong.
2796	Paradise Valley	.....	.....	.....	do	.....	25.6	5.72	1.6	.....	.0049	.35	Faint.	Pronounced.	Pronounced.
2961	Winfield Scott	2 N.	4 E.	23	Dec. 5, 1902	60	171.4	91.2	21.22	.....	.....	.....	Very strong.	Very strong.	Strong.
	TEMPE.														
1525	J. W. Johnson	1 N.	4 E.	27	Mar. 15, 1897	11	79.2	Strong.	.....	.....	.....	.....	Faint.	.....	.....
2110	Hough's creamery	1 N.	4 E.	23	Dec. 2, 1898	.....	103.0	67.0	Strong.	.....	.....	.....	.....	.....	.....
2111	Hough's ranch	.....	.....	.....	Dec. 2, 1898	8	188.5	109.0	Strong.	.....	.0004	.30	.....	.....	.....
2113	J. W. Wolf	1 N.	4 E.	23	do	15	160.0	94.0	Strong.	.....	.0012	.20	.....	.....	.....

[illegible]	[illegible]	2 N.	4 E.	22	.....do.....	.....	189.4	93.0	.....	.....	.....	.....	Very strong.	Pronounced.	Strong.
3201	——— Warner.....	2 N.	4 E.	8	.....do.....	120	52.0	17.0	.....	.....	.....	.....	Pronounced.	Very faint.	Pronounced.
	Geo. U. Collins.....	1 N.	2 E.	15	Aug. 25, 1903	29	150.0	94.8	17.40	.0	.....	.....	Strong.	Strong.	Strong.
	L. Kunz.....	1 N.	3 E.	18	.....do.....	24	223.0	146.8	53.7	.0	.....	.....	Very strong.	Strong.	Very strong.
	J. Heaton.....	1 N.	1 W.	15	.....do.....	45	28.0	5.2	1.09	.0	.....	.....	Pronounced.	Pronounced.	Pronounced.
2092	H. L. Underhill....	2 N.	4 E.	22	Sept. 17, 1898	61	84.4	50.0	Strong.	.....	.....	.15	.....	.....	.....
2093	Geo. Blont.....	2 N.	4 E.	26	.....do.....	40	159.4	90.0	.....	.....	.....	.40	.....	.....	.....
2795	Winfield Scott.....	2 N.	4 E.	23	Jan. 9, 1902	67	167.4	100.8	42.7	.....	.001	.50	Very strong.	Very strong.	Very strong.
2796	Paradise Valley....	.....	.....	.....	.....do.....	.....	25.6	5.72	1.6	.....	.0049	.35	Faint.	Pronounced.	Pronounced.
2961	Winfield Scott.....	2 N.	4 E.	23	Dec. 5, 1902	60	171.4	91.2	21.22	.....	.....	.....	Very strong.	Very strong.	Strong.
	TEMPE.														
1525	J. W. Johnson.....	1 N.	4 E.	27	Mar. 15, 1897	11	79.2	Strong.	.....	.....	.....	.....	Faint.	.....	.....
2110	Hough's creamery..	1 N.	4 E.	23	Dec. 2, 1898	.....	103.0	67.0	Strong.	.....	.....	.....			
2111	Hough's ranch.....	.....	.....	.....	Dec. 2, 1898	8	188.0	109.0	Strong.	.....	.0004	.30	.....	.....	.....
2113	J. W. Wolf.....	1 N.	4 E.	23	.....do.....	15	160.0	94.0	Strong.	.....	.0012	.20	.....	.....	.....
2114	J. B. Mullen.....	1 N.	4 E.	35	.....do.....	13	287.6	192.0	Strong.	.....	.0004	.25	.....	.....	.....
2115	W. T. Fowler.....	.....	.....	.....	.....do.....	12	163.1	88.5	.....	26.82	.0028	.30	.....	.....	.....
2116	Niels Peterson.....	1 N.	4 E.	29	.....do.....	20	221.8	141.5	.....	24.91	.0004	.20	.....	.....	.....
2118	A. P. McKern.....	1 N.	3 E.	6	.....do.....	.....	171.5	110.0	6.8	.....	.0004	.05	.....	.....	.....
2363	Wolf & Jones.....	.....	.....	.....	Mar. 28, 1900	.....	128.8	80.8	12.0	.....	.0006	.30	.....	.....	.....
2304	.....do.....	.....	.....	.....	.....do.....	.....	190.4	120.0	6.1	.....	.....	.25	.....	.....	.....
2339	Hotel Casa Loma...	1 N.	4 E.	15	May 7, 1900	.....	169.8	105.8	12.9	.....	.0027	.18	Very strong.	Pronounced.	Very strong.
2748	Geo. Kinney.....	.....	.....	.....	Oct. 17, 1901	40	202.6	130.5	8.16	.....	None.	.25	Strong.	Very strong.	Strong.
2766	Normal School.....	1 N.	4 E.	22	Nov. 19, 1901	30	219.2	133.6	15.78	.....	None.	.51	Very strong.	Very strong.	Very strong.
2966	A. R. Jenkins.....	1 N.	4 E.	19	Jan. 2, 1903	50	217.0	142.4	.....	3.6	.004	.20	Very strong.	Strong.	Strong.
2967	.....do.....	1 N.	4 E.	19	.....do.....	50	223.0	171.2	.....	3.4	.....	.....	Very strong.	Strong.	Strong.
2968	A. J. Hansen.....	1 S.	4 E.	35	.....do.....	156	509.0	355.0	60.9	.....	.....	.....	Very strong.	Very strong.	Very strong.
2980	.....do.....	1 S.	4 E.	35	.....do.....	156	446.8	307.0	135.4	.....	Faint.	Faint.	Very strong.	Very strong.	Very strong.
2969	H. L. Chandler.....	1 N.	4 E.	21	.....do.....	180	224.0	146.0	.....	2.12	.....	.....	Very strong.	Very strong.	Strong.
2973	Tempe city supply.	.....	.....	.....	Jan. 8, 1903	200	103.0	58.8	9.52	.....	None.	.17	Strong.	Strong.	Strong.
3118	Valley Seedless Grape Co.....	1 S.	4 E.	4	Mar. 19, 1903	200	115.2	78.6	11.4	.....	.....	.....	Strong.	Pronounced.	Strong.
3119	.....do.....	1 S.	4 E.	4	.....do.....	300	155.8	105.4	21.8	.....	.....	.....	Strong.	Pronounced.	Strong.
2226	Salt River.....	.....	.....	.....	Nov. 17, 1899	.....	134.5	81.8	.....	.....	.04	.10	.....	.....	.....
2251	A. R. Jenkins ditch.	1 N.	4 E.	20	Dec. 26, 1899	.....	189.4	136.0	.....	8.4	.....	.....	Very strong.	Strong.	Very strong.
2252	.....do.....	1 N.	4 E.	20	.....do.....	.....	216.4	142.9	.....	7.7	.....	.....	Strong.	Strong.	Strong.
2285	Buckeye canal.....	.....	.....	.....	Mar. 5, 1900	.....	182.0	119.2	23.1	.....	.0032	.126	Very strong.	Strong.	Very strong.
2286	Richardson ditch...	1 N.	1 W.	(?)	.....do.....	.....	30.0	6.0	.....	1.17	.004	.16	Strong.	Strong.	Strong.
2340	.....do.....	1 N.	1 W.	(?)	May 21, 1900	.....	33.4	7.4	.....	1.3	Faint.	.148	Strong.	Strong.	Strong.
2287	Salt River seepage, Phoenix.....	.....	.....	.....	Mar. 5, 1900	.....	130.0	86.4	.....	.32	.0064	.30	Strong.	Strong.	Very strong.
2288	Salt River at Tempe.	.....	.....	.....	Mar. 5, 1900	.....	118.0	79.6	10.2	.....	.008	.22	Strong.	Strong.	Very strong.
2289	Salt River at Arizona dam.....	.....	.....	.....	.....do.....	.....	102.2	68.4	.62	.....	.....	.20	Strong.	Strong.	Strong.
2293	Agua Fria underflow, Buckeye....	.....	.....	.....	Mar. 6, 1900	.....	78.4	32.2	1.50	.....	Faint.	.08	.....	.....	.....
2341	Buckeye canal.....	.....	.....	.....	May 21, 1900	.....	185.0	121.8	23.4	.....	Faint.	.165	Very strong.	Very strong.	Very strong.
	Lewis Wetzler.....	1 N.	3 E.	11	Sept. 19, 1903	40	144.0	86.0	23.9	0.0	.....	.....	Pronounced.	Very faint.	Strong.

Chemical analyses of waters in or near Salt River Valley, Arizona—Continued.

Number.	Owner.	Location.			Date.	Depth of well.	Total solids soluble at 110° C.	Chlorine, NaCl (common salt).	Hardness, $CaSO_4$ (sulphate of lime).	Alkalinity, Na_2CO_3 (black alkali).	Nitrogen in the form of nitrites.	Nitrogen in the form of nitrates.	Qualitative.		
		Township.	Range.	Section.									Sulphates.	Magnesia.	Lime.
	TEMPE—Cont'd.					*Feet.*									
3154	C. T. Sharp, Sacaton	.....	.....	.....	May 20, 1903	30	132.6	66.8	29.4	.....	0.031	0.083	Very strong.	Strong.	Very strong.
3156	Beet-sugar factory	2 N.	2 E.	8	June 10, 1903	112	54.6	15.6	0.0	1.99	.08	1.24	Pronounced.	Faint.	Pronounced.
3236	Ostrich ranch	1 N.	1 E.	3	Feb. 16, 1904	170	130.0	76.0	8.2	0.00	.....	.....	Very strong.	Distinct.	Strong.
3230	Bartlett-Heard	1 N.	4 E.	30	Feb. 4, 1904	100	194.0	126.0	5.44	0.0	0.0	0.0	Strong.	Strong.	Strong.
3237	D. B. Heard	.....	.....	.....	Feb. 16, 1904	.....	185.0	111.6	13.6	0.0	.....	.....	Strong.	Strong.	Very strong.
3238	Bristol Flummerfelt	1 S.	4 E.	11	.....do.....	61	186.0	122.0	13.6	0.0	.....	.....	Strong.	Strong.	Very strong.
3239	Robert Bowen	2 S.	9 E.	(?)	.....do.....	212	54.0	24.0	16.3	0.0	.....	.....	Distinct.	Distinct.	Strong.

[Parts in 100,000.]

Owner of well.	Location.			Depth of well.	Total salts in solution.	Calcium sulphate.	Calcium and magnesium carbonates.	Chlorine reckoned as common salt.	Sodium carbonate.	Sodium nitrate.	Qualitative.
	Township.	Range.	Section.								
				Feet.							
Phoenix city supply	1 N.	3 E.	4	42	116.8	1.0	22.0	72.0	.....	1.0	Magnesium sulphate.
A. P. McKern	1 N.	3 E.	6	.....	171.46	1.3	32.65	110.0	.....	.06	Magnesium chloride and sulphate.
—— Thomas	.....	.....	.....	30	117.65	1.35	14.60	66.5	.....	.2	Do.
School building	1 N.	3 E.	5	.....	216.10	5.60	23.05	150.0	Trace.	.2	Magnesium sulphate.
Indian School	2 N.	3 E.	20	15	222.0	.....	26.65	141.0	33.36	.....	Sodium, magnesium, and potassium sulphates.
Do	2 N.	3 E.	20	60	362.25	29.95	27.45	258.0	.....	.3	Calcium chloride, magnesium chloride and sulphate.
Well south of W. S. Lawrence's places.	.....	.....	.....	30	413.10	5.45	47.75	285.0	.....	.6	Magnesium chloride and sulphate.
Well at middle one of W. S Lawrence's places	.....	.....	.....	24	370.80	.....	22.15	176.5	23.59	.3	Sodium and potassium sulphates.
—— Cawthorn	2 N.	3 E.	29(?)	65	97.60	1.60	11.35	61.0	.....	.4	Sodium and magnesium sulphates.
—— Blaine	2 N.	3 E.	4(?)	105	44.90	1.85	5.35	16.0	.....	.8	Magnesium sulphate.
J. A. Wieder	3 N.	3 E.	32	146	76.1	1.20	15.75	31.5	.....	.7	Calcium chloride. magnesium chloride and sulphate.
—— Beshier	2 N.	3 E.	20(?)	36	126.90	.26	5.05	43.0	39.22	.1	Sodium and potassium sulphates.
—— Churchill	2 N.	3 E.	20(?)	92	284.60	7.15	21.10	103.0	.....	.8	Magnesium sulphate.
M. Morrison	2 N.	3 E.	32(?)	28	287.50	19.30	16.65	203.0	.....	.8	Calcium chloride, magnesium chloride and sulphate.
Col. Wm. Christy	1 N.	2 E.	1	22	150.60	2.65	20.45	84.0	.....	.05	Magnesium sulphate.
G. R. Brewster	2 N.	2 E.	36	35	122.46	.21	10.60	44.5	33.63	.4	Sodium and potassium sulphates.
Blacksmith shop	2 N.	2 E.	26	50	116.30	.22	9.15	56.0	34.13	.05	Do.
A. H. Smith	2 N.	2 E.	21	95	130.50	6.8	11.65	40.0	.....	10.0	Calcium chloride, magnesium chloride and sulphate.
Frank Alkire	2 N.	2 E.	21	96	41.10	2.2	8.7	10.0	.....	1.5	Magnesium chloride and sulphate.
—— Barclay	2 N.	2 E.	17	90	340.80	56.90	12.25	68.0	.....	16.0	Do.

[a] McClatchie, Alfred J., and Forbes, Robert H., Ariz. Agric. Exp. Station, Bull. 30, 1899.

Analyses of water from Salt River Valley—Continued.

Owner of well.	Location.			Depth of well.	Total salts in solution.	Calcium sulphate.	Calcium and magnesium carbonates.	Chlorine reckoned as common salt.	Sodium carbonate.	Sodium nitrate.	Qualitative.
	Township.	Range.	Section.								
				Feet.							
—— Boyer	2 N.	2 E.	18(?)	80	234.45	21.30	10.85	149.0	.....	0.6	Calcium and magnesium chlorides.
W. S. McClain	2 N.	2 E.	18	80	117.55	1.2	11.75	29.0	.....	7.0	Sodium and magnesium sulphates.
Glendale town well	2 N.	2 E.	5	90	79.2	2.8	20.0	39.0	.....	.....	Sodium sulphate, magnesium chloride and sulphate.
—— Bartlett	3 N.	2 E.	30	140	53.05	2.0	6.95	17.0	.....	.8	Magnesium chloride and sulphate.
—— Mosher	2 N.	1 E.	9	70	346.40	111.50	13.85	112.0	.....	1.0	Sodium and magnesium sulphates.
J. B. Morgan	2 N.	1 E.	5	40	46.20	1.45	15.75	10.0	.....	.4	Do.
H. L. Underhill	2 N.	4 E.	22	61	84.4	1.55	12.80	50.0	.....	.15	Magnesium chloride and sulphate.
George Blount	2 N.	4 E.	26	40	159.35	20.90	22.40	90.0	.....	.4	Sodium and magnesium sulphates.
Arizona Falls canal water, taken Sept. 17, 1898.	.....	.....	.....	.....	93.30	1.0	13.60	61.5	.....	.....	Do.
Arizona Falls water, taken Jan. 5 to Jan. 31, 1897.	.....	.....	.....	.....	46.4	.....	16.3	17.0	.....	.....	
F. A. Hough	1 N.	4 E.	23	22	103.03	.9	16.35	67.0	.....	.....	Magnesium chloride and sulphate.
J. W. Woolf	1 N.	4 E.	23	15	159.96	1.90	32.90	94.0	.....	.2	Magnesium sulphate.
J. B. Mullen	1 N.	4 E.	35	13	287.56	4.0	40.45	192.0	.....	.25	Magnesium chloride and sulphate.
W. T. Trusler	1 N.	4 E.	27	12	163.10	.43	12.0	88.5	26.82	.3	Sodium and potassium sulphates.
Nels Peterson	1 N.	4 E.	29	20	221.80	.66	15.30	141.5	24.91	.2	Do.
Canaigre ranch, 6 miles southeast of Phoenix.	.....	.....	.....	34	171.40	1.60	29.05	108.5	.....	.2	Magnesium chloride and sulphate.

Arizona Falls canal water, taken Sept. 17, 1898.	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	Do.
Arizona Falls water taken Jan. 5 to Jan. 31, 1897.	.....	.....	.....	.....	46.4	.....	16.3	17.0	.....	.....	.....	.....	Magnesium chloride and sulphate.
F. A. Hough	1 N.	4 E.	23	22	103.03	.9	16.35	67.0	.....	.....	.....	.....	Magnesium sulphate.
J. W. Woolf	1 N.	4 E.	23	15	159.96	1.90	32.90	94.0	.....	.....	.....	.2	Magnesium chloride and sulphate.
J. B. Mullen	1 N.	4 E.	35	13	287.56	4.0	40.45	192.0	.....	.....	.....	.25	Sodium and potassium sulphates.
W. T. Trusler	1 N.	4 E.	27	12	163.10	.43	12.0	88.5	26.82	.3	.2	.2	Do.
Nels Peterson	1 N.	4 E.	29	20	221.80	.66	15.30	141.5	24.91	.2	.....	.....	Magnesium chloride and sulphate.
Canagre ranch, 6 miles southeast of Phoenix.	.....	.....	.....	34	171.40	1.60	29.05	108.5	.....	.....	.....	.2	

Analyses of waters in Salt River Valley by electrical method.

[Data furnished by Thos. H. Means.]

Source of sample.	Location.	Depth to water.	Parts of Na_2CO_3 in 100,000.	Parts of solids in 100,000.
		Feet.		
mpe ditch	1 mile south of Tempe	.....	.....	105
nkins ditch	⅜ mile east of Bell Butte	.....	.....	209
Do	do	.....	5.8	195
Do	do	.....	.....	211
Well	Sec. 33, T. 1 N., R. 4 E., just below canal	.....	.....	258
anal	do	.....	.....	115
Well	Sec. 3, T. 1 S., R. 4 E., ¼ mile south of date orchard	.....	.....	251
Do	Sec. 27, T. 1 S., R. 4 E., Harmon's place	5	10.5	160
Do	Sec. 19, T. 1 N., R. 4 E., Reed's place	16	.....	265
Do	Sec. 27, NE. ¼ NE. ¼, T. 1 N., R. 4 E., Rice place	9	.....	209
Do	Sec. 35, SE. ¼ SW ¼, T. 1 S., R. 4 E.	(a)	.....	167
anal	do	.....	.....	111
Well	Sec. 24, SE. ¼ SW. ¼, T. 1 N., R. 5 E.	11	.....	179
Do	Sec. 19, NE. ¼ SE. ¼, T. 1 N., R. 5 E.	30	.....	161
Do	Sec. 2, NW. corner, T. 1 S., R. 5 E.	15	.....	213
anal	Sec. 36, T. 1 N., R. 5 E., Consolidated canal	.....	.....	99
Well	Sec. 12, NE. corner, T. 1 S., R. 5 E	50	.....	436
Do	Pumping plant below Highland canal, east of Mesa	60	.....	92
Springs	Sec. 13, T. 1 N., R. 4 E., springs along Salt River seeping from gravel.	.....	.....	167
alt River	Sec. 13, T. 1 N., R. 4 E.	.....	.....	152
Do	At Tempe Bridge	.....	.....	123
Well	Sec. 13, NE. ¼ NW. ¼, T. 1 N., R. 4 E.	12	.....	189
alt River	Above intake of Tempe canal	.....	.....	113
Well	Sec. 9, SW. ¼ SW. ¼, T. 1 N., R. 4 E	13	.....	158
Ditch	Sec. 23, T. 1 N., R. 3 E., south side	.....	.....	150
alt River	Southwest of Phoenix	.....	.....	135
Well	Sec. 6, SW. corner, T. 1 S., R. 6 E	40	.....	184
Do	Sec. 9, SW. ¼ SW. ¼, T. 1 N., R. 3 E., brickyard	12	.....	179
alt River	Sec. 19, SW. corner, T. 1 N., R. 2 E.	.....	.....	131
anal	St. Johns canal, meridian line	.....	.....	144
Well	Sec. 9, T. 1 N., R. 3 E., south of S. P. depot	.....	.....	177
Do	T. 1 N., R. 1 E.	.....	.....	305
Do	Sec. 13, NW. ¼ SW. ¼, T. 1 N., R. 1 E.	.....	.....	277
raw	Emptying into Gila River 2 miles above Agua Fria	.....	.....	258
ila River	At initial monument	.....	.....	169
anal	St. Johns canal	.....	.....	159
Well	¾ mile north of initial monument	.....	.....	213
ila River	¼ mile west of initial monument	.....	.....	158

a Rises to surface.

ORIGIN OF SALTS.

SALTS IN WELL WATER.

An inspection of the chemical analyses of well waters and a comparison of them with analyses of the river water given below reveals a remarkable similarity in the salt content. Since the débris contributed by Salt River is the principal source of the valley fill, we naturally look to Salt River as the source of the salts found in the sediment. The accompanying table by Professor Forbes[a] indicates the character

[a] Forbes, R. H., The river irrigating waters of Arizona: University of Arizona Agric. Exp. Sta. Bull. No. 44, 1902, p. 174.

of Salt River water. The salts of the valley fill are regarded as concentrations by evaporation from the river waters. A study of the conditions as they exist in and near the river bed at the present time throws some light upon the manner of concentration.

Composition of the waters of Salt River.

[Samples taken at the Consolidated Canal Company's office, Mesa, Ariz., representing the Arizona Canal dam supply.]

PARTIAL ANALYSES.

	High and low summer waters (average of 4 weekly composites of samples taken daily, Aug. 1–Sept. 1, 1899).	Summer flood water (one weekly composite of daily samples taken Sept. 2–9, 1899).	High and low summer waters (average of 4 weekly composites of daily samples taken Sept. 10–Oct. 9, 1899).	Winter flood water (one composite of daily samples taken Oct. 10–17, 1899).	Low winter water (average of 10 weekly composites of daily samples taken Oct. 18–Dec. 30, 1899).	Low winter water (average of 13 weekly composites of daily samples taken Feb. 17–May 30, 1900).	Very low summer water (average of 8 weekly composites of daily samples taken June 1–Aug. 1, 1900.
Silt, per cent by weight	0.32	0.95	0.096	0.714	0.025	0.024	0.026
Soluble solids, parts in 100,000	72.40	110.00	114.20	95.10	102.64	106.90	139.15
Containing chlorine stated as common salt, NaCl	46.2	52.1	72.9	61.9	67.6	72.2	98.1
Containing alkalinity stated as sodium carbonate, Na_2CO_3	.....	1.80	.....	.....	.....	.....	.....
Containing permanent hardness stated as calcium sulphate, $CaSO_4$	1.59	.....	2.79	2.45	2.12	5.43	13.70
Nitrogen, parts in 1,000,000:							
Total nitrogen in silt and water	6.94	26.7	4.36	12.19	1.96	1.48	1.30
Nitrogen in nitrates	1.32	1.2	1.90	1.52	1.21	.67	.78
Nitrogen in nitrites	Traces nearly always.						

COMPLETE ANALYSES OF SOLUBLE SALTS, STATED BY IONS.

[Parts in 100,000 of water.]

Sodium, Na	12.2	18.3	27.45	.....	30.99	32.7	40.73
Potassium, K	1.29	1.41	1.09	.....	1.53	1.23	1.12
Calcium, Ca	6.79	10.2	7.24	.....	4.02	4.37	6.51
Magnesium, Mg	1.74	2.33	2.79	.....	2.84	2.92	3.28
Chlorine, Cl	27.99	31.57	44.11	.....	40.96	43.75	59.44
Sulphuric, SO_4	9.79	4.81	7.27	.....	7.48	7.64	9.19
Carbonic, CO_3	.....	15.45	8.02	.....	11.71	11.51	13.15
Silicic, SiO_3	2.06	1.11	5.83	.....	4.65	5.29	3.55

COMPLETE ANALYSES OF SOLUBLE SALTS CALCULATED TO COMPOUNDS.

[Parts in 100,000 of water.]

Sodium silicate, Na_2SiO_3	3.31	1.79	9.35	.....	7.46	8.50	5.69
Sodium chloride, NaCl	27.84	42.80	60.84	.....	67.54	72.16	98.04
Sodium sulphate, Na_2SO_4	.....	.....	.....	.....	4.97	3.46	.07
Sodium carbonate, Na_2CO_3	.....	1.80	.....	.....	.....	.....	.....
Potassium chloride, KCl	2.45	2.69	2.07	.....	.....	.....	.....
Potassium sulphate, K_2SO_4	.....	.....	.....	.....	3.40	2.74	2.50
Magnesium chloride, $MgCl_2$	6.88	5.81	8.34	.....	.....	.....	.....
Magnesium carbonate, $MgCO_3$	.....	3.03	2.37	.....	9.93	10.21	11.49
Calcium chloride, $CaCl_2$	.7.50	.....	.....	.....	.....	.....	.....
Calcium sulphate, $CaSO_4$	13.87	6.82	10.30	.....	3.18	5.37	11.00
Calcium carbonate, $CaCO_3$	.....	20.48	10.53	.....	7.71	7.00	8.20

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er waters. A study of t
iver bed at the present ti
ncentration.

Salt River.

e, Mesa, Ariz., representing the Ar

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High and low summer waters (average of 4 weekly composites of daily samples taken Sept. 10–Oct. 9, 1899).	Winter flood water (one composite of daily samples taken Oct. 10–17, 1899).	Low winter water (average of 10 weekly composites of daily samples taken Oct. 18–Dec. 30, 1899).	Low winter water (average of 13 weekly composites of daily samples taken Feb. 17–May 30, 1900).	Very low summer water (average of [illegible] weekly composites of daily samples taken June [illegible]
0.096	0.714	0.025	0.024	[illegible]
14.20	95.10	102.64	106.90	139.[illegible]
72.9	61.9	67.6	72.2	98.[illegible]
.....	.....	.....	.....	.....
2.79	2.45	2.12	5.43	13.[illegible]
4.36	12.19	1.96	1.48	1.[illegible]
1.90	1.52	1.21	.67	.5[illegible]

Traces nearly always.

TS, STATED BY IONS.

:.]

27.45	.....	30.99	32.7	40.[illegible]
1.09	.....	1.53	1.23	1.[illegible]
7.24	.....	4.02	4.37	[illegible]
2.79	.....	2.84	2.92	[illegible]
44.11	.....	40.96	43.75	[illegible]
7.27	.....	7.48	7.64	[illegible]
8.02	.....	11.71	11.51	[illegible]
5.83	.....	4.65	5.29	[illegible]

CULATED TO COMPOUNDS.

r.]

9.35	.....	7.46	8.50	[illegible]
60.84	.....	67.54	72.16	[illegible]
.....	.....	4.97	3.46	[illegible]
.....	.....	.....	.....	.....
2.07	.....	.....	.....	.....
.....	.....	3.40	2.74	[illegible]
8.34	.....	.....	.....	.....
2.37	.....	9.93	10.21	[illegible]
.....	.....	.....	.....	.....
10.30	.....	3.18	5.37	[illegible]
10.53	.....	7.71	7.00	[illegible]

In certain localities along the river the surface of the underground water is so near the land surface that evaporation takes place readily. Water from the river directly or from the underflow is continually finding its way into these localities, bearing its burden of soluble salts, and escaping from the surface by evaporation, leaving its load of salts behind. Localities which have been thus affected are found near Tempe (Pl. XXIII, *A*) and in many places in Gila Valley. Floods may remove these deposits of salt or may bury them, according to circumstances. At the present time both results are being accomplished. The constant shifting of the river channel causes a corresponding shifting of degradational and aggradational localities. Where the aggradational processes predominate, a notable amount of the accumulated salts are necessarily buried.

SALTS IN RIVER WATER.

The origin of the salts contained in the river water presents a different problem. It has recently been demonstrated by M. O. Leighton and his assistant, Sheldon Baker,[a] of the United States Geological Survey, that the common salt so abundant in Salt River is probably due to large salt springs. Several springs were found along the upper reaches of Salt River whose water is described as a weak brine. The water is also strong in carbonates, as evidenced by large travertine deposits at the point of issuance. Iron is also abundant in the water and is deposited near the springs as red oxide. The carbonates contained in the waters are probably due in part to the limestones drained by Salt River and its tributaries and in part to the decomposition of the granitic rocks in its basin. The sodium carbonate, or "black alkali," seems to be due to the decomposition of the igneous rocks. It will be noted that the river water is ordinarily lacking in black alkali, but that it is contained occasionally in flood waters. It is the belief that this is due to the fall of rain upon some alkali-charged slope or mesa which is seldom visited by rains in sufficient quantity to carry away the soluble salts. Specific examples are given by Professor Forbes[b] as follows:

For the period from September 2 to 17, during which a flood occurred, the salts were greater than in the low water preceding and following. The alkali in this water was also distinctly black in character. These circumstances indicate that this flood, which was due to heavy rainfall on the lower half of the Verde River, washed large surface accumulations of salts from a black-alkaline district into the drainage. To a less degree the same holds true of the small flood from August 16 to 22. In most instances, however, during flood time the soluble salts more or less abruptly decrease oppositely to increasing sediments. Mountain rainfall such as was that of August and October, 1899, and May, 1900, is evidently responsible for this freshening of the water. Mountain rainfall in southern Arizona is more abundant than upon the level, lower deserts. The higher watersheds, being better drained, afford

[a] Personal communication.

[b] Forbes, R. H., op. cit, p. 165.

fresher water. The less frequent, though often copious, floods which sweep the lower levels carry much accumulated soluble salt into the drainage, which is often thus rendered strongly saline.

EFFECT OF SALTS ON VEGETATION.

EFFECT IN ARIZONA.

There is a widespread opinion among water users of Salt River Valley that the waters of the underflow are injurious to vegetation. The evidence on this question is conflicting. It is probable that too little is known of determining conditions in Salt River Valley to draw any general conclusion at the present time. The character of the soil, the manner of manipulation, and the kind of crop should be considered as well as the character of the water. Professor Forbes[a] has studied this question and concludes that waters containing more than 100 parts of soluble salts in 100,000 parts of water "are liable in a few years to cause harmful accumulations of alkali."

On the other hand there are many instances of land irrigated with pumped water alone where no detrimental effects can be detected. The Collins well has supplied land entirely with irrigation water containing 150 parts of soluble salts in 100,000 parts of water, for several years, with no detrimental effect that can be detected. Doctor Kunz's garden has had no water for five years other than well water containing 223 parts of salts. The court-house yard in Phoenix has been irrigated for about twenty years with well water alone, containing from 102 to 136 parts of salts. The Indians at the western end of the Piña Reservation have used the seepage water from Salt River, containing about 200 parts of salts, for many years. Land upon which this water has been used continuously at least since the Indians came under the supervision of the white men, about thirty years ago, is at the present time the most productive land on the reservation.

The sodium carbonate (black alkali) is the salt most feared by those who object to the use of pumped water. It will be noted from an inspection of the tables that no sodium carbonate is found in the underflow from which the great proportion of the pumped water is to be secured. The sodium carbonate is found only in the comparatively unimportant surface waters in the Mesa region and in the Phoenix region and is north of the area in which irrigation waters can probably be pumped with profit. It is evident, therefore, that the quantity of this salt which would probably find its way into waters pumped for irrigation is too small to be seriously considered.

The effects of accumulation of salts in the soil is plainly marked in certain parts of the valley. A considerable part of the land south of Tempe is barren in places and covered with white incrustations of salt

[a] Forbes, R. H., op. cit., p. 166.

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VEGETATION.

ZONA.

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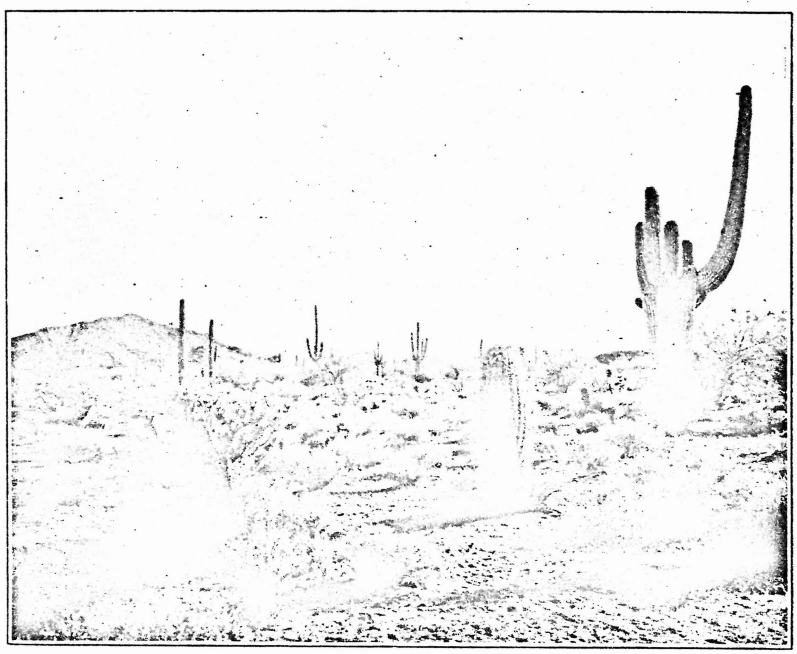
[a] p. 166.

A. AN ORCHARD NEAR PHOENIX KILLED BY LACK OF WATER.



B. DESERT NEAR TEMPE, SHOWING TYPICAL DESERT VEGETATION.

(Pl. XXIII, A). Some of this land has been under cultivation, and has been abandoned on account of the accumulations of alkali. It is in this region that the Bureau of Soils has leased a tract of land for the purpose of demonstrating the methods of reclaiming alkali land.

EFFECT IN EGYPT.

Waters much more saline than those of Salt River Valley may be used for irrigation if used properly, as is shown by the following extract from a circular by Mr. Means:[a]

During the summer of 1902 a representative of the Bureau of Soils visited the oases of the Oued Rihr country in the Desert of Sahara in eastern Algeria. In these oases artesian waters carrying very large quantities of soluble matter are used successfully for irrigation. From the information gathered there, and from experience in this country, it seems that the amount of soluble matter allowable in an irrigation water has been greatly underestimated by American writers, and that many sources of water which have been condemned can be used with safety and success, provided the proper precautions are taken to prevent the accumulation of the salts. As the precautions are those which should be taken by every irrigator, even if pure water is used, it seems an important matter to bring before the American people the methods in use in the Sahara.

The staple crop grown by the Arabs in the oasis country is the date, the fruit of a palm tree known to be one of the plants most resistant to alkaline or saline conditions of the soil, but in addition to this considerable quantities of the deciduous fruits, garden vegetables, and alfalfa are produced for home consumption.

Some of the vegetables successfully grown are those considered sensitive to alkali, and yet they were being irrigated with water containing in some instances as much as 800 parts of soluble salts to 100,000 parts of water, sometimes as high as 50 per cent of the salts being sodium chloride.

The limit of concentration for irrigation water in the United States, even where only the most resistant field crops are to be grown, has been placed by some authorities at 30 parts sodium chloride (common salt) or sodium carbonate (black alkali), and at from 170 to 300 parts of the less harmful salts, per 100,000 of water.

* * * * * * *

The fact that the Arabs in Algerian oases are actually growing sensitive plants by the aid of irrigation waters containing from 400 to 800 parts of soluble salts, in some instances 50 per cent sodium chloride, shows that the Bureau has been on the conservative side in its estimates and should encourage a more hopeful feeling among the people occupying areas where only alkali water is available for irrigation.

The prerequisite to the use of water of high salt content in irrigation is the knowledge that the methods employed are opposed to the teachings of most American writers on the subject. Those who place the low limit of safety for alkaline irrigation waters have taught that where water was badly alkaline irrigation should be sparing. They have not insisted on thorough drainage, and they have warned irrigators against too frequent irrigation. With such practices the limit of concentration which they set is probably high enough, and even then all except the most sandy soils or those with exceptionally good natural drainage would ultimately be damaged.

The methods in the oases are quite different. The Arab gardens are divided into small plats, about 200 feet square, between which run drainage ditches dug to a depth of about 3 feet. The soils being very light and sandy, this ditching at short intervals

[a] Means, T. H., The use of alkaline and saline waters for irrigation: Bur. Soils Circular No. 10, U. S. Dept. Agric., 1903.

insures the most rapid and thorough drainage. Irrigation is by the check method, and application is made at least once a week, though often two wettings a week are deemed necessary. A large quantity of water is used at each irrigation. Thus a continuous movement of the water downward is maintained, and there is little opportunity for the soil water to become more concentrated than the water as applied, and the interval between irrigations being so short but little accumulation of salt from evaporation at the surface takes place. What concentration or accumulation does occur is quickly corrected by the succeeding irrigation.

The native gardens are situated in the date palm groves and the vegetables and fruit are grown in the partial shade cast by these trees. The natives not only have the question of very saline irrigation waters to contend with, but the soils originally are often very alkaline. In three years they reclaim land too salty to grow the minor crops, using the saline water for that purpose, following the same plan of drainage and weekly irrigation as where crops are growing. One garden situated on the side of a salt flat and originally very saline was visited. Here alfalfa was in very good condition, and fig, pomegranate, melon, tomato, cabbage, pepper, and other plants were growing luxuriantly. The reclamation of this plat by irrigation twice a week had taken three years.

* * * * * * *

The irrigation water is all drawn from artesian wells. A number of samples were sent in to the laboratory for analysis, the results of which are shown in the following table. These are fair average samples of the irrigation waters in use, and do not represent by any means the maximum of salinity. Field tests showed as high as 816 parts to 100,000 of water in actual use on soils growing vegetables.

Chemical analyses of artesian water used in irrigating gardens in Sahara oases, Algeria.

Constituent.	Well at oasis Tabesbest.	Well at oasis Kudi Asli.	Well at garden of Ben Hadrian.
Ions:	*Per cent.*	*Per cent.*	*Per cent.*
Calcium (Ca)	9.92	4.19	9.86
Magnesium (Mg)	4.52	6.02	4.26
Sodium (Na)	14.03	20.48	14.18
Potassium (K)	4.27	2.35	2.72
Sulphuric acid (SO_4)	34.38	29.43	17.59
Chlorine (Cl)	28.06	36.21	27.05
Bicarbonic acid (HCO_3)	5.02	1.32	24.34
Conventional combinations:			
Calcium sulphate ($CaSO_4$)	33.04	14.23	24.90
Magnesium sulphate ($MgSO_4$)	13.63	24.29	7.04
Magnesium chloride ($MgCl_2$)	7.23	4.41	16.72
Potassium chloride (KCl)	8.12	4.48	5.19
Sodium bicarbonate ($NaHCO_3$)	6.92	1.81	33.54
Sodium chloride (NaCl)	31.06	50.78	12.61
Total solids in 100,000 parts water	601.50	408.10	571.90

A. SEEPAGE LAND SOUTHEAST OF TEMPE.

B. VIEW SOUTHWARD FROM TEMPE BUTTE.

QUANTITY OF UNDERGROUND WATER.

THE UNDERFLOW.

WATER ENTERING THE VALLEY.

In order to secure a measure of the water entering the valley fill as underflow, it would be necessary to measure all streams, both permanent and intermittent, as well as the occasional waters entering as sheet wash from the surrounding hills. It would be necessary, furthermore, to measure the quantity of surface water escaping from the valley. The greater part of the supply is from Salt River and the total quantity entering from this source is known from the records of the gaging stations on Salt and Verde rivers. The amount taken from the river by the canals is known, but the loss from the valley during times of flood is unknown on account of the want of a gaging station at the outlet of the valley. It is, therefore, obviously impossible to arrive in this way at even an approximate measure of the water entering the underflow. Other methods must be resorted to in order to obtain a quantitative estimate.

RETURN WATER.

The Tempe canal diverts all the surface water of the river north of Mesa. Near Tempe the underground water returns to the surface, making a flow of about 35 second-feet. West of Phoenix the underground water again returns to the surface. It is not possible at present, however, to state what proportion of the seepage water comes from Salt River, since its underflow joins that from Gila River. It is probable, however, as previously stated, that the underflow of the Gila is fed in large measure by the waters from Salt River passing as underflow east of Salt River Mountains. In Gila Valley west of Florence all the waters diverted from the river, except during occasional floods, are seepage waters. The flow in the Gila channel and in the Indian ditches at Gila Crossing was 800 inches when measured on August 17, 1902. Mr. M. M. Murphy estimated the water diverted by the Indian ditches east of the junction of Gila and Salt rivers in January, 1903, as 500 inches, leaving 1,000 inches in the river. The smaller canals of Salt River, between Tempe and the Buckeye, divert water as follows:

Water received by canals west of Phoenix, Ariz.

[Information furnished by M. M. Murphy.]

Canal.	June, 1902.	June, 1903.
	Inches.	*Inches.*
Leon	265	None.
Peninsula	35	234
Lambeye	74	138
Meridian	153	180
Indian	82	72
Total	609	624

The winter flow is about double the above. Available summer flow at the head of St. Johns canal is 400 inches.

Maximum winter flow (not flood) at St. Johns is 800 inches.

Indian ditches on the lower Gila take a minimum of 400 inches.

The amount taken by the Salt River and Maricopa canals—joint head—for June, 1903, averaged 1,344 inches. This is slightly more than usual.

The amount diverted by the Buckeye canal is given by Mr. W. A. Apgar, as follows:

Flow in Buckeye canal.

	Second-feet.
July, 1902	78
July, 1902 [a]	80
May 14, 1903	129
May 23, 1903	133
May 24, 1903	128

Davis[b] says:

The amount of seepage water was measured by Mr. Cyrus C. Babb in June, 1896, and the results showed in one case an increase of over 80 second-feet in a distance of 7 miles.

Code[c] states that "the return flow picked up by the head of the Maricopa and Salt River canals in ordinary years is found to approximate 60 cubic feet per second. This flow has naturally decreased during the past summer owing to the scanty irrigations received by the Mesa, Utah, and Tempe lands above, and to the gradual lowering of the underground supply." He states further that—

at the head of the Buckeye canal, some 24 miles farther down the stream, is again found a volume approximating in ordinary summers 150 cubic feet per second. * * * Some 20 miles below the Buckeye, I am told, another flow of approximately 50 cubic feet per second is to be picked up.

[a] A few days later.

[b] Davis, A. P., Irrigation near Phoenix, Ariz.: Water-Sup. and Irr. Paper No. 2, U. S. Geol. Survey, 1897, p. 43.

[c] Code, W. H., Irrigation in Salt River Valley, in Report of irrigation investigations for 1900, No. 2: U. S. Dept. Agric., Bull. 104, 1901, p. 103.

According to Code's estimate the return water is 210 second-feet, whereas the estimate given above is only 150.

There is no time for which measurements are available for all the canals diverting seepage water. The amount, however, of the seepage water does not vary to any great extent. The average amount, then, according to the best measurements and estimates available is something over 150 second-feet, making a total of more than 100,000 acre-feet per year.

If Code's estimate be accepted the return water east of the Buckeye canal is something over 150,000 acre-feet per year. A small part of this is return water from irrigated lands, but the greater part is from the natural underground flow. A considerable but undetermined part of it is from the Gila underflow, but the greater part is from Salt River.

The seepage waters estimated at 100,000 acre-feet per year are only those returning to the surface east of the Buckeye canal, and take no account of a large quantity of return water diverted by the several canals farther down the river. Furthermore no account is taken of the quantity passing as underflow through the gravels at the lower end of the valley, at the Buckeye head-gates. The 100,000 acre-feet is a measure of the spill from the top of the underflow—water which the valley fill for some reason is unable to hold. The total volume of underflow is therefore something greater than 100,000 acre-feet per year.

MEASURING THE UNDERFLOW.

SLICHTER'S METHOD.

The most elaborate and scientific method of arriving at a quantitative estimate of the underground waters of the valley is obtained from the application of Slichter's[a] method. On account of the great importance of arriving at as accurate an understanding as possible of the underflow and its probable volume, I quote from this paper such portions as apply to the principles and methods of procedure. After a discussion of the principles relating to the movement of underground waters, Professor Slichter proceeds:

Formula.—The formula which the writer has devised for determining the flow of water through a column of sand is as follows:

$$q = 0.2012 \frac{pd^2s}{\mu hK} \text{ cubic feet per minute.} \qquad (3)$$

In this formula q stands for the quantity of water transmitted by the column of sand in one minute; p is the difference in pressure at the ends of the columns, or the head under which the flow takes place, measured in feet of water; s is the area of the cross section of the sand column, measured in square feet; h is the length of

[a] Slichter, Charles S., The motions of underground waters: Water-Sup. and Irr. Paper No. 67, U. S. Geol. Survey, 1902, pp. 24-30.

COMPUTATIONS OF VOLUME.

Since the maximum velocity previously quoted is 3.6 miles, or 18,908 feet per year, it seems probable in view of the great freedom of movement of the underground waters in a number of places in Salt River Valley, as shown by pumping tests and otherwise, that the effective size may be much greater in places than 0.72 mm., and the porosity may be greater than 40 per cent with a rate of movement correspondingly greater. It is reasonable to suppose that in material of such varying size as that of Salt River Valley accumulations of the coarse gravel and bowlders in places occur with little sand and silt. Such beds would offer little resistance to the underflow and a velocity even exceeding the maximum quoted above (3.6 miles) might easily occur. It is evident from the quantity of return water—more than 100,000 acre-feet per year—that the underflow of which this return water is a part may easily amount to the 148,196 acre-feet per year indicated by the application of Slichter's formula, and may possibly be much greater. Let it be remembered, however, that the 100,000 acre-feet of return water is from Gila and Salt rivers combined, there being no way at present of separating the two.

It may be useful to compute the volume of underflow for several possible velocities, bearing in mind always that since the actual rate of underflow is unknown, the results are only possibilities and have only illustrative values.

In a former paper[a] on the underground waters of Gila Valley certain estimates of the possible quantity of the Gila underflow were made. Much less is known of that valley than is known of Salt River Valley, and the estimates are less likely to be correct than those for Salt River Valley. Since the two underflows join and their relative values are not determinable, the estimates made in that paper are quoted for comparison with those herein given. The two underflows should be considered together for the reason that the only reliable measure of the quantity of underflow at hand is the return water of Salt and Gila rivers combined.

Quantitative estimates of underflow of Salt and Gila rivers.

	Area of cross section in square feet.	Acre-feet per year at velocity of—			
		1,360 feet per year.	¼ mile per year.	1 mile per year.	2 miles per year.
Salt River	11,880,000	148,196	287,760	575,520	1,151,040
Gila River	2,872,320	35,830	69,564	139,128	378,256
Total		184,026	357,324	714,648	1,529,296

[a] Lee, W. T., The underground waters of Gila Valley, Arizona: Water-Sup. and Irr. Paper No. 104, U. S. Geol. Survey, 1904.

It will be observed that with the given cross sections and a porosity of 40 per cent a velocity of one-half mile per year yields a volume of 357,324 acre-feet per year. Considering the great volume of return waters—100,000 acre-feet or more east of the Buckeye canal and a large though unknown volume west of that canal—and considering also the coarseness of the water-bearing material and the freedom of movement evident at many of the pumping plants, it seems probable that the rate of movement may be greater than the computed rate of 1,360 feet per year, and that the average velocity may be more nearly one-half mile per year, making a normal volume of underflow of 287,760 acre-feet per year in Salt River Valley and 69,564 acre-feet per year in Gila Valley, or a total of 357,324 acre-feet of water entering the underflow each year.

THE RESERVE.

The computations thus far have dealt only with the flow—that is, with the volume passing through the assumed cross section during the year; they take no account of the water already in the valley-fill. An estimate of this amount may be instructive.

There are in Salt River Valley, north of the Pima Indian Reservation, about 525 square miles (fig. 21) beneath which underground water occurs less than 50 feet below the surface. About 275 square miles of this area are underlain by bowlder beds. These beds are known to be thicker than 150 feet, but how much thicker can not be stated. They are known to extend beyond the limits of the area indicated in the map, but to what extent remains unknown. Over a considerable part of the 525 square miles the water is only 10 to 20 feet beneath the surface. Assuming the limit of lift for pumping as 65 feet, and allowing 15 feet for the local depression of the water table due to the action of the pump, it is evident that pumps placed in the lower portions of the region might permanently lower the level of underground water 35 feet and still obtain water within the limit of cost. It is furthermore evident from the readiness of movement of the underground waters that pumps placed on the lower grounds might readily draw from the whole region and depress the water table uniformly.

It is thought that water contained in the vast quantities of material beyond the 50-foot contour will much more than compensate for the area in which the finer material predominates, as indicated in fig. 21, and that it is safe to assume a porosity of 40 per cent for the material over an area of 525 square miles as a working basis. In order that the water table shall be permanently lowered 35 feet the gravels must part with the water contained in the spaces, amounting to 40 per cent of the volume over an area of 525 square miles, or 336,000 acres, and 35 feet deep. This amounts to 4,704,000 acre-feet of water.

Viewing the problem from another standpoint, there is available for pumping in the gravels at the present time, provided none escape, water in sufficient quantity to cover the 336,000 acres to a depth of 14 feet. This water if applied to 200,000 acres, the estimated area cultivated in Salt River Valley, would supply the entire area, allowing 4 acre-feet of water per acre per year, for nearly 40 years.

It should be stated in this connection that the immense quantity of water contained in the gravels is continually moving down the valley. While the water table remains constant, the inflow at the head and sides of the valley equals the outflow or discharge at the lower end. The total quantity, therefore, should be considered as a reserve rather than an available supply. The quantity entering the underflow represented by the volume of flow is the maximum amount which can be considered as permanently available for pumping. This amount might be withdrawn continuously if the pumps could be arranged in such a manner as to secure the whole flow. Since this is obviously impossible, something less than the normal flow is permanently available for pumping. A greater draft will draw upon the reserve and continued use of the reserve may lower the water table in time to a horizon too deep for pumping.

From the quantity of the reserve it is evident that pumps might be operated for years before the reserve was exhausted, provided the natural escape of the water from the valley could be prevented. But since this escape is great and constant—more than 100,000 acre-feet per year (besides an unknown quantity passing as underflow in the Buckeye region as previously described)—any great quantity of water extracted by pumps would probably cause a material depression of the water table.

The elevation of the surface where the underflow returns in part, west of Phoenix, is about 200 feet lower than at Mesa. Should the inflow cease the surface of underground water must eventually lower to the level of the point where the water escapes. It is the friction due to passage through the sands and gravels retarding the flow, coupled with the supply from the inflow, that maintains the water gradient. When this balance is disturbed, a disturbance of the water table must result. The practical question is: How much of a disturbance in the way of pumping can be made and still have water within pumping distance?

It is evident that, other things equal, an increase of water entering the valley will raise the water table and a decrease will lower it; an increased draft at the lower end of the valley, whether by escape as seepage or by the demand of pumps, will lower the water table; water withdrawn by pumps at any point in the valley will affect the water table, particularly below the pumps and in general over the whole valley, by disturbing the equilibrium established in nature.

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A lowering of the water table of several feet has taken place during the past few years. How much of this lowering, if any, is due to the operation of pumps and how much to the scarcity of water during the past few years, owing to the scant rainfall, is not determinable at present.

The underflow, even though the volume be great, should not be considered as inexhaustible. There is a large quantity of water available; a quantity well worth the necessary expense of pumping plants for securing it. But it is fairly certain that a large number of pumps run continuously will cause a permanent lowering of the water table, and pumps established on high ground may find the lift too great for economic operation after a few years.

Probably the most satisfactory way of utilizing the underground water is to withdraw by pumps no more than the normal flow, leaving the gravels saturated as a reserve to be used in times of need and replaced in times of plenty; in other words, to use the water in the valley fill as a reserve supply rather than to exhaust it quickly in the extension of cultivated land, with the consequent loss of property when the water level falls beyond the reach of the pumps.

PRACTICAL POROSITY.

The proportion of voids given for various diameters of sand grains usually assumes a comparatively uniform size of grain. It is obviously erroneous in heterogenous materials to make computations for any selected size or even for an average size. The finer material packs into the interstices of the coarser. It would be entirely possible to have such materials packed in such a manner as to hold very little water. No doubt such cases occur in the valley fill. There is also no doubt that places may be found where coarse material occurs apart from the fine, and also where, although coarse and fine exist together, they are loosely packed and allow a free passage of water.

It is furthermore obvious that since the sands can not be pumped dry, much water might be held by them which is properly a part of the underflow, but which is not available for pumping. In order to arrive at an approximation of the quantity of water available for pumping in the mixed gravels of the valley, a series of measurements were made by filling a barrel with gravel and sand and measuring the quantity of water which could be poured into it, assuming that this quantity would be a fair measure of the quantity that might be withdrawn by pumping. In order to obtain representative material, the measurements were made at a well east of Phoenix (G. W. Smith's), where the material thrown from the well lies undisturbed. The barrel held 46⅜ gallons—measured by a standard graduate. Such material was first selected as seemed to be a fair average of the water-bearing materials observed throughout the valley. It was sand, pebbles, and

bowlders up to 8 inches in diameter. The sand was slightly moist from a shower which fell the day before the measurements were made. The material was carefully packed in the barrel in order to approximate as nearly as possible the natural conditions. Water was then poured slowly into the material until the barrel was full. It was found that 10½ gallons of water could be poured into the barrel, representing 20.5 per cent of the total space. These gravels might easily be packed more closely in nature than they were in the experiment, and the amount of water that could be pumped from them, leaving them damp since all the water could not be withdrawn, would be something less than 20 per cent of the total bulk.

For a second experiment a place was selected where only coarse gravel and bowlders occurred, varying in size from half an inch to 8 inches in diameter. With this material in the barrel, 16⅝ gallons of water were added to fill the barrel, or 35.8 per cent of the total space. In this case, as in the former one, the percentage of voids in nature would be something less, owing to the closer packing of the gravels. The actual quantity of water available for pumping in this case is something less than 35 per cent of the volume.

Volume of water contained in sands and gravels of different porosity 35 feet deep.

[In acre-feet.]

Valley.	Area in acres.	Porosity.					
		15 per cent.	20 per cent.	25 per cent.	30 per cent.	35 per cent.	40 per cent
Salt River.....	336,000	1,764,000	2,352,000	2,940,000	3,528,000	4,116,000	4,704,000
Gila River	224,000	1,176,000	1,568,000	1,960,000	2,352,000	2,744,000	3,136,000
Total ...	560,000	2,940,000	3,920,000	4,900,000	5,880,000	6,860,000	7,840,000

It is evident that the estimated volume of the reserve previously stated as 4,704,000 acre-feet is much greater than the volume which could actually be withdrawn by pumping. In order to have something tangible to consider, the preceding table has been so prepared as to show the volumes of water contained in a given volume of sand and gravel with assumed porosities. The area is chosen to include only the land beneath which water is 50 feet or less below the surface, and where the water level might be lowered 35 feet and still be within pumping distance. Since there is a large area beyond the 50-foot contour beneath which water occurs which is left out of account, it is evident the volumes given in the table are smaller than the actual quantity within reach.

The quantitative estimates for Gila Valley are inserted because of the close association of the two valleys.

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Porosity.			
5 per cent.	30 per cent.	35 per cent.	40 per cent
, 940, 000	3, 528, 000	4, 116, 000	4, 704, 000
, 960, 000	2, 352, 000	2, 744, 000	3, 136, 000
, 900, 000	5, 880, 000	6, 860, 000	7, 840, 000

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It is probable that the practical porosity—that is, the percentage of volume consisting of water actually available for pumping—is somewhere between 15 and 30 per cent.

A pumping plant of average capacity, such as those of the Consolidated Canal Company, throws a continuous stream of about 200 inches. If operated without stop, one pump would raise 3,620 acre-feet of water per year. But since there is always more or less stoppage for repairs, etc., it is assumed, for convenience, that one pump will raise about 3,000 acre-feet per year. The number of pumps required to raise the possible volume of underflow are as follows:

Number of pumps required to raise the water[a] of the underflow.

Number of pumps of 3,000 acre-feet per year capacity.	Volume of underflow in acre-feet.
30	148, 196
96	287, 760
192	575, 520
384	1, 151, 040

[a] For volume, see tables on pp. 170, 174.

If a volume of underflow of 287,760 acre-feet per year be accepted, as previously suggested, it is evident that 96 pumps would lift the entire flow, provided it could all be secured. It is evident, however, that it could not all be secured. A withdrawal of the supply in any large measure must lower the water table, since the escape of the seepage waters below can not be prevented. The withdrawal of the total supply, if that were possible, would cause a lowering of the water table in time to the level of the outlet, a distance of about 200 feet for the Mesa region. Any depression of the water table due to the loss by seepage at the lower end of the valley will in turn depress the water table in the pumping region. It is therefore evident that, with an inflow of 287,760 acre-feet per year, 96 pumps would soon depress the water table beyond easy reach. In other words, in order to maintain conditions such that the underflow may be permanently and regularly useful, the pumps must be limited, under assumed conditions, to a number notably less than 96.

It is impossible at the present time to give more than a rough estimate of the quantity of water now being withdrawn from the underflow. Few of the pumps run continuously and there are many that run only occasionally to secure irrigation water when other sources fail. The most accurate estimate possible at present (summer of 1904) of the water pumped is 4,000 inches. This amount is pumped only during the summer. Should the pumps now in operation be run continuously

at the estimated rate (4,000 inches) they would supply about 54,000 acre-feet of water per year, or more than one-third of the minimum estimated volume of the underflow.

If the reserve be considered as a part of the available supply for pumping, a much greater number of pumps might be operated for some time before the water table was lowered beyond reach. The pumping area described is about 36 miles in length. At the assumed rate of underflow, water entering at the head of the valley above Mesa would require seventy-two years to make the journey to the mouth of the Agua Fria. At this rate of movement water not only to the amount of the inflow but also large quantities of the reserve might be

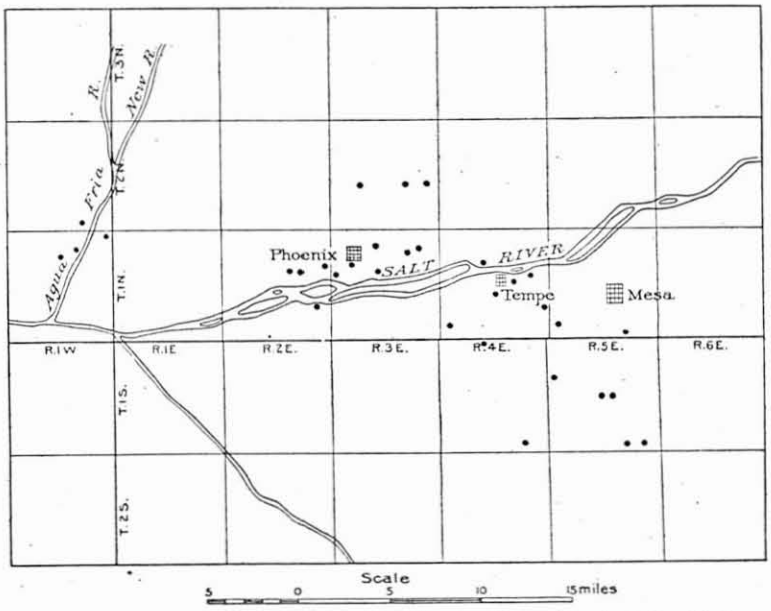

FIG. 24.—Map of Salt River Valley, showing location of pumping plants described.

withdrawn for years before the water table was permanently depressed beyond the limit of lift. Its recovery, however, would be equally slow. If the pumping project is pushed too far, it is inevitable that the more inefficient pumping plants, especially those on higher ground, must be abandoned, owing to increasing lift as the water table is depressed. In this, as in other cases of competition, only the fittest can survive.

If it be objected that the assumed velocity of half a mile per year is too small, and that 1 mile or more per year is the rate of movement, then the volume of flow is correspondingly greater and the number of possible pumping plants will be greatly increased.

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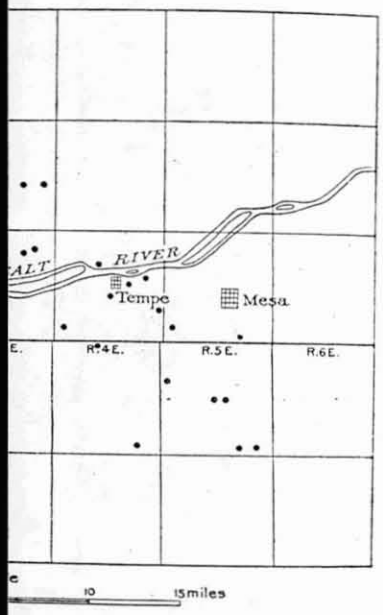

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COST OF PUMPING WATER.

SALT RIVER VALLEY.

Comparatively little has been known up to the present time of the actual expense of pumping water in Salt River Valley. The pumping tests described in the first chapter and summarized below, deal with conditions as they actually exist. In most cases these conditions are far from ideal. Indeed there are few pumping plants in the valley which are working with the efficiency that could reasonably be expected. There have been no experiments until recently tending to show the most economical method of pumping water, and there is no agreement among those using pumped water as to what kind of pump or what power is best, or even how to construct a well in order that it may give the best permanent results. It is thought that the computations of cost of raising water at the various pumping plants just as they exist with all their imperfections may be of value by way of comparison with guaranteed cost, which is usually based on ideal conditions.

I have excluded from the list all computations except those which I have reason to believe are essentially correct. In some cases certain elements are doubtful; for example, at the Collins well the exact amount of wood used was not obtained. It should be stated also that the test runs upon which the computations are based were short, varying from one to three hours. The figures consequently show the rate irrespective of stoppage for repair or for other cause.

In making the computations I have included in the cost of the acre-foot interest at 7 per cent per annum on the investment, the legal rate of interest in Arizona, and 10 per cent per annum depreciation, the time in each case being the time required for pumping 1 acre-foot of water. No allowance is made for stoppages. In each case the expense for oil and incidentals is estimated at 5 cents per acre-foot.

Records of pumping plants in Salt River Valley, Arizona, on which pumping tests were made.

Name.	Kind of well.	Size.	Total depth.	Depth to water.	Amount of lowering.	Total lift.
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Murphy-McQueen	Drilled	1	1,305	23	19	44
Consolidated Canal Co.:						
No. 2	do	1¼	246	36	15	50.65
No. 3	do	1¼	266	37	11	47.56
Valley Seedless Grape Co	do	1	348	30	11.5	47
Tempe waterworks	do	1	152	23	14	249
T. J. Parry	Dug	40 by 60	21	17	1	18
L. Kunz	do	6 by 6	24	18	(?)	18
Geo. U. Collins	do	60 by 100	29	14	6	22
Nelson & McIlwaine	do	7	26	16	5	21
John Heaton	Dug		12	(?)	(?)	28
	Drilled	¼	45			

Records of pumping plants in Salt River Valley, Arizona, on which pumping tests were made—Continued.

Name.	Kind of pump.	Power.	Cost of well and pump.	Capacity per minute.	Cost per acre-foot.	Cost per acre-foot per foot of lift.
				Gallons.		
Murphy-McQueen [a]	Centrifugal.	Steam and wood.	.....	3,038	$2.27 2.97	$0.051 .068
Consolidated Canal Co.:						
No. 2	.....do.....	Electric ..	$8,000	2,223	2.84	.056
No. 3	.....do.....	.....do....	8,000	2,273	2.69	.054
Valley Seedless Grape Co	.....do.....	Gasoline..	.....	518	3.80	.08
Tempe waterworks	Triplex.....	Electric ..	3,700	275	14.55	.058
T. J. Parry	Bucket.....	Gasoline..	900	673	2.91	.161
L. Kunz	Plunge	Horse.....	250	62	1.14	.063
Geo. U. Collins	Centrifugal.	Steam and wood.	1,500	2,200	1.93 2.75	.07 .124
Nelson & McIlwaine	.....do.....	Gasoline..	2,200	900	2.88	.137
John Heaton	Plunge	.....do....	500	120	3.87	.138

[a] Cost does not include interest and depreciation. If this be added, the total cost becomes approximately $2.97 per acre-foot or 6.8 cents per foot per acre-foot.

It has been estimated that electric power can be furnished at a cost not exceeding $50 per horsepower per year. In three of the pumping plants previously described the horsepower consumed at the pumping station is accurately known. Since these three use electric power, direct comparison can be made as in the following table:

Cost of pumping with power furnished at $50 per horsepower per year compared with present cost.

Name.	Horsepower consumed.	Present cost per acre-foot.	Cost per acre-foot with power at $50 per horsepower per year.	Present cost per acre-foot per foot of lift.	Cost per acre-foot per foot of lift with power at $50 per horsepower per year.
Consolidated Canal Co.:					
No. 2	42.88	$2.84	$0.60	$0.056	$0.012
No. 3	42.88	2.69	.59	.054	.0118
Tempe waterworks	31.51	14.55	3.62	.058	.0144

The experiments upon which these costs are based were performed by Engineer P. E. Fuller, and are thought to be very accurate. For irrigation purposes the first two are most reliable, since they are pumping stations established exclusively for irrigation. No allowance has been made for loss of time for repairs. With such an allowance the price per foot per acre-foot with power at $50 per horsepower per year will be slightly more than 1.2 cents. Owing

to the careful and painstaking experiments of Mr. Fuller this rate can be stated with considerable confidence.

As previously stated, there are places, for example near Tempe, where the water table is less than 10 feet beneath the surface. Allowing a local depression of 15 feet due to the action of the pump, or a total lift of 25 feet, water can be raised for 30 cents per acre-foot, a price much lower than the present cost of canal water.

The actual cost of canal water in Salt River Valley at present is somewhat difficult to estimate, owing to the manner in which water is sold. The price nominally paid is much less than the actual cost, for the quantity nominally paid for is seldom received. It is probable that the actual cost of canal water at the present time is little, if any, below $1 per acre-foot. With a lift of 65 feet, which has been assumed as the present limit, an acre-foot of water would cost 78 cents. The Consolidated Canal Company finds it profitable to pump water at a cost of $2.84 per acre-foot while others are pumping at a cost as high as $3.87 per acre-foot. At the rate of 1.2 cents per foot, water could be raised with profit from a depth much greater than 65 feet, and the pumping area indicated in the map (fig. 21) could be greatly extended.

COST OF PUMPING IN OTHER REGIONS.

It will be instructive to compare the cost of pumping water in Salt River Valley with the cost as determined elsewhere. The following extract contains some data which may be useful:[a]

COST IN ARIZONA, WISCONSIN, AND CALIFORNIA.

The reports of former years and this report have given meager returns from a few pumping plants, showing the cost of raising water. Mr. Code reports the details of tests made by him, and gives as his general conclusion that with wood at $4 per cord water can be lifted 45 feet for $2.50 per acre-foot, and that with power delivered to the pump at $60 per horsepower per annum water can be lifted 45 feet at a cost of $1 per acre-foot. Both these estimates include the cost of attendance and a fair rate of interest on the investment.

Professor King gives the cost of raising water in Wisconsin. At Madison water was raised 25 feet at a cost of $2.64 per acre-foot, using coal which cost $5 per ton. At Stevens Point water was raised 33 feet at a cost of $3.32 per acre-foot, using a gasoline engine, with gasoline at 11.98 cents per gallon.

Professor Chandler gives the cost of an acre-foot of pumped water in the Tule River Valley at from $5 to $7.40, with a lift of 71 feet and power costing $50 per horsepower per annum.

The following table gives all the data regarding the capacities of various kinds and sizes of pumps which have been included in all the bulletins published by this office:

[a] Report of irrigation investigations for 1901, No. 1: U. S. Dept. Agric. Bull. 119, 1902, p. 34.

Capacity of pumps.

Pump.	Power.	Lift.	Capacity per 24 hours.
		Feet.	*Acre-feet.*
2.5-inch Lawrence centrifugal	5-horsepower gasoline		0.264
5-inch Krogh centrifugal	12-horsepower gasoline	30	1.32
Do	do		.99
5.5 by 8 inch triplex-acting pump.	do	125	.594
8-inch centrifugal			8.80
Do			6.60
Do		19	7.26
Do			7.04
Do		14	8.80
Do	18-horsepower engine (burning wood).		4.40
Do		18	7.70
8-inch Krogh		32	6.60
10-inch centrifugal	80-horsepower engine	39	17.60
12-inch centrifugal		23	15.40
16-inch centrifugal	80-horsepower Frick engine	14.5	35.20
18-inch centrifugal			44.00
20-inch centrifugal		15	44.00
Double-cylinder 6-inch pump	4-horsepower gasoline		.396
Triplex pump, 5.5 by 8 inch plungers.	5-horsepower gasoline		.594
Compound duplex pumping engine.	80-horsepower boiler		132.00
Worthington compound duplex steam pumping engine.	do		176.00

COST OF PUMPING IN NEW MEXICO.

An instructive series of experiments has recently been made at the New Mexico Agricultural Experiment Station calculated to show the comparative merits of several makes of pumps. The most economic speed was determined for each make of pump tested, and the cost determined per acre of irrigating 3 inches deep, using wood for fuel at $2.25 per cord. In order that the table may correspond with those previously given, the figures have been altered to read in cost per acre-foot. Otherwise the figures are those given in the various tables by Vernon and Lester,[a] except those in the last column; there the cost is reduced to unit of lift.

[a] Vernon, John J., and Lester, Francis E., Pumping for irrigation from wells: N. Mex. Agric. Exp. Sta. Bull. No. 45, 1903.

of pumps.

Power.	Lift.	Capacity in 24 hours.
	Feet.	*Acre-feet.*
power gasoline		[illegible]
epower gasoline	30	[illegible]
		[illegible]
	125	[illegible]
		8.[illegible]
		6.[illegible]
	19	7.[illegible]
		7.[illegible]
	14	8.[illegible]
epower engine (burn-ood).		4.[illegible]
	18	7.70
	32	6.[illegible]
epower engine	39	17.[illegible]
	23	15.[illegible]
epower Frick engine	14.5	35.[illegible]
		44.[illegible]
	15	44.[illegible]
power gasoline		.[illegible]
power gasoline		.[illegible]
epower boiler		132.[illegible]
		176.[illegible]

G IN NEW MEXICO.

ments has recently been made at the iment Station calculated to show the akes of pumps. The most economic ake of pump tested, and the cost de inches deep, using wood for fuel at he table may correspond with those been altered to read in cost per acre those given in the various tables by se in the last column; there the cost

nping for irrigation from wells: N. Mex. Agric. Exp.

Cost of pumping at New Mexico Agricultural Experiment Station.[a]

Name of pump.	Pump running at most economic speed, in gallons per minute.	Cost per acre-foot.	Lift.		Cost per foot of lift per acre-foot.
			Ft.	*in.*	
Van Wie	600	$2.05	27	10¼	$0.073
R. D. Wood	600	2.59	28	½	.092
Kingsford	824	2.39	34	5½	.069
Bryon Jackson	944	2.46	36	8½	.067
Fairbanks-Morse	824	2.47	35	8¾	.069

[a] Fuel is dry tornillo wood at $2.25 per cord.

COST OF PUMPING IN CALIFORNIA.

The principal expense of pumping is the fuel, and the great cost of fuel is responsible for the high rate of cost of pumping in Salt River Valley. In order to compare this with the cost where fuel is inexpensive, I give the following table of costs from pumping plants in California. The data were furnished by Thomas H. Means, of the Bureau of Soils, having been collected by his assistant, W. H. Knox. It appears from these data that water is pumped with crude oil and distillate as fuel, at a minimum cost of less than 1 cent per foot per acre-foot, as compared with a minimum of 8 cents in Salt River Valley, using distillate, and 5.4 cents, using electric power. It appears, also, that with fuel at the price paid in California, water is pumped cheaper than the estimated cost with electric power at $50 per horsepower per year, the minimum being 1.18 cents for electric power and 0.8 cent for crude oil. It should be stated, however, that allowance is made in the California rates for little besides fuel. It is thought that due allowance for interest, depreciation, etc., would bring the rate up to at least the estimated rate for electric power.

Cost of pumping in California.

[Data collected by W. H. Knox, of the Bureau of Soils of the Department of Agriculture.]

Owner.	Location.	Kind of pump used.	Source of supply.	Total lift.
				Feet.
M. T. Ireland	Fowler, Cal	Burton, 4-inch	Pond	15
J. Vincent	do	Krogh, 5-inch	Well	22
J. S. Brander	do	Krogh, 8-inch		20
John Hartly	Fresno, Cal	Richardson, 5-inch	Well	45
J. H. Marsh	Lone Star, Cal	Krogh, 6-inch	do	25
Aug. Ganfraw	Sanger, Cal	do	Slough	36
L. C. Jolley	Del Rey, Cal	Sampson, 6-inch	Pond	15

Cost of pumping in California—Continued.

Owner.	Capacity in acre-feet per hour.	Fuel used.	Cost of fuel per hour.	Cost per acre-foot per foot of lift.	Remarks.
			Cents.	*Cents.*	
M. T. Ireland	0.115	Distillate	6 to 7.5	4.3	
J. Vincent	.10	do	17	7.7	Plant not yet regulated for best results.
J. S. Brander	[a].75	Crude oil	12.5	.8	Has been operating two years.
John Hartly	.207	Distillate	10	1.1	Distillate costs 10 cents per gallon.
J. H. Marsh	.15	do	6 to 7.5	2	12-horsepower engine—cost of fuel thought to be underrated.
Aug. Ganfraw	.3	Crude oil	[a]10	.9	
L. C. Jolley	.4	Distillate	11	1.8	

[a] Estimated.

COST OF PUMPING IN EGYPT.

It may be of interest to know the cost of well-established pumping plants abroad. Thomas H. Means, of the Bureau of Soils, who is familiar with irrigation operations in Egypt, has kindly furnished the following information for this paper:

Cost of pumping drainage water at Mex., Egypt.

Season.	Acre-feet pumped.	Price of coal per ton.	Cost per acre-foot per foot of lift.
			Cents.
1895–96	141,750		2.42
1896–97	175,800		2.31
1897–98	187,900		2.36
1898–99	230,800	$6.19	1.87
1899–1900	164,430	8.39	2.87
1900–1901	255,960	8.73	2.79

Equipment consists of five Farcot direct-acting centrifugal pumps and two 48-inch centrifugals, with a total maximum capacity of 1,400 cubic feet per second, though the normal output is not intended to exceed 1,125 cubic feet per second; lift about 10 feet. This is one of the largest pumping plants in the world.

Estimated cost of pumping drainage water at Kassasin, Egypt.—Equipment consists of two 30-inch centrifugals and one 20-inch, run by direct-connected double-expansion engines. Total capacity given as 88 cubic feet per second; expenses of plant about $20,000 per year, making cost of lifting about 4.8 cents per acre-foot per foot of lift.

—Continued.

Cost per acre-foot per foot of lift.	Remarks.
Cents.	
4.3	
7.7	Plant not yet [illegible] lated for best [illegible] sults.
.8	Has been operating two years.
1.1	Distillate costs cents per gallon.
2	12-horsepower [illegible] gine—cost of [illegible] thought to be [illegible] derrated.
.9	
1.8	

EGYPT.

of well-established pumping [illegible] he Bureau of Soils, wh[illegible] pt, has kindly furnished the [illegible]

t Mex, Egypt.

Acre-feet pumped.	Price of coal per ton.	Cost per acre-foot per foot of lift
		Cents
141,750	.....	2 [illegible]
175,800	.....	2 [illegible]
187,900	.....	2 [illegible]
230,800	$6.19	1 [illegible]
164,430	8.39	2 [illegible]
255,960	8.73	2 [illegible]

entrifugal pumps and two 48-in[illegible] 400 cubic feet per second, th[illegible] 5 cubic feet per second; lift al[illegible] n the world.

sin, Egypt.—Equipment con[illegible] irect-connected double-expan[illegible] second; expenses of plant al[illegible] ents per acre-foot per foot of [illegible]

VALUE OF WATER.

Having ascertained the cost of procuring water by pumping, it is well to know what return can reasonably be expected from its use. Prof. Alfred J. McClatchie, of the Arizona Agricultural Experiment Station, has published a paper dealing with this problem.[a] The following table (Table VI of McClatchie's paper) gives the returns realized from the use of water:

Record of principal crops grown on the farm of the Arizona Experiment Station during 1901.

	Amount of water applied previous to planting.	Date of planting.	Date of first irrigation.	Date of last irrigation.	Number of irrigations.	Depth of water applied during growing of crop.	Total amount applied.
	Feet.					*Feet.*	*Feet.*
Wheat sown in moist soil	0.6	Nov. 26	Mar. 4	Apr. 6	3	1.6	2.2
Wheat sown in dry soil	.....	....do ...	Dec. 8	....do ...	4	2.5	2.5
Wheat sown in moist soil	.6	Dec. 5	Mar. 5	Apr. 11	3	1.5	2.1
Do	.6	Jan. 3	Mar. 7	Apr. 14	3	1.5	2.1
Potatoes	.7	Jan. 9	Mar. 17	May 10	4	1.7	2.4
Do	.7	Feb. 1	Mar. 27	....do ...	3	1.3	2.0
Do	.7	Feb. 22	....do ...	....do ...	3	1.3	2.0
Tomatoes	.6	Feb. 14	Feb. 26	Oct. 28	27	3.7	4.3
Strawberries	.7	Feb. 16	Feb. 16	Dec. 26	36	5.5	6.2
Melons	.7	Mar. 16	Mar. 26	July 8	12	2.6	3.3
Egyptian cotton	.7	Mar. 30	Apr. 11	Oct. 3	13	4.3	5.0
Corn	.6	Aug. 3	Aug. 9	Oct. 7	5	1.5	2.1

[a] McClatchie, Alfred J., Irrigation at the station farm, 1898-1901: Ariz. Agric. Exp. Sta. Bull. No. 41, 1902.

Record of principal crops grown on the farm of the Arizona Experiment Station during 1901—Continued.

	Date of harvesting.	Yield per acre.	Gross value per acre.	Cost of producing and marketing crop per acre.	Net value per acre.	Net return per foot of water applied.
		Pounds.				
Wheat sown in moist soil	May 22	2,150	$22.55	$10.25	$12.30	$5.60
Wheat sown in dry soil	do	1,850	19.40	9.65	9.15	3.65
Wheat sown in moist soil	May 24	2,120	22.25	10.20	12.05	5.74
Do	May 30	1,920	20.15	9.95	10.20	4.85
Potatoes	do	3,200	80.00	35.00	45.00	18.75
Do	May 25	3,600	85.00	34.50	50.50	25.25
Do	May 30	3,000	70.00	34.50	35.50	17.75
Tomatoes	July 1–Dec. 9	12,300	225.00	75.00	150.00	34.90
Strawberries	Apr. 15–July 15	5,000	500.00	150.00	350.00	56.45
Melons	June 15–July 15	27,000	140.00	26.00	114.00	34.55
Egyptian cotton	Dec. 14	400	68.00	48.00	20.00	4.00
Corn	Dec. 10	1,735	18.00	9.50	8.50	4.05

LOCATION OF PUMPING PLANTS.

From the information previously given it appears that the best places for pumping plants are in the region south of Tempe where water is but a few feet beneath the surface and on the lowlands along the river in the Phoenix region. Unfortunately the lands upon which pumped water would be most useful do not lie at a lower elevation than the areas where that water is most easily obtained. The elevation of the land to be irrigated therefore enters as an important factor. In order to flow water over a certain tract of land it frequently happens that pumps must be placed on comparatively high land back from the river. The farther a well is from the axis of the gravel beds—not necessarily coincident with the present river's course—the more likely it is to encounter unfavorable conditions.

The irregular distribution of materials in the valley fill gives rise to many annoying surprises in constructing wells. Certain wells have entirely failed where every known condition promised success. On the other hand, wells have been successful in localities which gave little promise. It is obviously impossible to foresee in more than a general way what conditions are to be met with in sinking wells. The figures which follow are diagrammatic illustrations explaining condi-

the Arizona Experiment Station
ued.

Gross value per acre.	Cost of producing and marketing crop per acre.	Net value per acre.	
$22.55	$10.25	$12.30	
19.40	9.65	9.15	
22.25	10.20	12.05	
20.15	9.95	10.20	
80.00	35.00	45.00	
85.00	34.50	50.50	
70.00	34.50	35.50	
225.00	75.00	150.00	
500.00	150.00	350.00	
140.00	26.00	114.00	
68.00	48.00	20.00	
18.00	9.50	8.50	

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tions known to exist in Salt River Valley. In fig. 25 let A and B represent two wells with the water standing 20 feet below the surface in each well. Assume (1) that the material in which they are put down is all water-bearing gravel with one-third of the space occupied by water; it is plain then that a lowering of 30 feet, for example, will yield water represented by one-third of the space *a b h f*—the space in heavy lining. (2) Assume that *a g c* is impervious clay and *a c f* is water bearing; then a lowering of 30 feet in either well would yield water represented by one-third of the space *a i h f*—the shaded portion of No. 2. (3) Assume that *a g c* is gravel and the rest clay; then a lowering of 30 feet in well A will yield water represented by one-

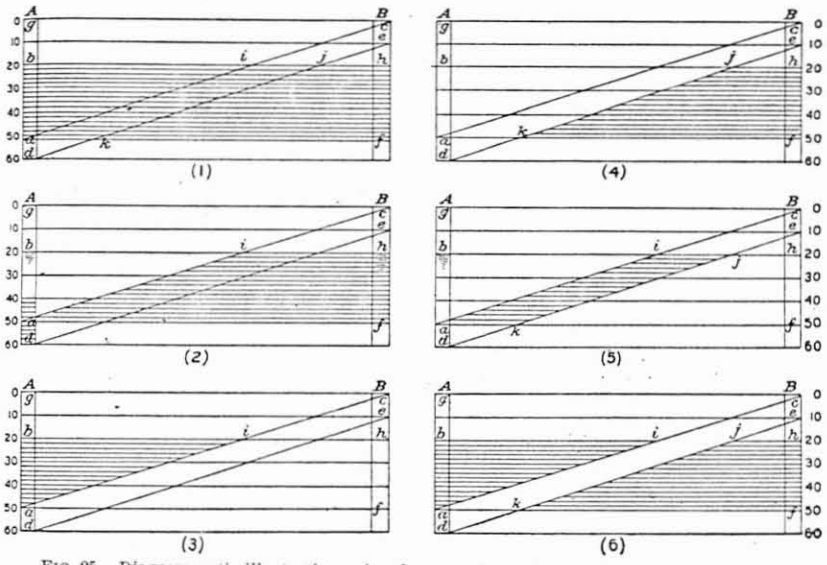

FIG. 25.—Diagrammatic illustrations of underground conditions affecting yield of wells.

third of the space *a b i*, and well B will yield nothing (No. 3). (4) Assume that *d e f* is gravel and the remainder clay; then well A will have no water and well B, in lowering 30 feet, will yield water represented by one-third of the space *k j h f*. (5) Assume that *a c e d* is gravel and the remainder clay; then well B will yield no water and well A only so much as is represented by one-third of the space *a i j k*. (6) Assume that *a c e d* is clay and the remainder gravel; then well A, in lowering 30 feet, will yield water represented by one-third of space *a b i*, while well B will yield water represented by one-third of the space *k j h f;* and the waters may differ in quality as well as quantity.

As a matter of application from the foregoing illustrations it may be stated: (1) That a given set of conditions in one locality will not necessarily be repeated in another, although the two localities are close together; (2) that favorable conditions in one place are not to be interpreted too freely, and, vice versa, that unfavorable conditions in one place are not to be considered entirely discouraging.

RÉSUMÉ.

Some of the more important facts and deductions presented in this paper may be stated as follows:

1. The geological formations which are of most importance in and near Salt River Valley fall naturally in three groups:

(*A*) Pre-Cambrian rocks, consisting of Archean granites and pre-Cambrian quartzites and argillites, in which Salt River Valley was originally formed.

(*B*) Extensive bodies of eruptive rock associated with a limited amount of massive breccia, apparently of Tertiary age.

(*C*) Quaternary and recent formations, consisting of waterworn bowlders, gravel, sand, clay, etc., which partly fill the ancient valley, and are known as the valley fill.

2. The valley fill, at least to a depth of several hundred feet, is regarded as upland or fluviatile accumulation and consists of—

(*A*) River débris, composed principally of waterworn bowlders and gravel of quartzite, quartz, chert, granite, etc.

(*B*) Wash or angular material derived from near-by hillsides.

(*C*) Chemical precipitates, of which caliche is the most important from a geological standpoint. The caliche occurs in more or less impervious layers throughout the valley fill, and serves in many cases to confine the underground water under more or less pressure.

3. The valley fill is not the result of a single period of aggradation. Its accumulation is due to at least two periods of aggradation, perhaps more, separated by a period of degradation.

4. The alternating periods of aggradation and degradation in Salt River Valley correspond with similar periods in other parts of Arizona. Definite correlation of the similar, but widely separated, deposits is impossible at the present time, but uniformity in character and succession over wide areas suggests uniformity of cause.

5. The cause of the accumulation of upland deposits and of the changes from degradational to aggradational condition of streams and vice versa is regarded as due (1) to changes in elevation of the land, and (2) to climatic changes.

6. Salt River Valley is a part of the wide aggraded plain lying southwest of the great continental plateau. Between the plateau and the plain is a mountainous area in which faulting and local crustal movements are numerous. Some of these movements have probably affected Salt River Valley.

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7. The isolated peaks and mountain groups in and near Salt River Valley may be due in part to upthrust of crust blocks, but are regarded mainly as remnants of erosion.

8. The plain of which Salt River Valley is a part is due principally to upland accumulations. In the process of accumulation the lowest outlying hills were buried and the higher ones, being only partly buried, are now found rising abruptly from the level plain.

9. The valley fill is saturated with water, and the various beds of gravel are so intimately connected that the water rises to a definite level forming a well-defined water table.

10. During the early part of the accumulation of the valley fill Salt River joined Gila River east of Salt River Mountains, forming in that region the bowlder beds through which the main course of the underflow now finds its way, but at a later stage of the accumulation the river changed to its present course north of Salt River Mountains, forming the uncemented bowlder beds of recent origin, in which the underflow occurs in the Phoenix region.

11. The underground waters are derived mainly from Salt River and to a less extent from the occasional floods entering the valley from the surrounding hills.

12. The valley fill of the Mesa region, to a depth of over 200 feet, consists mainly of river gravels with a subordinate amount of finer material. In the Phoenix region the valley fill consists mainly of fine material with a subordinate amount of river gravels. The river gravels of the Phoenix region occur parallel to the river, and were deposited in a secondary valley, cut in the finer materials of the first period of accumulation.

13. The valley fill is more or less impregnated with various salts derived from the waters of Salt River in former ages and deposited with the detritus.

14. The distribution of the gravel beds and the depth to the water table are such that pumping for irrigation can probably be carried on with profit over an area of 525 square miles.

15. Although some of the underground waters of the valley contain salts in quantities which may be harmful to land under certain conditions, it is probable that with proper manipulation all of the waters can be safely used.

16. The underflow returns in part to the surface in certain places in the valley, making a surface flow estimated as something over 100,000 acre-feet per year.

17. The principal water-bearing horizon is about 15 miles wide in the Mesa region, and extends to a depth of over 200 feet.

18. The quantitative estimate of the underflow, based on experiments, indicates a volume of flow of 148,196 to 287,760 acre-feet per year. At this rate something less than 96 pumping plants of the

average capacity (200 inches) could be operated continuously and retain the water level within pumping distance of the surface.

19. The reserve, or the quantity of water contained in the valley fill at any one time within pumping distance is very much greater than the volume of flow. Conservative estimates place the volume of the reserve of Salt River Valley at from 2,500,000 to 4,000,000 acre-feet.

20. The cost of pumping water in Salt River Valley varies from 5.4 to 13.8 cents per acre-foot per foot of lift, or a cost per acre-foot of pumped water of from $2.50 to something like $5.

21. Since fuel is the great item of cost, the cost could be greatly reduced by the use of electrical power, which might be furnished for about $50 per horsepower per year. At this rate the best pumping plants of Salt River Valley can raise water at a cost of 1.2 cents per acre-foot per foot of lift, or at an average cost per acre-foot of pumped water of something like 75 cents for the present lift.

22. The value of an acre-foot of water applied to irrigation in Salt River Valley varies from $3.65 to $56.45.

23. The volume of underflow is large, but not inexhaustible by the operation of pumps. It is capable of extended development, but there is danger that a greater draft will be made upon it than is consistent with the maintenance of the water level within practicable pumping distance.

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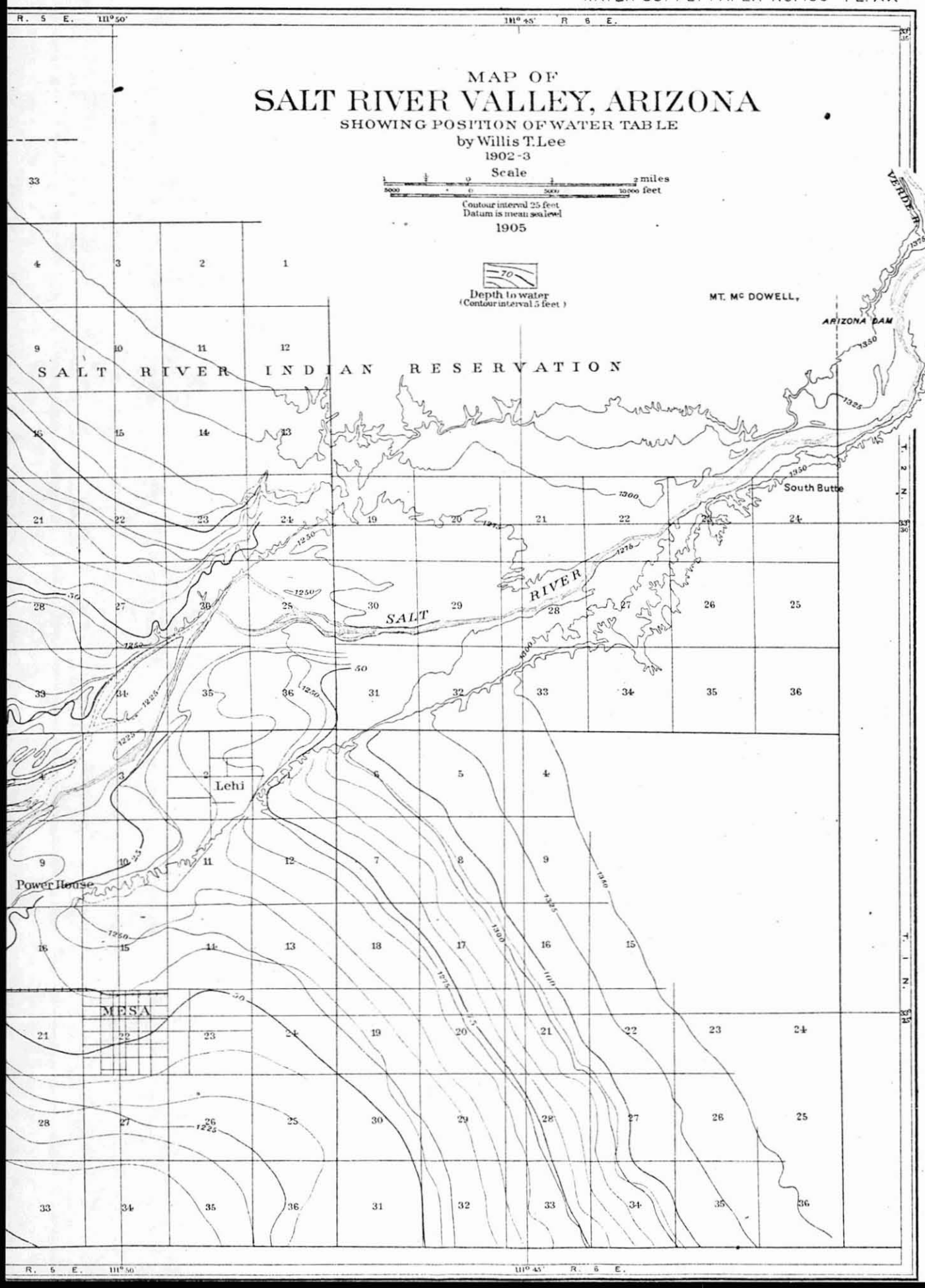
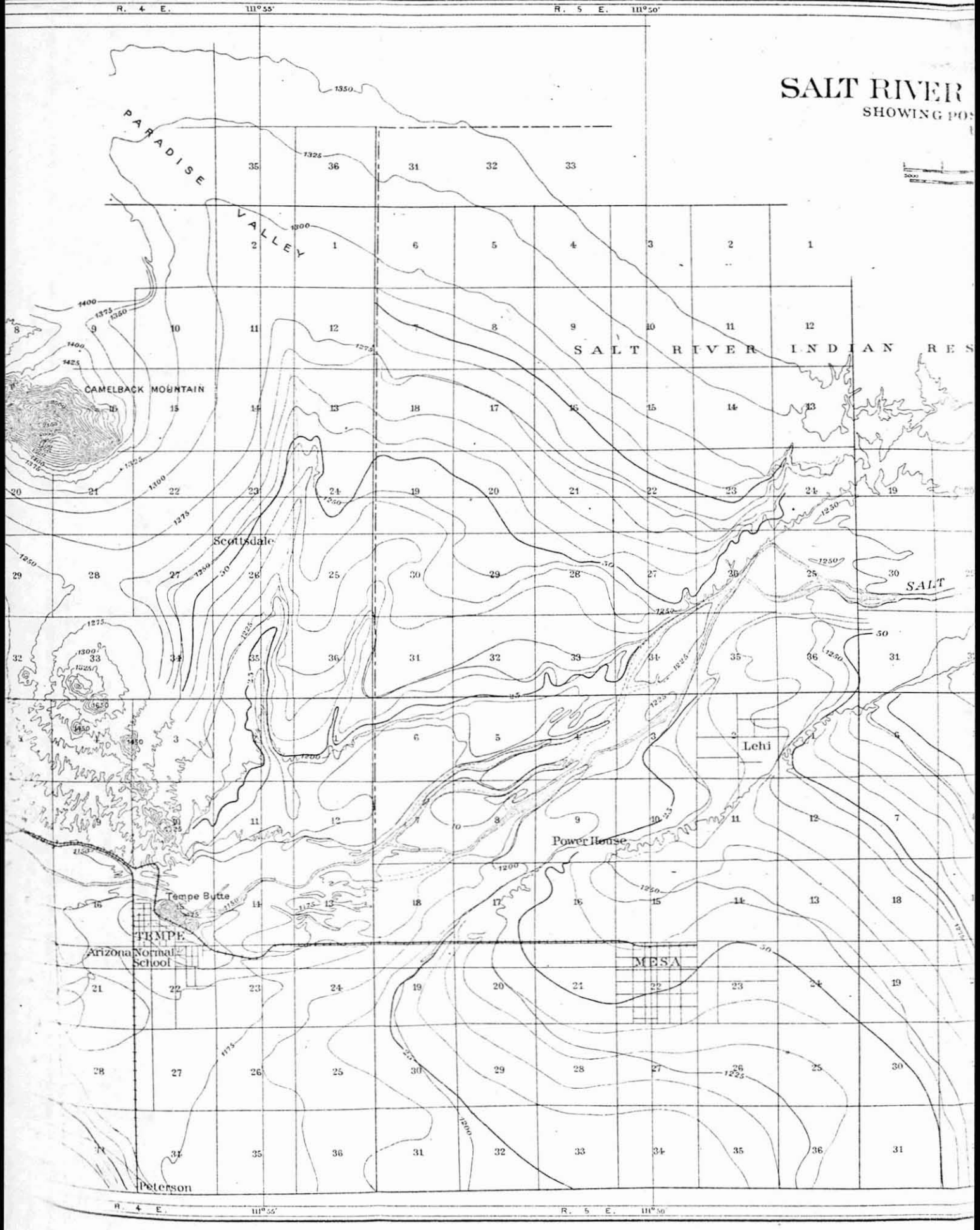
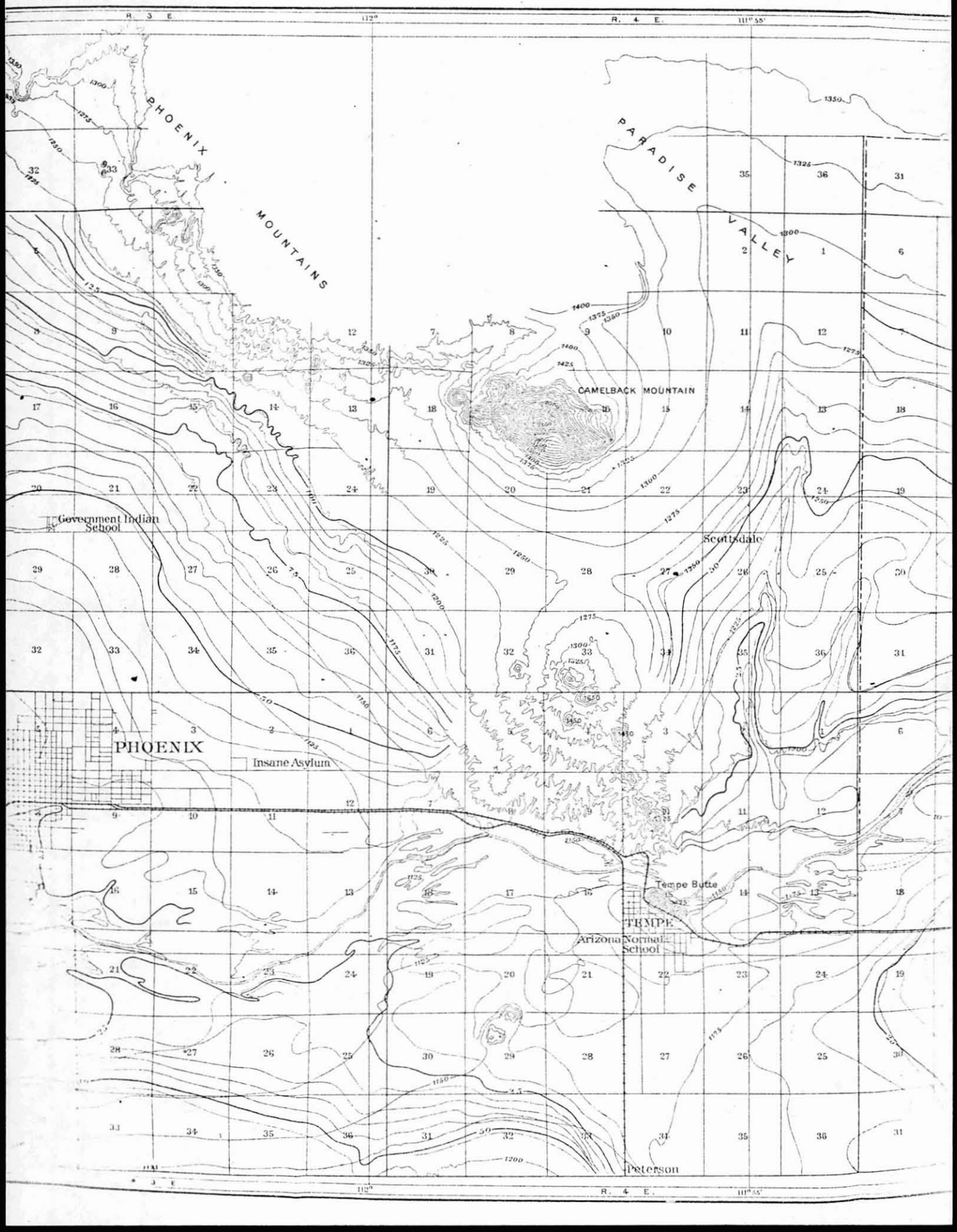
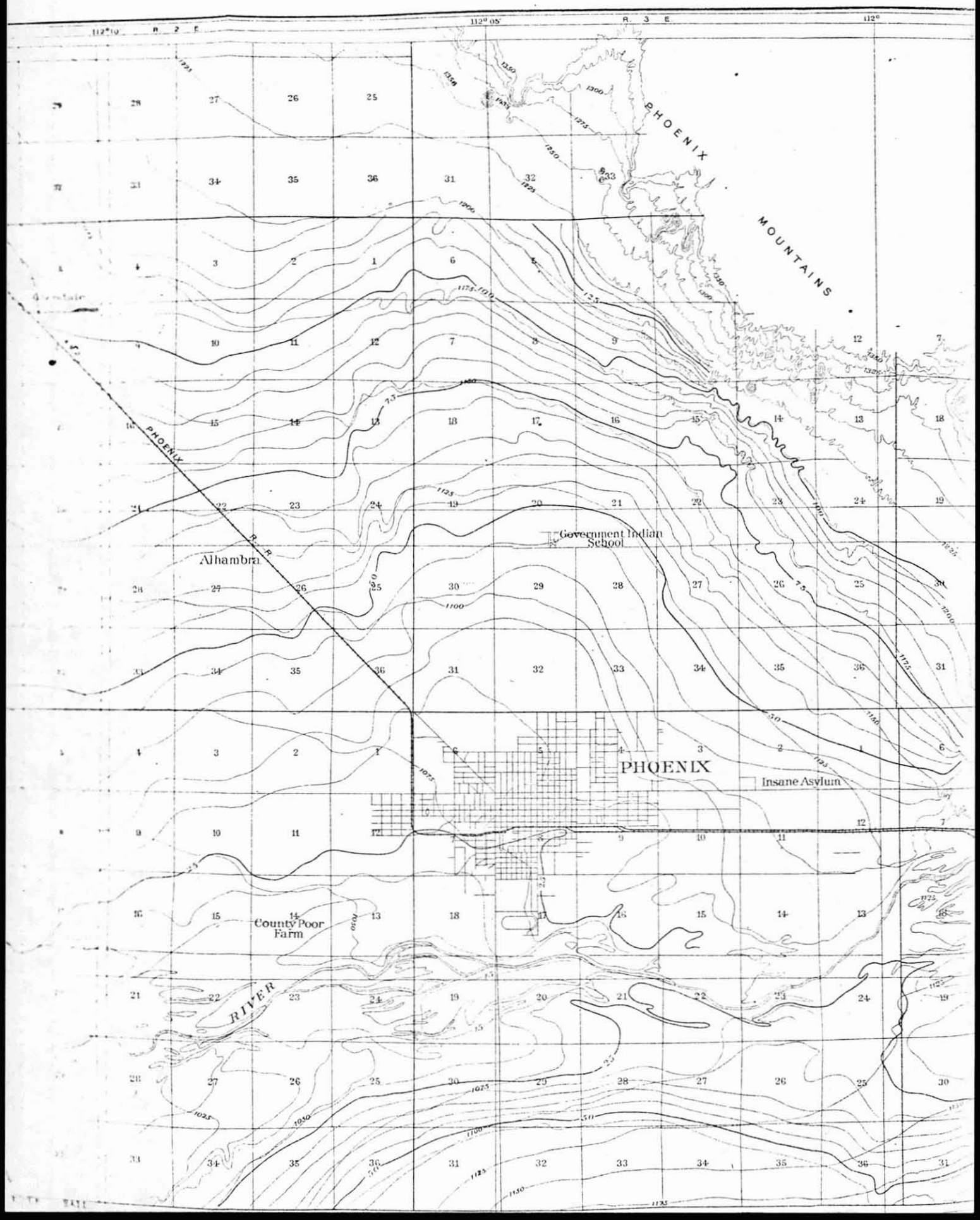
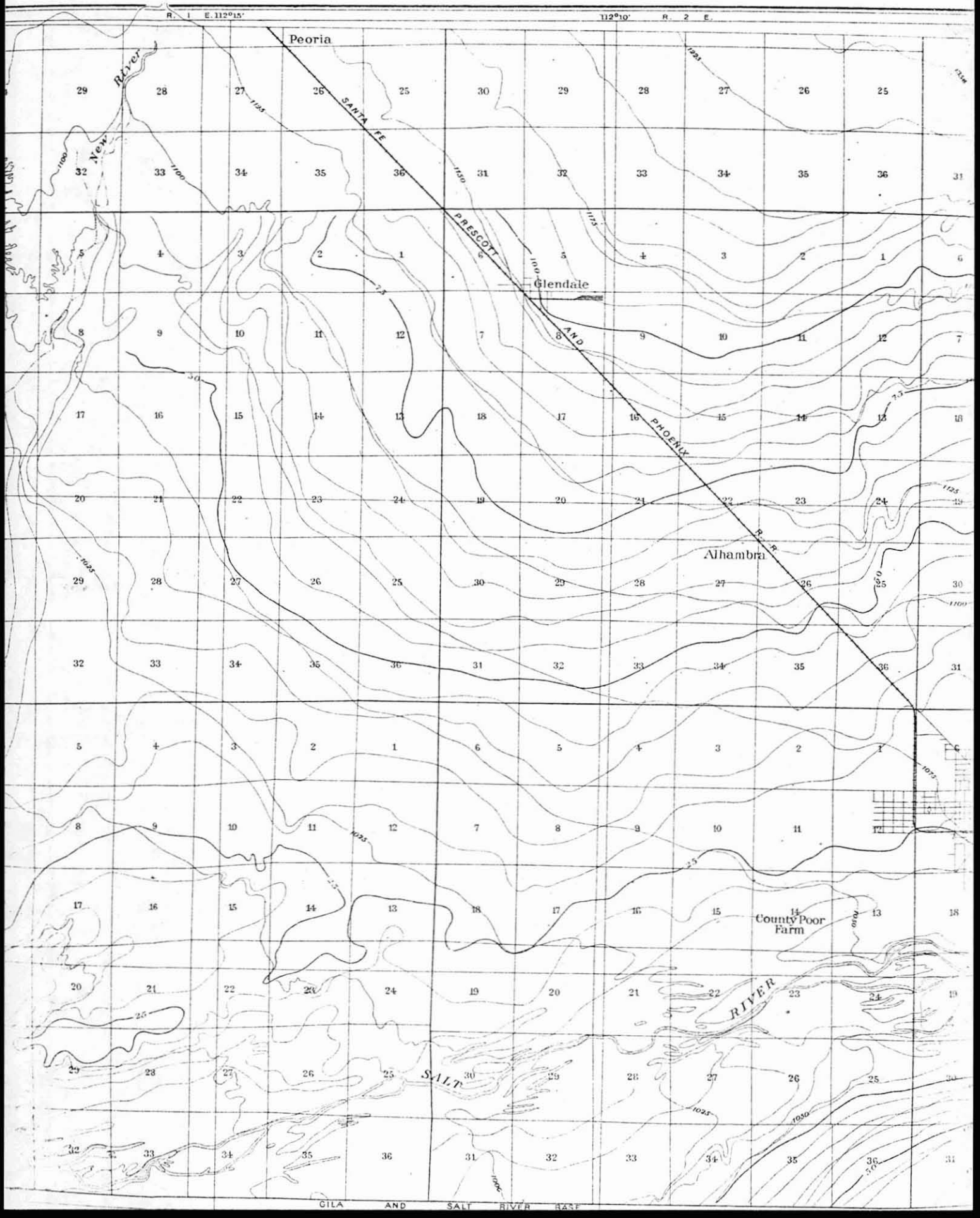
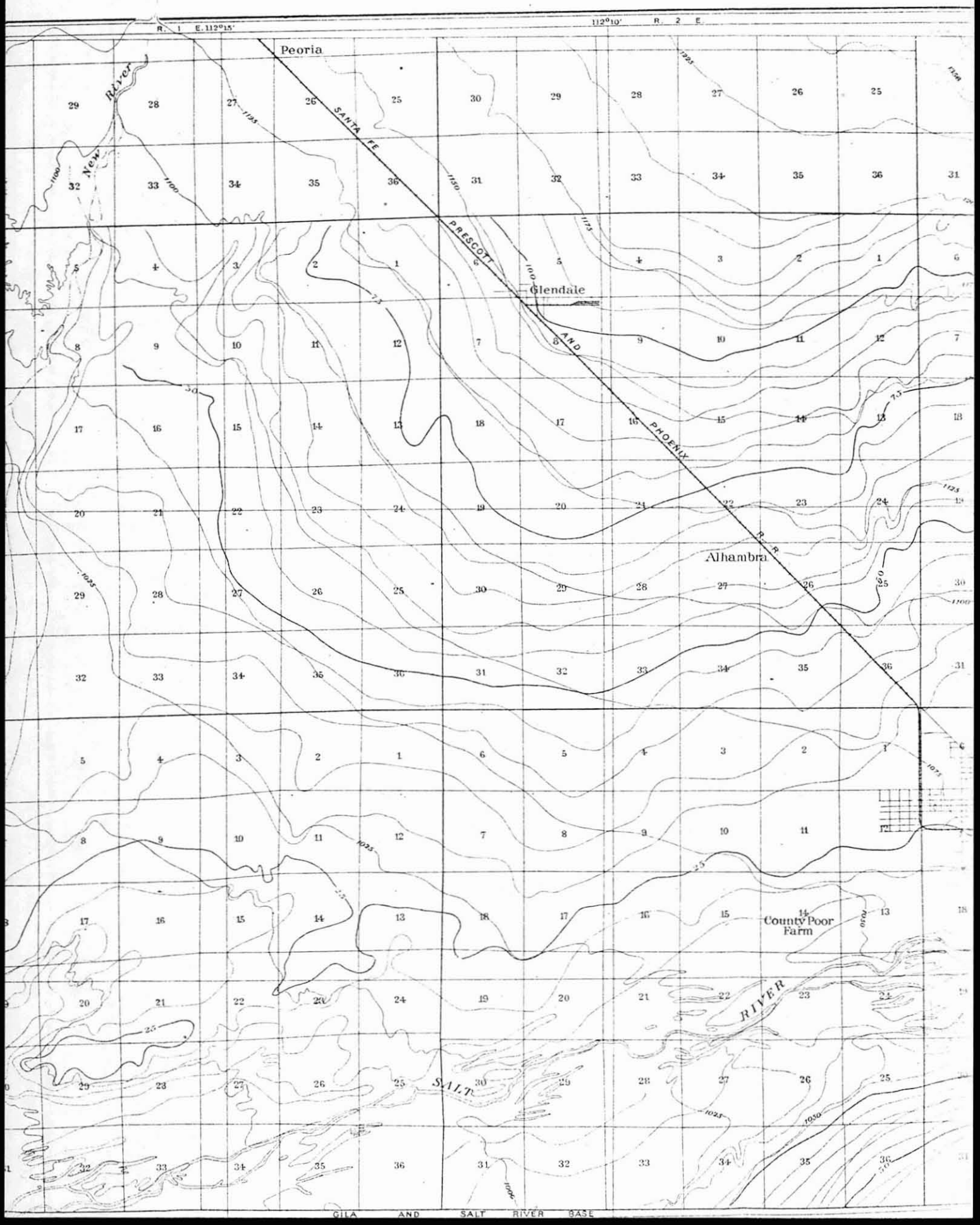

MAP OF
SALT RIVER VALLEY, ARIZONA
SHOWING POSITION OF WATER TABLE
by Willis T. Lee
1902-3
Scale
miles
feet
Contour interval 25 feet
Datum is mean sea level
1905
Depth to water
(Contour interval 5 feet)
MT. Mc DOWELL
ARIZONA DAM
VERDE R.
SALT RIVER INDIAN RESERVATION
South Butte
SALT RIVER
Lehi
Power House
MESA
R. 5 E. 111° 50'
111° 45' R. 6 E.
T. 2 N.
T. 1 N.


SALT RIVER
SHOWING POS
R. 4 E.
111°55'
R. 5 E.
111°50'
PARADISE VALLEY
SALT RIVER INDIAN RES
CAMELBACK MOUNTAIN
Scottsdale
SALT
Lehi
Power House
Tempe Butte
TEMPE
Arizona Normal School
MESA
Peterson

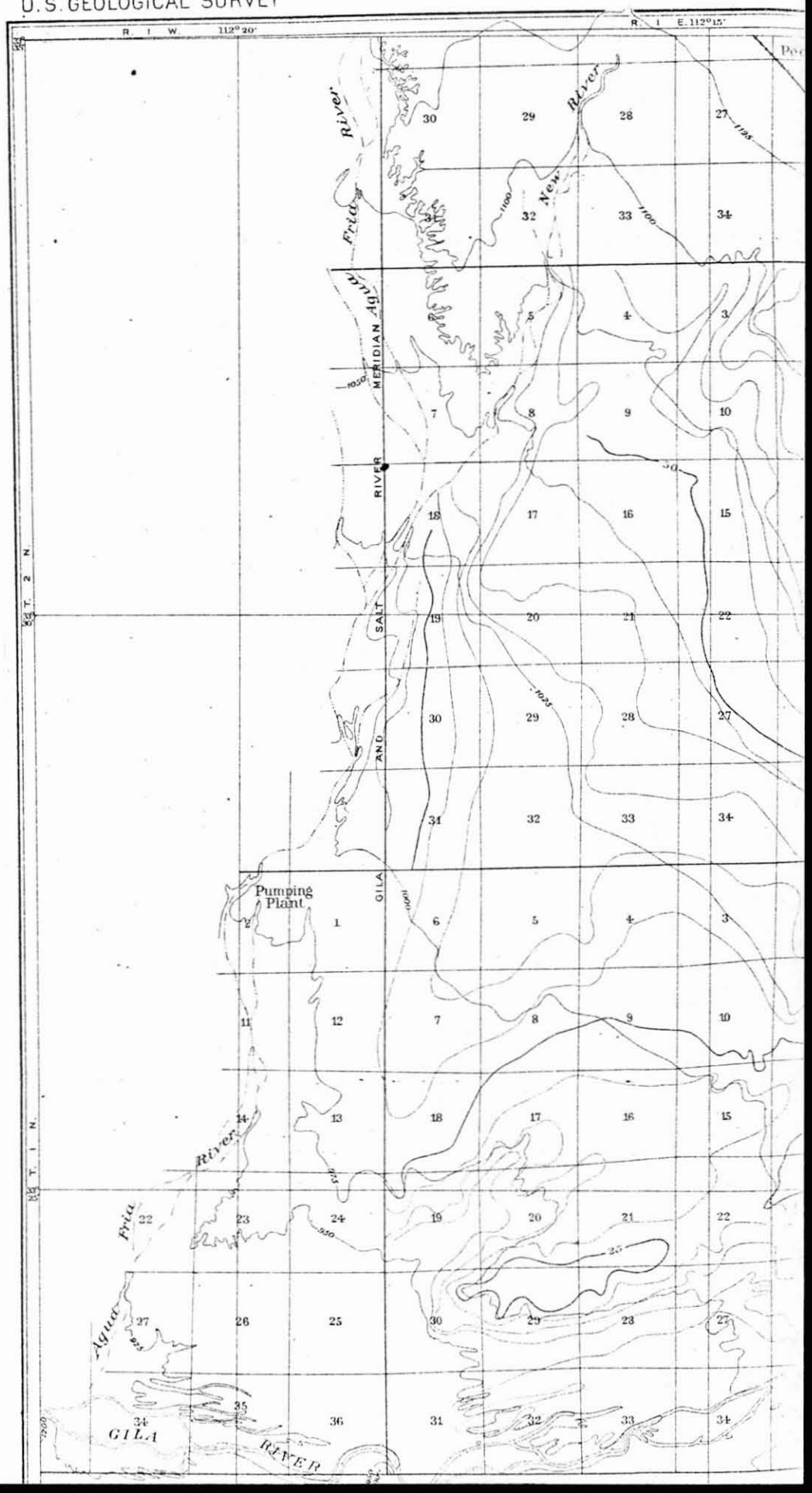

R. 3 E.
112°
R. 4 E.
111° 55'
PHOENIX MOUNTAINS
PARADISE VALLEY
CAMELBACK MOUNTAIN
Government Indian School
Scottsdale
PHOENIX
Insane Asylum
Tempe Butte
TEMPE
Arizona Normal School
Peterson

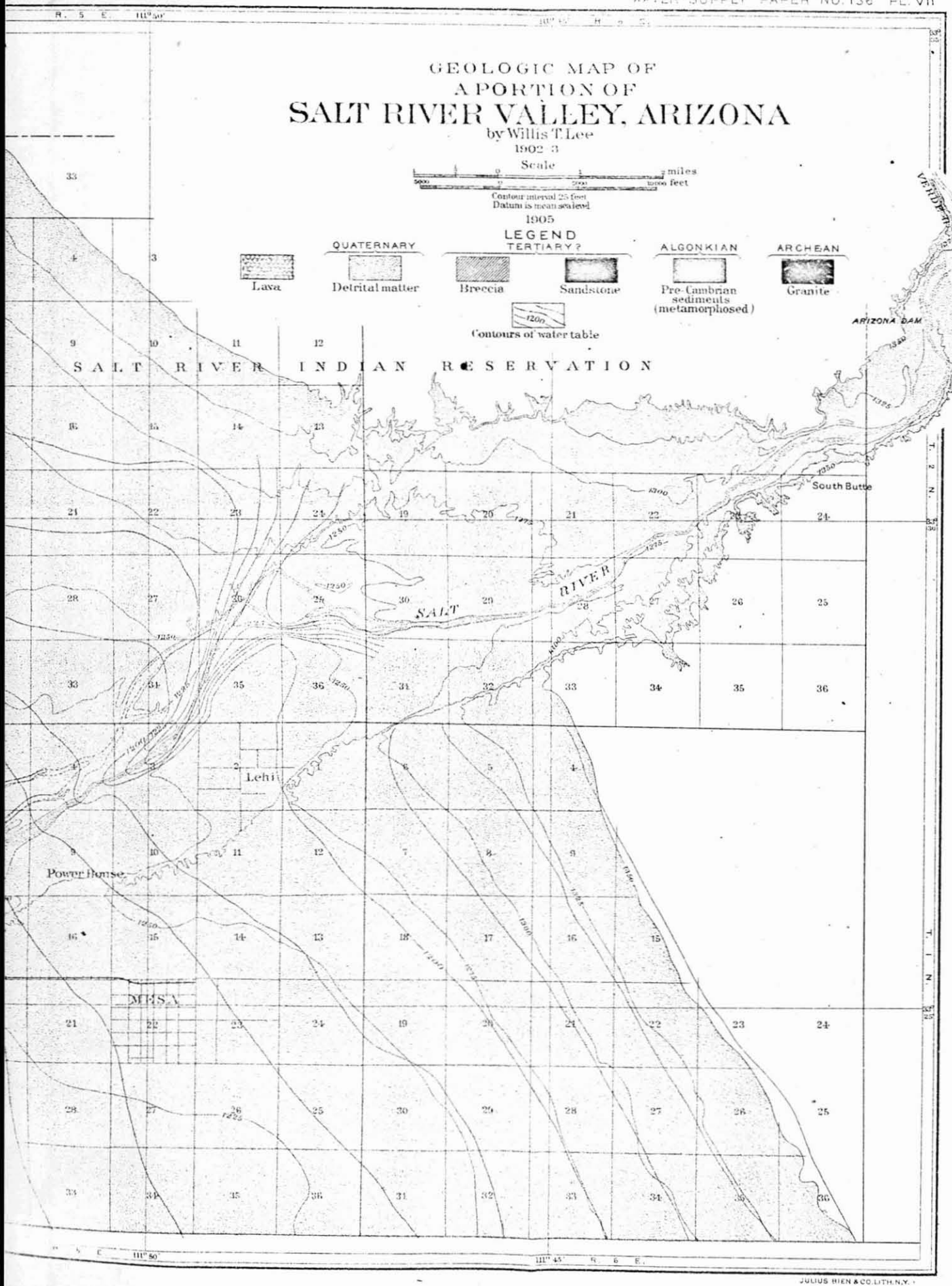

112°19'
R. 2 E.
112° 05'
R. 3 E.
112°
PHOENIX
MOUNTAINS
PHOENIX
R. R.
Alhambra
Government Indian School
PHOENIX
Insane Asylum
County Poor Farm
RIVER


R. 1 E. 112°15'
112°10' R. 2 E.
Peoria
New River
SANTA FE
PRESCOTT
AND
PHOENIX
R. R.
Glendale
Alhambra
County Poor Farm
SALT
RIVER
GILA AND SALT RIVER BASE

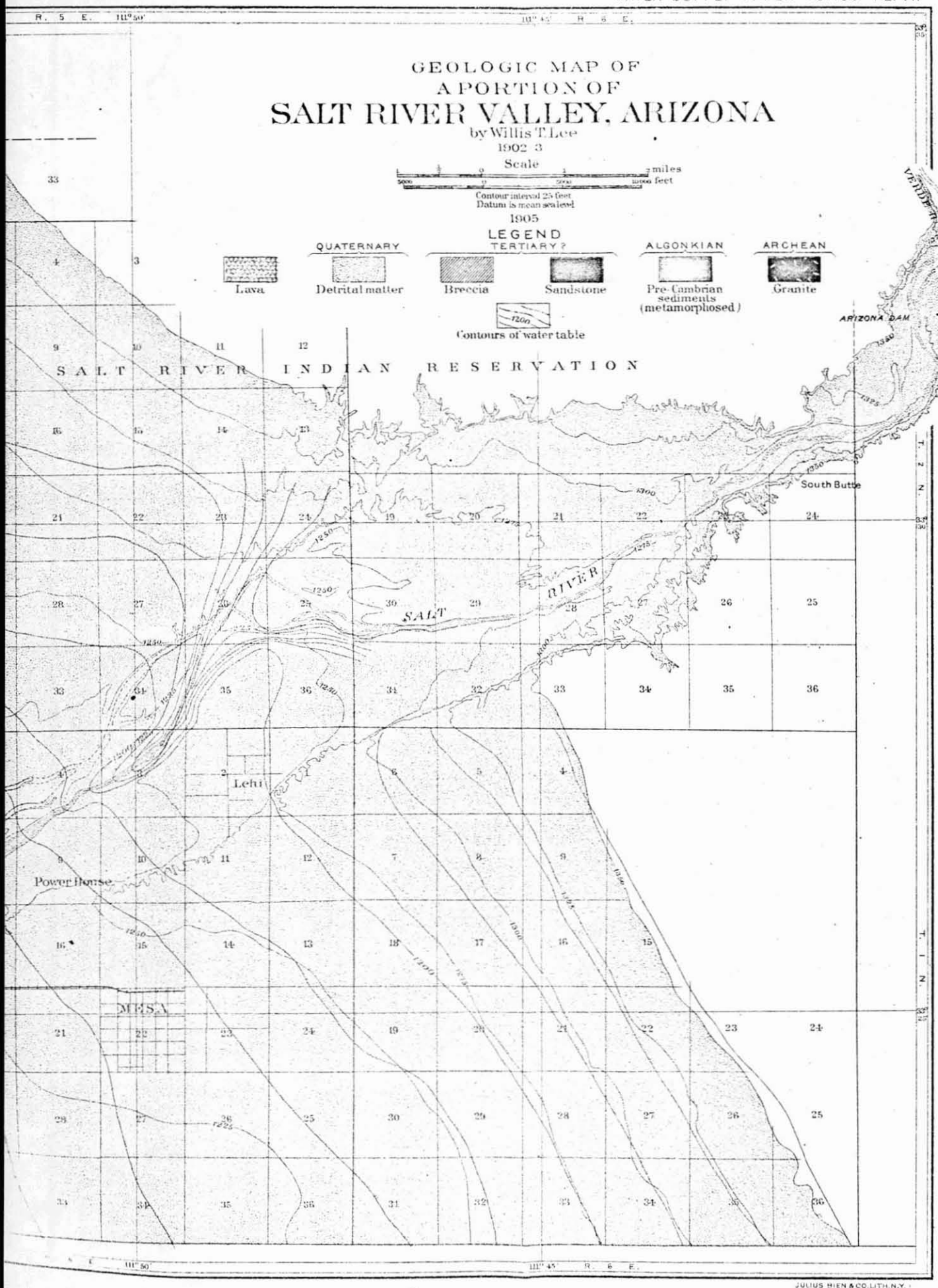

R. 1 E. 112°15'
112°10' R. 2 E.
Peoria
SANTA FE
PRESCOTT
AND
PHOENIX
R. R.
Glendale
Alhambra
County Poor Farm
New River
SALT RIVER
GILA AND SALT RIVER BASE

U.S. GEOLOGICAL SURVEY

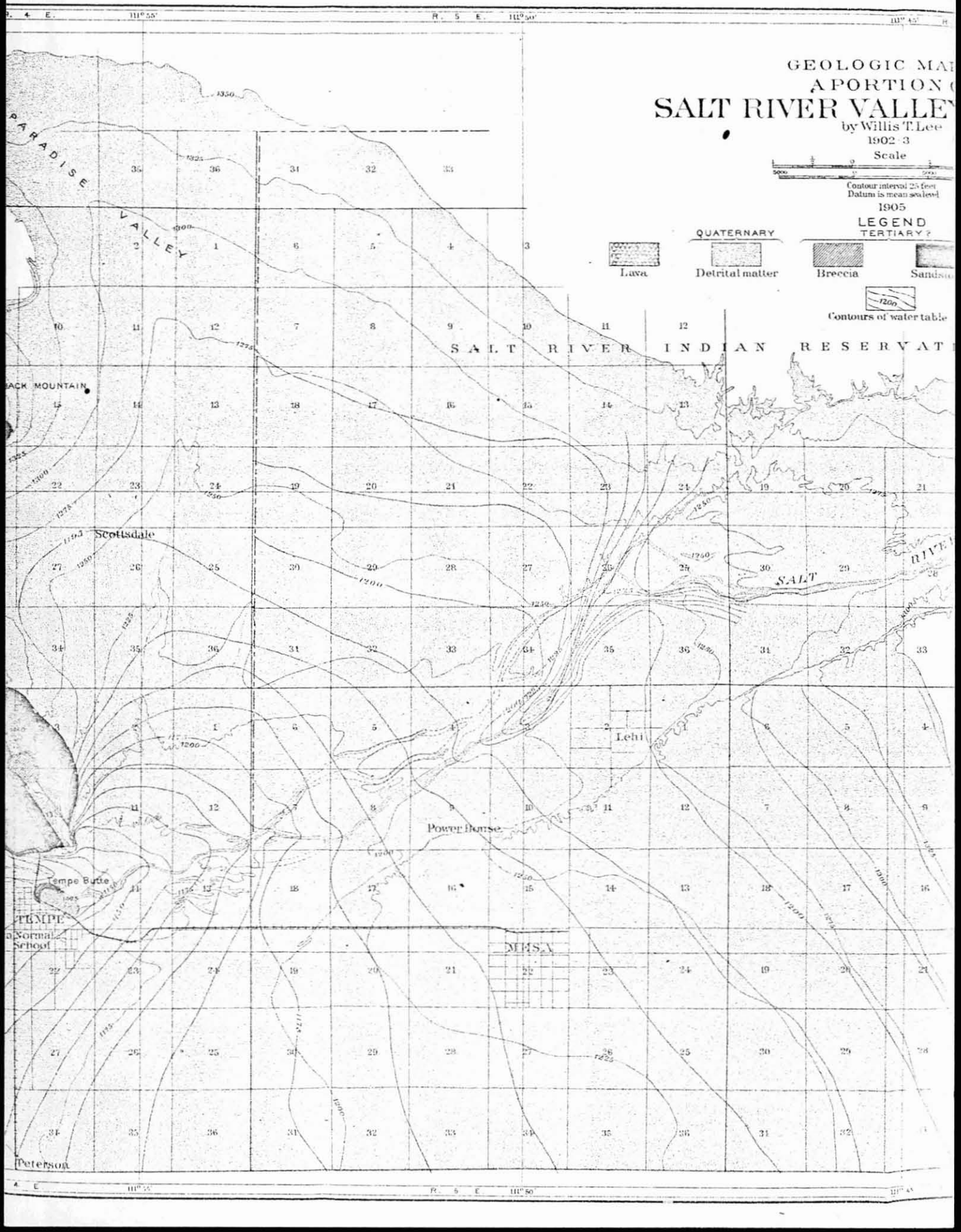


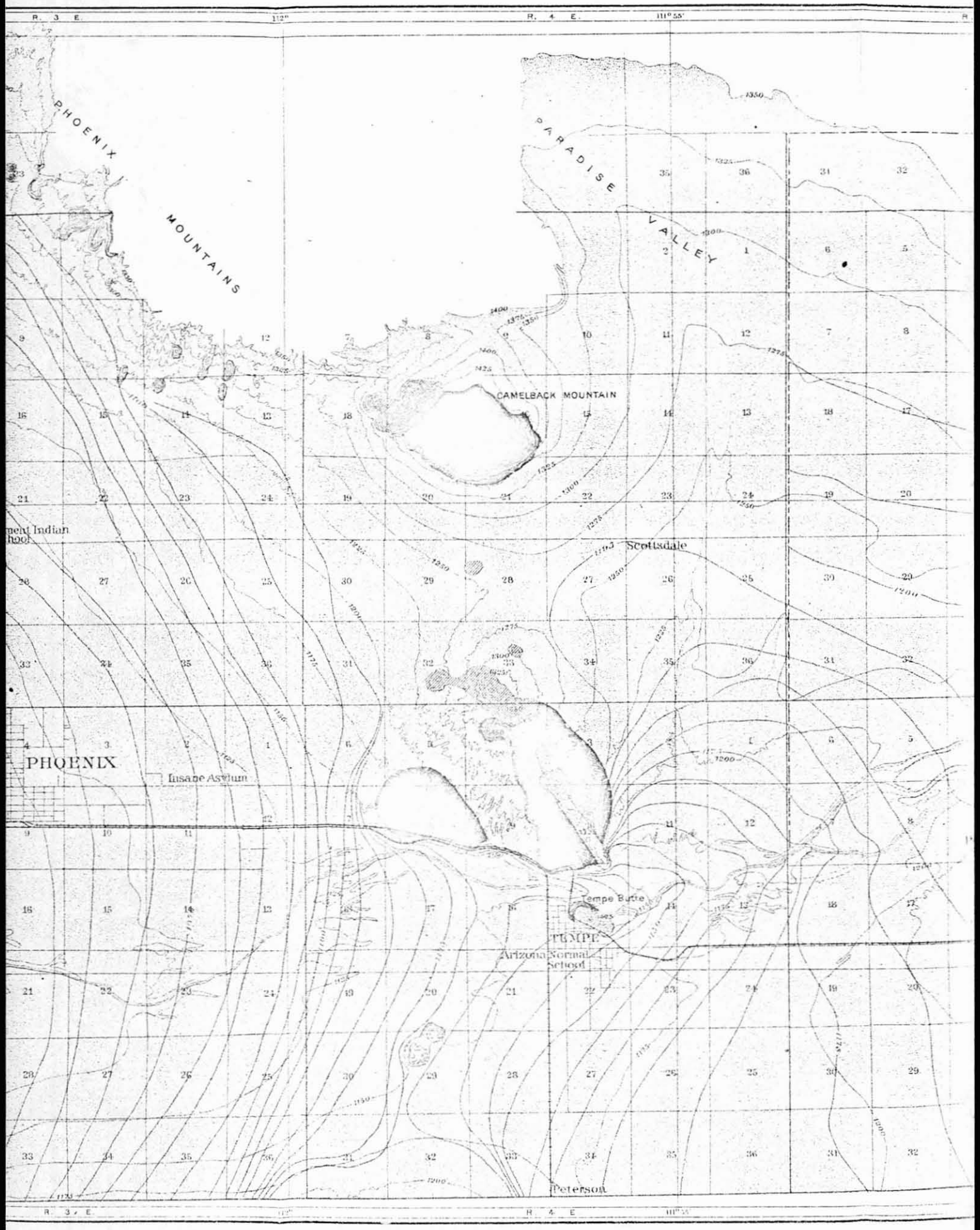
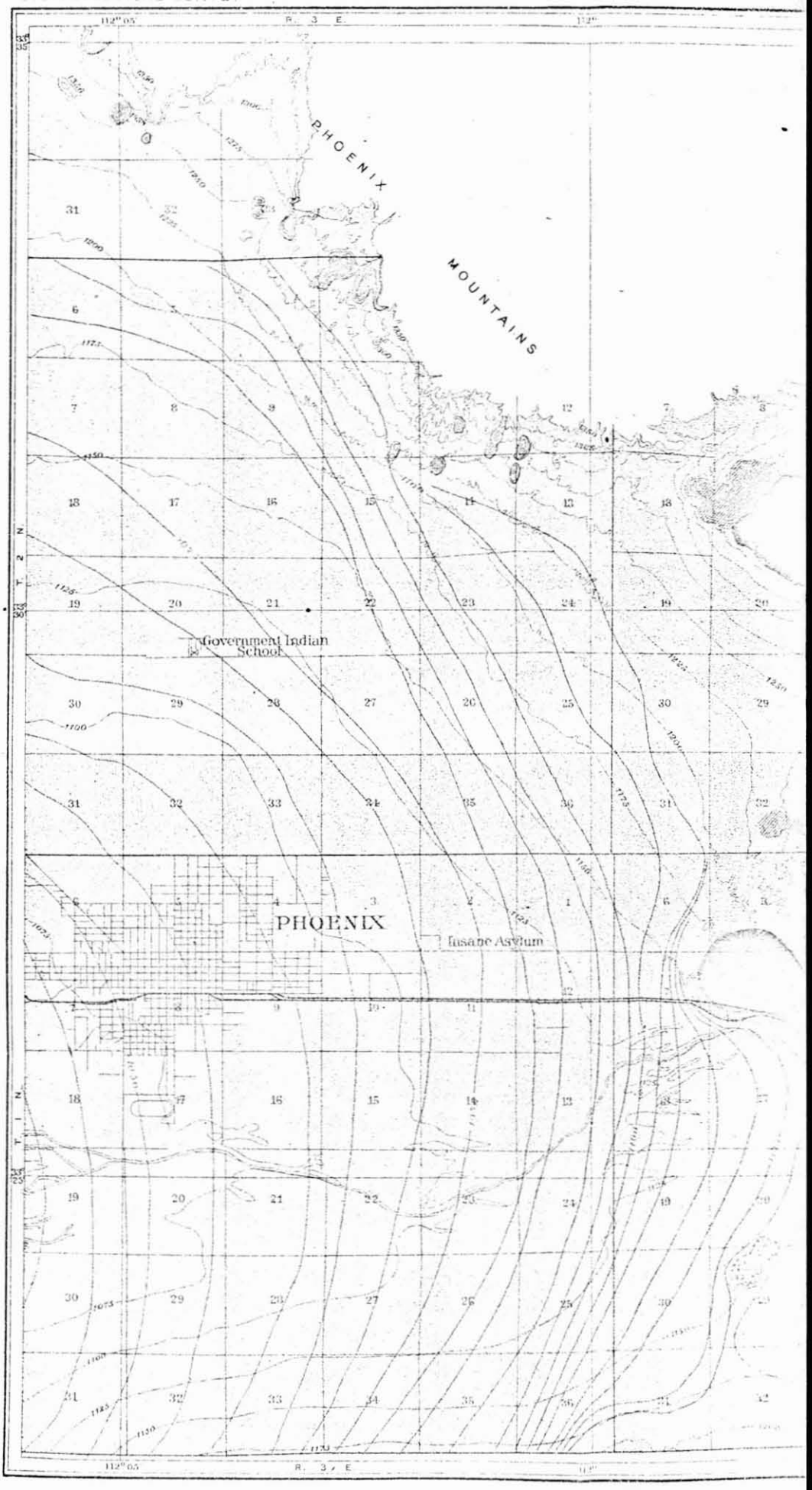


JULIUS BIEN & CO. LITH. N.Y.



JULIUS BIEN & CO. LITH. N.Y.


GEOLOGIC MA
A PORTION
SALT RIVER VALLE
by Willis T. Lee
1902-3
Scale
Contour interval 25 feet
Datum is mean sea level
1905
LEGEND
QUATERNARY
TERTIARY?
Lava
Detrital matter
Breccia
Contours of water table
PARADISE VALLEY
SALT RIVER INDIAN RESERVAT
Scottsdale
SALT
Lehi
Power House
Tempe Butte
TEMPE
Normal School
MESA
Peterson
111° 55'
R. 5 E.
111° 50'


R. 3 E.
112°
R. 4 E.
111°55'
PHOENIX MOUNTAINS
PARADISE VALLEY
CAMELBACK MOUNTAIN
Scottsdale
PHOENIX
Insane Asylum
Tempe Butte
TEMPE
Arizona Normal School
Peterson
R. 3 E.
R. 4 E.

U.S. GEOLOGICAL SURVEY