ILLUSTRATIONS

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GEOLOGY AND GROUND-WATER RESOURCES OF THE VALLEY OF GILA RIVER AND SAN SIMON CREEK, GRAHAM COUNTY, ARIZONA

By MAXWELL M. KNECHTEL

ABSTRACT

The valley formed by the Gila River and San Simon Creek, in Graham County, Ariz., is an intermontane trough 10 to 20 miles wide that extends from the San Carlos Indian Reservation many miles southeastward. It is bordered on the southwest by the Chiricahua, Dos Cabezas, Pinaleño, Santa Teresa, Turnbull, and Mescal Mountains and on the northeast by the Peloncillo and Gila Mountains. The Gila River, a perennial stream, enters the trough northeast of Solomonsville through a gorge in the Peloncillo Mountains and flows northwestward to Coolidge Dam, where it turns southwest and leaves the relatively broad valley through a gorge in the Mescal Mountains. San Simon Creek, an intermittent stream, rises at the head of the trough and flows northwestward to join the Gila near Solomonsville.

Along the Gila River is an alluvial lowland plain, 1 to 3 miles wide, which is underlain, to an average depth of about 100 feet, by Quaternary silt, sand, and gravel deposited by the river. This plain, large portions of which are irrigated by water from the river, includes most of the crop-producing land of Graham County. Similar low plains lie along several of the larger tributary arroyos. Higher land borders the alluvial plains and grades gently upward on each side of the valley to the base of the steep mountain slopes. This higher land is terraced, and two principal terrace levels have been recognized. The terraces, the smooth upper surfaces of which are of the pediment type, are capped by naturally cemented gravel, which in most places is not more than 10 feet thick. The gravel on the terraces is believed to have been deposited in Pleistocene time, earlier than the materials in the low-lying alluvial plains, and it rests on still older (upper Pliocene) deposits, which are mostly lacustrine but partly fluviatile in origin and which represent the Gila conglomerate. The Gila deposits, which carry fossil mammals, amphibians, fresh-water mollusks, silicified wood, and diatoms, consist chiefly of clay in the central part of the valley and of sand and gravel along the valley margins. They crop out prominently on the steeply sloping escarpments of the terraces and along most of the watercourses but are hidden elsewhere under the alluvial deposits and terrace gravel. Beds of water-bearing sand and gravel occur in all the deposits, but the principal ground-water supply for the valley is obtained from wells in the Pliocene lacustrine strata and the Quaternary alluvium.

In the Quaternary alluvium underlying the lowland plains beds of water-bearing sand and gravel are numerous but irregular. Any one bed pinches out laterally in all directions and generally underlies only a small area. Consequently, the vertical spacing and the number of water-bearing layers encountered in sinking wells differ from place to place. The water in these layers is under little or no artesian pressure.

The Pleistocene (?) terrace gravel yields little water, and most of this water issues as springs on the escarpments of the terraces at the contact between the permeable gravel and the underlying dense lacustrine clay.

The upper Pliocene (Gila) deposits yield water to wells from beds of permeable sand and gravel, which in general lie nearly horizontal between thick layers of relatively impervious silt and clay. The water-bearing beds are commonly most numerous and thickest toward the sides of the valley, and many of them pinch out toward the center of the valley. A typical section across the valley shows the Gila beds to be chiefly impervious lacustrine clay beneath the central part and coarse fluviatile conglomerate at the valley margins, with nearly horizontal thin tongues or sheets of water-bearing sand and gravel extending out here and there from the belts of conglomerate into the lacustrine deposits. The water in the upper Pliocene beds is believed to be derived from the rain water that falls on the marginal belts, where it sinks into the permeable conglomerate and finds its way thence into the beds of sand and gravel in the lacustrine deposits. The water table in the permeable conglomerate of the intake area stands much higher than the ground surface of the central part of the valley, and the pressure of the water in the marginal belts is transmitted horizontally underground through the permeable layers of the lacustrine deposits. The artesian pressure thus produced is strong almost everywhere, and in wells at several favorably situated localities the pressure is great enough to force the water to the surface. A few small areas of cultivated land along tributaries of the Gila River are irrigated by water from artesian wells, and this water is also supplied extensively to cattle.

The temperature of the water issuing from flowing wells varies considerably, and as a rule the deeper the well the higher the temperature of the water it yields. A study of the relation of depth to temperature in 78 flowing artesian wells in the valley of the Gila River and San Simon Creek indicates an average rise in water temperature of 1° F. for each 57 feet of depth. This normal gradient probably accounts for the high temperature of the water of the Indian Hot Springs, near Eden, the indication being that they probably derive their water through a fault or fissure from a source at a depth of about 2,500 feet below the surface.

Successful drilling of artesian wells in the past and the generally favorable geologic conditions in the lacustrine deposits warrant the belief that water under artesian pressure is present in nearly all parts of the valley that are underlain by these beds, at depths within easy reach of drilling equipment.

Samples of water collected for analysis from 49 scattered localities in the valley proved to be mainly of the sodium chloride, sodium carbonate, and sodium sulphate types. Most of them showed a rather high mineral content, but the greater number proved sufficiently soft to be satisfactory for most industrial uses. About a third of the waters analyzed are regarded as chemically unsuited for use in irrigation, and many contain large amounts of sodium salts, which would be likely to cause foaming if used in boilers. A large proportion showed concentrations of fluoride sufficiently high to account for the dental defect known as mottled enamel, which afflicts many inhabitants of the region.

Rather extensive gullying of the lands in the valley, having developed since the advent of white settlers early in the eighties, is a local manifestation of the present widespread "epicycle of erosion" in the arid Southwest, a phenomenon that is currently viewed with apprehension by agronomists. It has been suggested by some geologists that the accelerated erosion might have been initiated by a recent climatic change or by a differential elevation of the land surface brought about by warping of the earth's crust. Most investigators, however, believe that it is due to causes related primarily to stock-raising.

INTRODUCTION

SCOPE OF REPORT

This paper contains the results of the writer's investigation, during 4 months in the winter of 1933–34, of the geology and ground-water resources of that part of the valley of the Gila River and San Simon Creek that lies in Graham County, Ariz. It includes descriptions of wells and springs and information on the stratigraphy, physiography, and hydrology of the valley. The work was supported by funds allotted to the Geological Survey by the Public Works Administration and was done under the supervision of G. A. Waring and the general direction of O. E. Meinzer, geologist in charge of the division of ground water of the Geological Survey.

ACKNOWLEDGMENTS

Generous assistance was rendered by the inhabitants of the region, who supplied much of the information presented. Messrs. C. A. Firth, of Safford, water commissioner for Graham County, and P. C. Merrill, also of Safford, secretary of the Graham County Chamber of Commerce, were especially helpful. The writer is indebted to O. E. Meinzer, G. A. Waring, N. H. Darton, P. B. King, M. G. Wilmarth, and W. W. Rubey for criticism of the manuscript, and to other members of the Geological Survey for helpful suggestions.

LOCATION AND GEOGRAPHY

Graham County, which contains about 2,963,000 acres[1] in the southeastern part of Arizona, is crossed by the thirty-third parallel of latitude and the one hundred and tenth meridian and lies in the Mexican Highland section of the Basin and Range province. (See fig. 29.) Safford, the county seat, on the line of the Southern Pacific Railroad known as the Arizona Eastern Railroad and U. S. Highway 70, is about 185 miles east of Phoenix, Ariz., and about 245 miles west of El Paso, Tex.

The valley of San Simon Creek and the Gila River above the San Carlos Indian Reservation forms a structural trough 10 to 20 miles wide. In Graham County the trough is bordered on the northeast by the Gila and Peloncillo Mountains and is separated from the Sulphur Spring and Aravaipa Valleys to the southwest by the Turnbull, Santa Teresa, and Graham (Pinaleño) Mountains. (See pl. 45.) San Simon Creek, an intermittent stream, flows northwestward down the axis of the valley in Cochise and Graham Counties, crossing the southern boundary of Graham County at about 3,650 feet above sea level, and discharges into the Gila River at an altitude of about 2,950 feet near Solomonsville. Its gradient averages nearly 20 feet to the mile.

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[1] Arizona Year Book, 1930–31, p. 203.

The Gila River, known as the "Upper Gila" above the San Carlos Reservoir, is a perennial stream that heads far to the east in New Mexico, enters the Gila-San Simon trough at about 3,075 feet above sea level a few miles northeast of Sanchez, and meanders down the valley northwestward 65 miles to the San Carlos Reservoir, at the

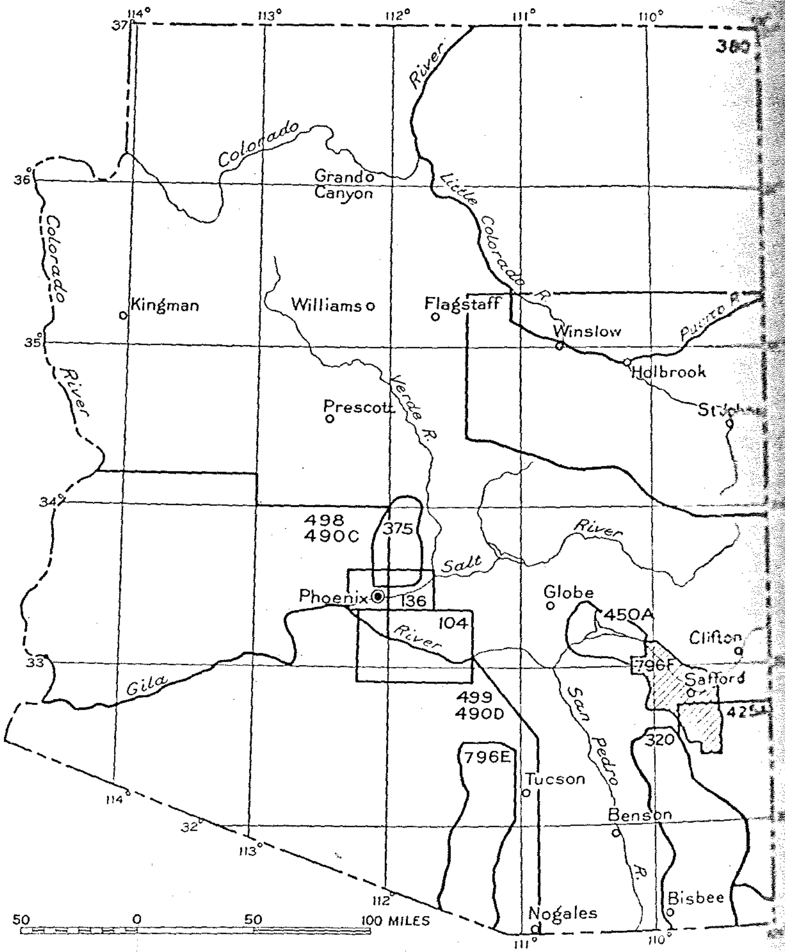
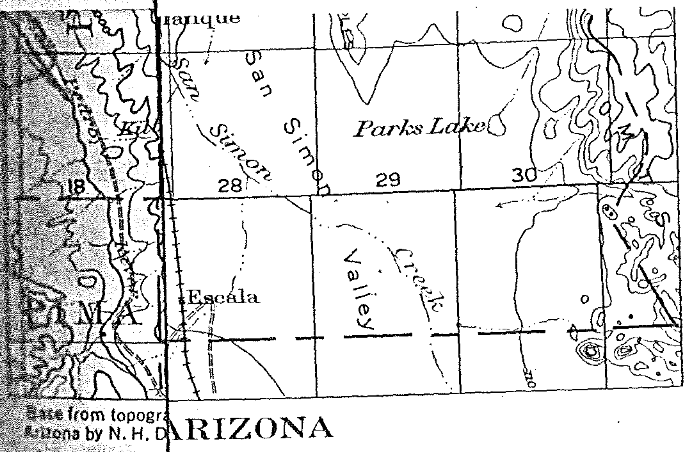


FIGURE 29.—Index map of Arizona showing areas considered in this report and other water-supply papers of the Geological Survey. Shaded area is described in this paper. The Holbrook region, indicated in outline, is described in a water-supply paper in preparation. Other areas are described in water-supply papers indicated by numbers.

west boundary of Graham County, where the altitude is about 2,400 feet. The average gradient of the river in the valley is about 10 feet to the mile.

Numerous intermittent tributaries heading in or near the bordering mountain ranges enter San Simon Creek and the Gila River from both sides of the valley.



Base from topogra
Arizona by N. H. D

Base from topographic map of Arizona by N. H. Darton, 1933.

TOPOGRAPHIC MAP OF GRAHAM COUNTY AND VICINITY. ARIZONA

Scale $\frac{1}{500,000}$

10 0 10 20 Miles

Contour interval 100 meters (328 feet)

Datum is mean sea level

MAPS AND SURVEYS

The part of the valley of the Gila River and San Simon Creek here described, except for a narrow strip along the base of the Graham Mountains,[2] has not been topographically mapped in detail, and at the time of writing good base maps are available for only a small part of the area covered by this report. The most detailed maps are those covering the irrigated lands along the Gila River and its tributaries, on a scale of 1,000 feet to the inch.[3] Good maps also cover five townships (Tps. 7 and 8 S., R. 28 E.; Tps. 10 and 11 S., R. 26 E.; and T. 6 S., R. 24 E.) that have been surveyed by the General Land Office in recent years; but the plats prepared by that office for the remainder of the area were issued prior to 1910 and do not show many details. Iron pins, which can usually be found with ease, have been used to mark the land corners in the five townships covered by the more recent surveys, but many of the stones used as markers in the earlier surveys have disappeared. A map including the area studied, published by the United States Forest Service on a scale of 4 miles to the inch, is little more than a compilation of the Land Office plats.[4] The base for the map presented as plate 46 of this paper, showing the geology, wells, and springs of part of the area studied, was prepared from the available maps.

A summary of the geology of the area discussed in the present report is given in an earlier paper by the writer,[5] and Schwennesen [6] has reported on the ground water in adjacent areas to the southeast and northwest in the San Simon and Gila Valleys, respectively.

ROUTES OF TRAVEL

The Bowie-Globe branch of the Southern Pacific Railroad, known locally as the Arizona Eastern Railroad, crosses Graham County and passes through Solomonsville, Safford, Thatcher, Pima, Fort Thomas, and Geronimo. In addition to these principal stations several sidings are provided for handling freight. A busy coast to coast highway, known between Lordsburg, N. Mex., and Globe, Ariz., as U. S. Highway 70, enters the valley from the east near San Jose and follows the railroad from Solomonsville to the Coolidge Reservoir, where it leaves Graham County. State Highway 81, which is graveled, leads from Safford southward through Cactus Flat and Artesia and joins

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[2] Map of the Crook National Forest (Mount Graham division), Ariz. (scale 1 inch to the mile, contour interval 100 feet), U. S. Dept. Agr., Forest Service, 1932.

[3] Gila River determination, Graham County, Ariz.; map (in 9 parts) of surveys showing irrigated lands under ditches taking water from Gila River or tributaries, district no. 3, Phoenix, Ariz., State Water Commissioner, 1920.

[4] Map of the Crook National Forest, Ariz., U. S. Dept. Agr., Forest Service, 1934.

[5] Knechtel, M. M., Geologic relations of the Gila conglomerate in southeastern Arizona: Am. Jour. Sci., 5th ser., vol. 31, pp. 80–92, February 1936.

[6] Schwennesen, A. T., Ground water in San Simon Valley, Ariz. and N. Mex.: Geol. Survey Water-Supply Paper 425, pp. 1–35, 1917: Geology and water resources of the Gila and San Carlos Valleys in the San Carlos Indian Reservation, Ariz.: Geol. Survey Water-Supply Paper 450, pp. 1–27, 1919.

an El Paso-Tucson highway near Bowie, Ariz. A road branching from State Highway 81 south of Artesia leads to Fort Grant, at the head of Sulphur Spring Valley. A better road to Fort Grant leaves U. S. Highway 70 about 7 miles northwest of Pima. State Highway 81, a graveled road, leads northward to Clifton from a point on U. S. Highway 70 about 6 miles east of San Jose. The settlements in the valley are connected with these main highways and with each other by numerous roads and trails.

TOWNS AND SETTLEMENTS

The incorporated towns of Graham County are Safford, Thatcher, and Pima, all of which are on the railroad and on U. S. Highway 70.

Safford, the chief commercial center, was founded in 1873 and incorporated in 1901. In 1930 its population was nearly 3,000. The principal industries of Safford are flour milling, cotton ginning, and the retail distribution of goods to residents of the valley. In recent years the automobile tourist traffic on U. S. Highway 70 has also been a notable source of income. Thatcher, 3 miles west of Safford, had in 1930 a population of nearly 1,300. It is a shopping center for the surrounding farming community and is the seat of the Gila Junior College. Pima, 8 miles west of Safford, which had a population of about 1,000 in 1930, is a minor mercantile center. Solomonsville, formerly the county seat, is the largest of the unincorporated communities. Its population in 1930 was about 1,300. It is on the railroad and on U. S. Highway 70, near the mouth of San Simon Creek, about 5 miles east of Safford. Next in size is Fort Thomas, about 21 miles northwest of Safford, on the railroad and on U. S. Highway 70, with a population of nearly 500 in 1930. Several smaller communities—Aravaipa, Ashurst, Bonita, Bylas, Central, Eden, Fort Grant, Geronimo, Glenbar, Klondyke, and Sunset—are provided with post offices. Escala, Tanque, Haeckel, and Solomon are railroad sidings. Bryce has only a few houses and a public school.

POPULATION

According to the United States census of 1930, Graham County had a population of 10,373, of whom 1,981 were Mexicans and 724 were Indians. Of the total number, 4,276 were classed as rural farm population.

CLIMATE

The climate of the valley of the Gila River and San Simon Creek is mild and dry, as shown by the following table, which is compiled from records of the United States Weather Bureau:

Climatic records in valley of Gila River and San Simon Creek

Station	County	Altitude	Temperature		Precipitation	
			Length of record	Mean annual	Length of record	Mean annual
		Feet	*Years*	° *F.*	*Years*	*Inches*
Bowie	Cochise	3, 756	55	63. 4	56	14. 29
Thatcher	Graham	2, 800	41	62. 6	32	9. 01
San Carlos Reservoir	Gila	2, 532	41	64. 3	41	12. 74

The higher portions of the Graham Mountains are usually covered with snow for several months during the winter, but snow seldom falls on the valley lands. Occasionally violent hailstorms damage crops.

NATIVE VEGETATION

Large areas of brush land in the portion of the valley occupied by San Simon Creek and on the upland terraces of the Gila River Valley support relatively abundant growths of creosote bush and mesquite and more scattered cholla, prickly pear, ocotillo, burro weed, snakeweed, yucca, sotol, and flowering annuals. Grama grass and curly mesquite grow well on the higher lands near the mountains, but much of the central part of the valley along San Simon Creek, which, according to early settlers, formerly contained excellent pasture of sacaton grass, is now reported to be incapable of supporting more than a few head of cattle to the square mile, and during excessively dry seasons many cattle must be removed to distant grazing lands. Native vegetation in the higher parts of the cultivated lowland along the Gila River consists mainly of mesquite, squawbush, saltbush, burroweed, and cactus. Scattered cottonwoods and thickets of tamarisk, willow, and arrowweed grow on the river flood plain, where numerous moist depressions support salt grass and tules.

The slopes of the Graham, Santa Teresa, and Turnbull Mountains are covered at high altitudes by pine forests and at lower levels by scattered juniper, oak, and walnut. The Gila and Peloncillo Mountains, northeast of the valley, are less heavily timbered. A sawmill at Pima, which had been idle for several years prior to 1934, obtained its supply of timber from the Graham Mountains.

AGRICULTURE

The irrigated lowland that lies along the Gila River is the principal agricultural area of Graham County, although numerous small cultivated tracts, aggregating about 1,000 acres, are scattered along the Gila and San Simon Valleys within the county. The largest of these are the Artesia, Cactus Flat, and Ash Creek areas. About 1,500 acres of land is cultivated in the Bonita district, south of Fort Grant, in the Sulphur Spring Valley.

The Federal census for 1890 ranked the chief crops of Graham County in order of importance as hay, corn, barley, and wheat. By 1900 wheat held first place, followed by alfalfa, barley, and corn. In 1910 alfalfa was leading and was followed by barley, wheat, and corn. In 1920 the order was alfalfa, wheat, barley, corn, and grain sorghums; cotton had been introduced. In 1930 cotton outranked all other crops, with an acreage nearly twice that of alfalfa.

Almost all agricultural products, other than alfalfa and cotton, are consumed locally. Practically all the cotton produced in recent years has been ginned at Safford and the lint exported to Japan through California ports. Yields of 2 bales to the acre are not uncommon on many of the farms. A large part of the alfalfa crop is sold outside the county.

The soil of the agricultural belt along the Gila River is generally described as "sandy loam" and "silt loam"[7] and is highly fertile.

GEOMORPHOLOGY

In early Quaternary or late Pliocene time a lake that had occupied the valley of the Gila River and San Simon Creek during late Tertiary time found an outlet, probably at the site of the Coolidge Dam, and as the water drained away it exposed to erosion a great mass of sediments that had accumulated in the basin, mainly unconsolidated clay, silt, sand, and gravel. The erosion of these sediments has produced a variety of land forms.

SAN SIMON VALLEY

The upper part of the valley, in Cochise County, is described by Schwennesen[8] as follows:

> The valley has the form of a broad, shallow trough, the sides of which are formed by the alluvial slopes that extend down from the bordering mountains. Where the valley is narrow the bases of the alluvial slopes almost meet at the axis, but where the valley is wide it has the appearance of a nearly level plain with upward-curving edges.

This description is applicable to the wide San Simon Valley at the southern boundary of Graham County. To the north lowering of the Gila River twice during Pleistocene time initiated cycles of erosion, the effects of which have progressed up the San Simon Valley for many miles, altering the form of the valley floor. The old surface of this part of the San Simon Valley, which no doubt resembled that of the upper part of the present valley, as described by Schwennesen, is now preserved in part as gravel-capped terrace remnants that slope gently downward toward the center of the valley from both sides, as shown in plate 47, *B*.

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[7] Lapham, M. C., and Neill, N. P., Soil survey of the Solomonsville area, Ariz.: U. S. Dept. Agr., Bur. Soils, Field Operations, 1903, pp. 10-20, 1904.

[8] Schwennesen, A. T., Ground water in San Simon Valley, Ariz. and N. Mex.: Geol. Survey Water-Supply Paper 425-A, p. 5, 1917.

Mormon settlers, who arrived from Utah early in the eighties, found the valley in essentially its present form, but the present trench, known as San Simon Creek, a steep-walled gully in the valley floor (see pl. 48, *A*, *B*), did not then exist. According to the statements of many inhabitants, the San Simon Valley lowlands at that time supported a luxuriant growth of grass, which has since vanished. Many investigators believe that these changes, which have occurred since the arrival of white settlers, are to be attributed, at least in part, to the removal of the protective cover of vegetation by excessive grazing followed by increased run-off and greater erosion. Stock trails are said to be the forerunners of small watercourses, which grow to become broad, steep-walled arroyos. A few writers, however, have pointed out that climatic changes or tectonic movements may be capable of producing similar results. A decrease in the mean annual precipitation would kill off part of the vegetation, and if accompanied or followed by storms of increased violence, streams that had been aggrading their beds might begin cutting. An increase in the gradient of streams by slight regional uplift would no doubt have a similar effect.

Bryan[9] favored the hypothesis of a recent climatic change. Regarding the approximate time at which the phenomena mentioned began to appear, he says:

> The change from aggradation and the building of flood plains to dissection and the formation of arroyos in many streams of southern Arizona can be confidently placed in the decade 1880 to 1890, although many tributary streams were not affected until the nineties, and some are still undissected. The date in southern Utah, northern Arizona, and southern Colorado is apparently earlier, and cutting probably began at some time after 1860.

Gregory,[10] in discussing the "recent cycle of erosion" in the Navajo country, states that

> human factors exert a strong influence but are not entirely responsible for the disastrous erosion of recent years. The region has not been deforested; the present cover of the vegetation affects the run-off but slightly, and parts of the region not utilized for grazing present the same detailed topographic features as the areas annually overrun by Indian herds.

Gregory[11] has later been inclined to regard recent regional tectonic activity as a possible cause of the trenching, an explanation which Bryan rejected.

Bryan[12] summarizes information on trenching in the San Simon Valley as follows:

> San Simon Creek, which enters the Gila River near Solomonsville, once flowed through uninterrupted meadows and flats from a point near Rodeo more than

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[9] Bryan, Kirk, Date of channel trenching (arroyo cutting) in the arid Southwest: Science, new ser., vol. 62, pp. 338-344, 1925.

[10] Gregory, H. E., Geology of the Navajo country, a reconnaissance of parts of Arizona, New Mexico, and Utah: Geol. Survey Prof. Paper 93, p. 132, 1917.

[11] Gregory, H. E., oral communication to the writer, 1934.

[12] Bryan, Kirk, op. cit., p. 342.

100 miles to its mouth. According to Olmstead,[13] settlers near Solomonsville in 1883 excavated a small channel 20 feet wide and 4 feet deep to confine the flood water. Since that time a channel formed and progressed headward through the flats for 60 miles to the lower end of the San Simon Cienaga. Above this point there is no definite channel, but the new channel of the creek downstream is 10 to 30 feet deep and 600 to 800 feet wide. Schwennesen [14] describes the drainage of the area and states that the channel has formed since the advent of American settlers. Carpenter and Bransford [15] make the same comment but also say that in large floods the channel is still overflowed.

As stated by Olmstead, the channeling in the San Simon Valley began with the digging of the Solomonsville drainage ditch, and much of the headward cutting is reported by early settlers to have followed the ruts of a former wagon road along the valley bottom between Bowie and Solomonsville. Branch trenches are likewise generally confined to the principal drainage channels, which head in or near the mountains bordering the valley. These channels existed long before the advent of stock, and the areas between them are not gullied excessively, as they supposedly should be if stock trails were important contributory factors. The present vehicular trail east of San Simon Creek between Bowie and Solomonsville (pl. 46) runs for miles near the creek over comparatively smooth surfaces, and the only trenches crossed are in old watercourses heading in or near the Peloncillo Mountains. Under these circumstances it would be difficult, to say the least, to determine which of the possible causes that have been suggested is the chief cause of the local phenomena under consideration, and it should be borne in mind that erosion in the ancient lake beds began in late Pliocene or early Pleistocene time. It is conceivable that numerous "epicycles of erosion", similar to that recently begun, may have occurred during each of the major cycles of aggradation and degradation recorded in the valley terraces and described in the following pages. In this connection, however, it is worthy of note that Bailey,[16] having compared the evidence of recent and earlier epicycles in several valleys in Utah, reached the conclusion that "utilization of the region by man and the consequent reduction and modification in the plant cover are major factors in starting the new epicycle of erosion." It is possible that further studies will confirm this view.

GILA VALLEY

GENERAL FEATURES

The Gila River, a perennial stream carrying a large volume of water, has cut down into the late Tertiary sediments much more effectively

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[13] Olmstead, F. H., Gila River flood control: 65th Cong., 3d sess., S. Doc. 436, 1919.

[14] Schwennesen, A. T., Ground water in San Simon Valley, Ariz. and N. Mex.: Geol. Survey Water-Supply Paper 425, pp. 5-6, 1917.

[15] Carpenter, E. J., and Bransford, W. S., Soil survey of the San Simon area, Ariz.: U. S. Dept. Agr., Bur. Soils, Field Operations, 1921, pp. 584, 594, 1924.

[16] Bailey, R. W., Epicycles of erosion in the valleys of the Colorado Plateau province: Jour. Geology, vol. 43, no. 4, pp. 337-355, 1935.

than San Simon Creek and other tributaries, which normally carry water only during and immediately after the infrequent rains. The present gradient of the Gila River is only 10 feet to the mile within the valley, whereas the gradient of San Simon Creek is about 20 feet to the mile. The maximum amount of erosion has occurred at the lower end of the valley, in the vicinity of the San Carlos Reservoir. Schwennesen [17] briefly describes the land forms in that part of the valley and gives his interpretation in part as follows:

> On the north and south sides of the basin, adjacent to the mountains, are belts of hilly country which stand higher than the middle of the basin and which have evidently been produced by the erosion of what were at one time smooth alluvial slopes extending from the mountains toward the middle of the basin. Inside these hilly belts are belts of lower country which are the remnants of a lake bottom that once extended across the axis of the basin. This lake apparently came into existence after the alluvial slopes had been considerably eroded. As a result of the large amount of sediment deposited in the lake its bottom became smooth and had only gentle slopes toward the middle of the basin. Although this former lake bottom has been eroded since the disappearance of the lake, it still forms a strong contrast to the more anciently dissected marginal belts.

This interpretation differs from that of the writer, who believes that the stream sediments exposed in the high marginal hilly belts are equivalent in geologic age to the lake sediments of the central part of the valley and are not an older formation underlying the lake beds. The marginal belts and the more central gently sloping terraces referred to are recognized as ancient surfaces developed by planation, inasmuch as they show certain features that are peculiar to mountain pediments. Discussions of the geologic and hydrologic aspects of the writer's interpretation are presented on pages 196 and 210 of this report.

The origin and development of typical mountain pediments have been discussed in some detail by Bryan.[18] The typical pediments of the Papago country, however, are surfaces formed in enclosed basins under arid conditions by erosion of the rocks composing mountain blocks, whereas the surfaces here described, although apparently produced by similar processes, were cut almost entirely on unconsolidated fill in a basin in which through drainage was maintained. As the products of erosion while the pediments were being formed were carried downstream and out of the Gila-San Simon trough, the baselevel in the trough was lowered. This circumstance probably accounts for the absence of the "suballuvial bench" of Lawson,[19]

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[17] Schwennesen, A. T., Geology and water resources of the Gila and San Carlos Valleys in the San Carlos Indian Reservation, Ariz.: Geol. Survey Water-Supply Paper 450, p. 5, fig. 2, 1919.

[18] Bryan, Kirk, The Papago country, Ariz., a geographic, geologic, and hydrologic reconnaissance, with a guide to desert watering places: Geol. Survey Water-Supply Paper 499, pp. 93-101, 1925; Pediments developed in basins with through drainage as illustrated by the Socorro area, N. Mex. [abstract]: Geol. Soc. America Bull., vol. 43, pp. 128-129, 1932, and Pan-Am. Geologist, vol. 57, p. 60, 1932.

[19] Lawson, A. C., Epigene profiles of the desert: California Univ., Dept. Geology, Bull., vol. 9, pp. 23-48, 1915. Field, R., Stream-carved slopes and plains in desert mountains: Am. Jour. Sci., 5th ser., vol. 29, no. 172, pp. 313-322, April 1935.

a feature characteristically associated with pediments formed while the baselevel is rising as a result of accumulation of detritus in an enclosed basin. The pediments that slope downward from both sides of the upper San Simon Valley flatten out and meet in the central part of the trough as described by Schwennesen. (See p. 188.)

UPPER TERRACE

Along the southwest side of the Gila Valley a dissected gravel-covered terrace (see pl. 49, *A*, *B*) is the remnant of an ancient pediment and is called in this paper the "upper terrace." This terrace extends southeastward from the San Carlos Indian Reservation and forms a continuous surface with the relatively undissected valley floor in the southern part of the San Simon Valley. At the base of the Graham Mountains southwest of Thatcher the upper limit of this terrace is several hundred feet higher than elsewhere along the margin of the valley. The highest point on the terrace is at the mouth of Frye Canyon and is about 5,200 feet above sea level. The longitudinal section of the upper terrace close to the mountains in this neighborhood is convex upward, suggesting a typical alluvial fan formed by aggradation at the mouth of Frye Canyon. However, a belt of fanglomeratic Gila conglomerate lies along the base of the Graham Mountains in this vicinity, and the contact between the Gila fanglomeratic phase and the similar overlying gravel that spreads out basinward as a thin coating over the lake beds of Gila age could not be located at the time of examination. It is possible that a detailed study of the prominent fan at the mouth of Frye Canyon would show it to belong to the degradational "rock fan" type, as originally described by Paige[20] and elaborated later by Johnson.[21]

At the mouth of Tripp Canyon the altitude of the upper terrace is about 4,400 feet above sea level; near the Swift Trail the highest point on it is at an altitude of about 4,100 feet; and at the Fort Grant road about 7 miles south of Artesia the altitude is about 4,300 feet. Schwennesen's diagrams show the edge of the valley deposits at the base of the Turnbull Mountains to be about 4,000 feet above sea level.

Nearer the central axis of the Gila Valley the upper terrace is preserved on numerous isolated mesas that have been carved by the streams in the clay, silt, and sandy layers characteristic of the late Pliocene lake beds of the central part of the basin. Each mesa is capped by a layer of Pleistocene (?) gravel, usually from 6 to 10 feet thick, firmly cemented by calcium carbonate (caliche) to form a conglomerate whose pebbles are fairly well rounded and are in general

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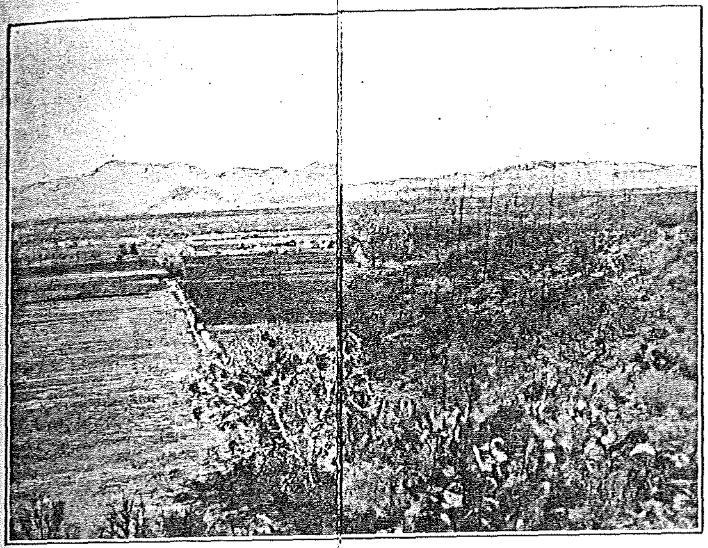
[20] Paige, Sidney, Rock-cut surfaces in the desert ranges: Jour. Geology, vol. 20, pp. 442-450, 1912.

[21] Johnson, D. W., Planes of lateral corrasion: Science, new ser., vol. 74, pp. 174-177, 1931; Rock fans of arid regions: Am. Jour. Sci., 5th ser., vol. 23, pp. 389-416, 1932; Rock planes of arid regions: Geog. Review, vol. 22, pp. 656-665, 1932.



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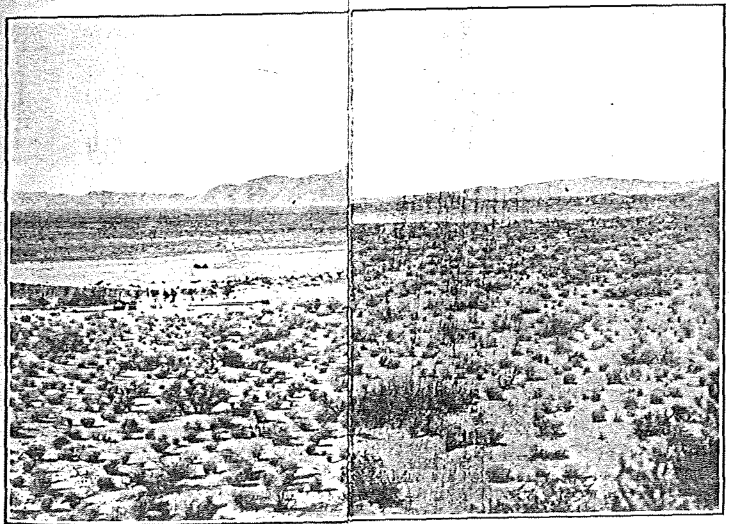

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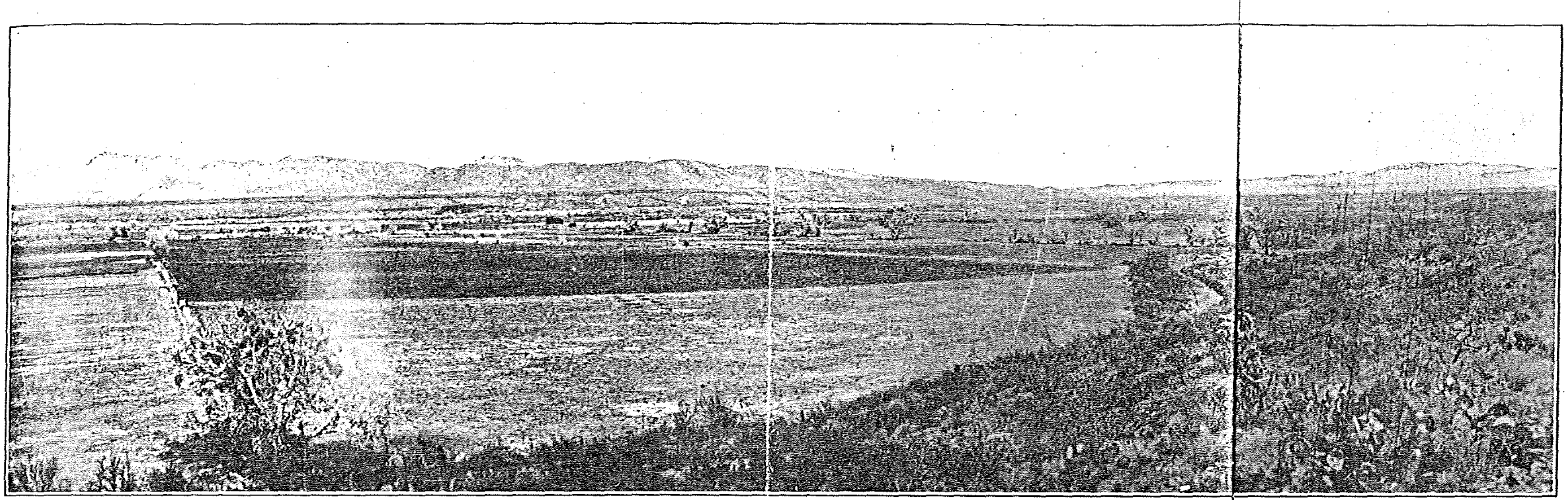
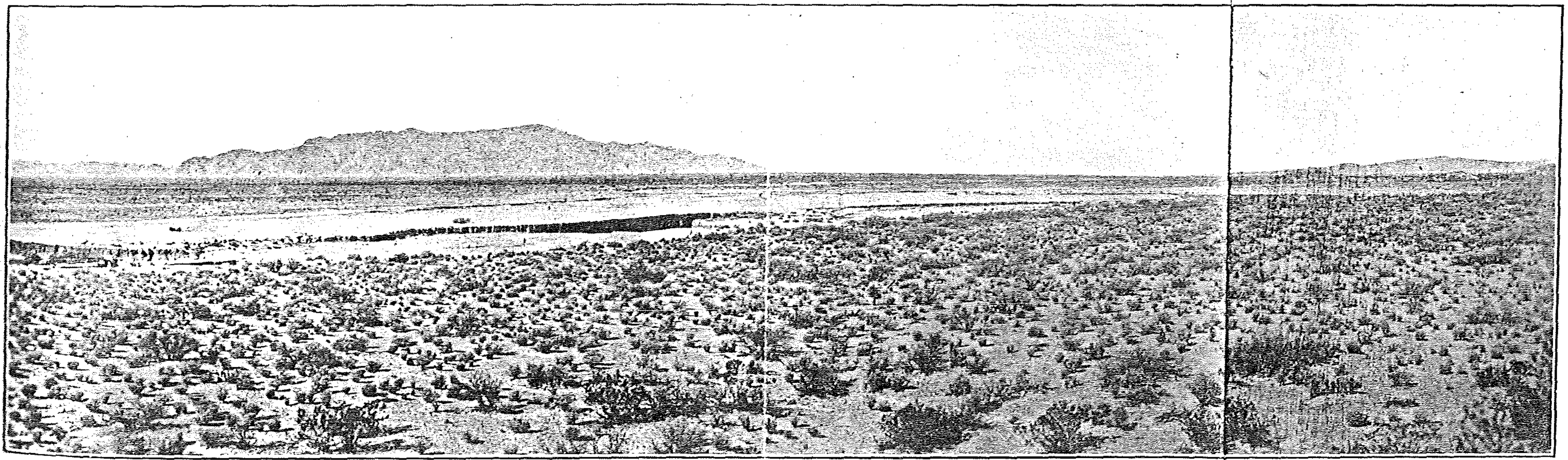
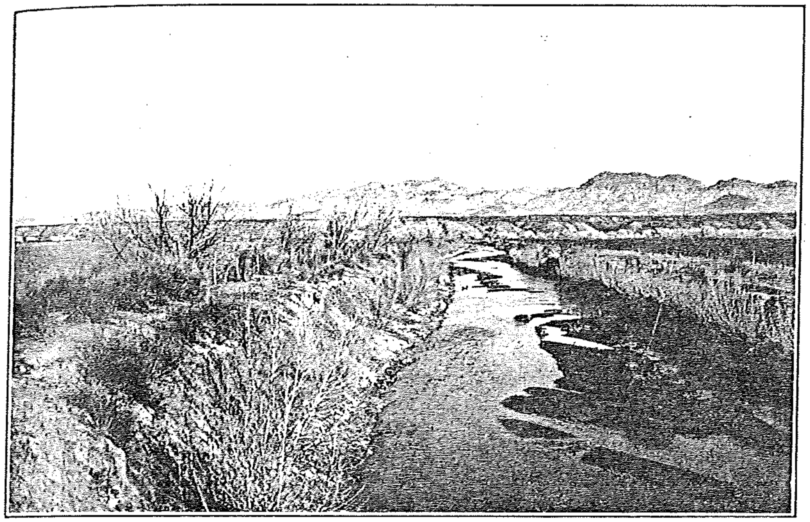


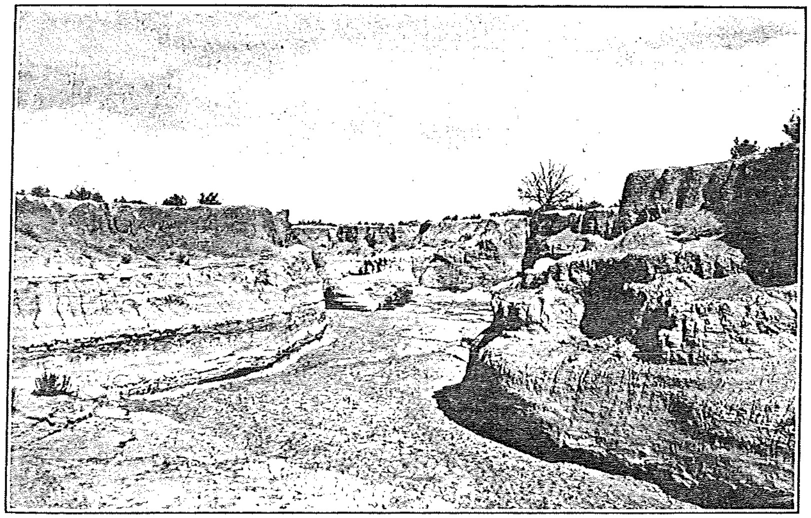
A. VIEW LOOKING NORTH OVER IRRIGATED LOWLANDS ALONG THE GILA RIVER NEAR SOLOMONSVILLE.



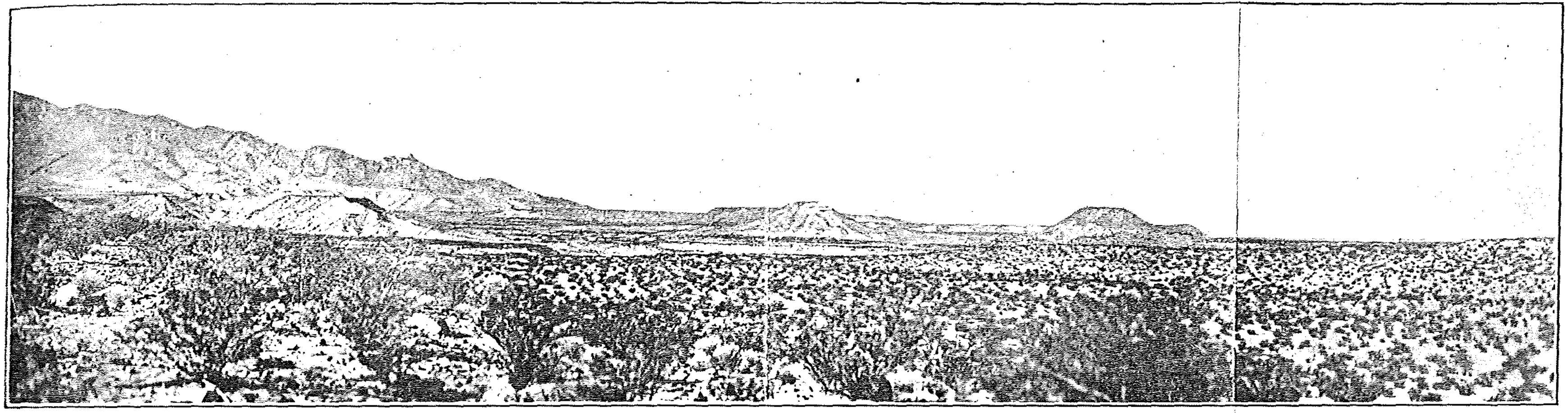
B. VIEW LOOKING NORTHWEST DOWN SAN SIMON VALLEY FROM A POINT NEAR TANQUE.
San Simon Creek in the foreground.



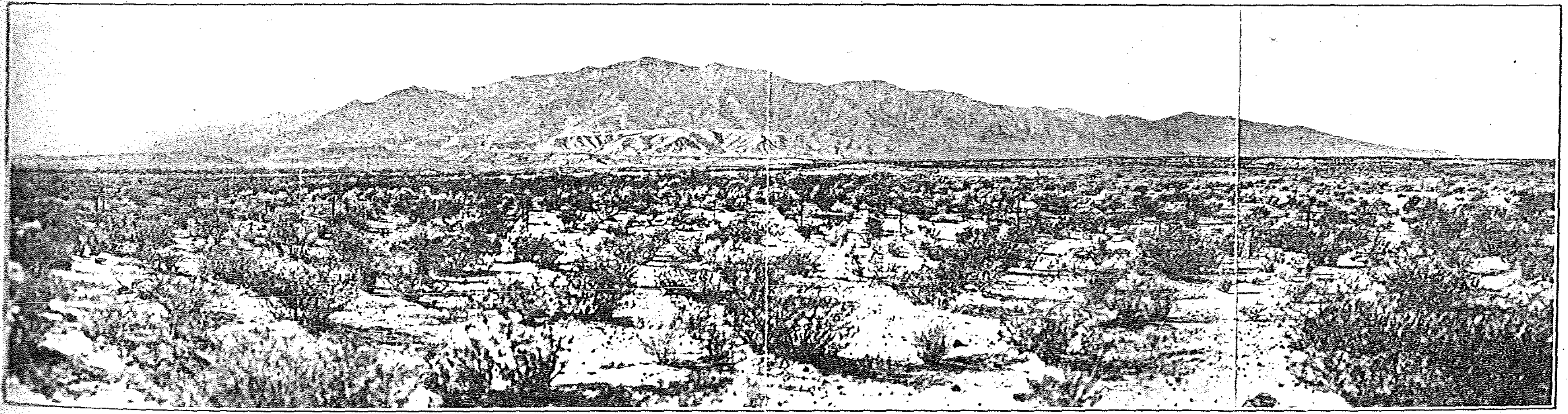
A. VIEW LOOKING NORTH ALONG SAN SIMON CREEK NEAR SOLOMONSVILLE.



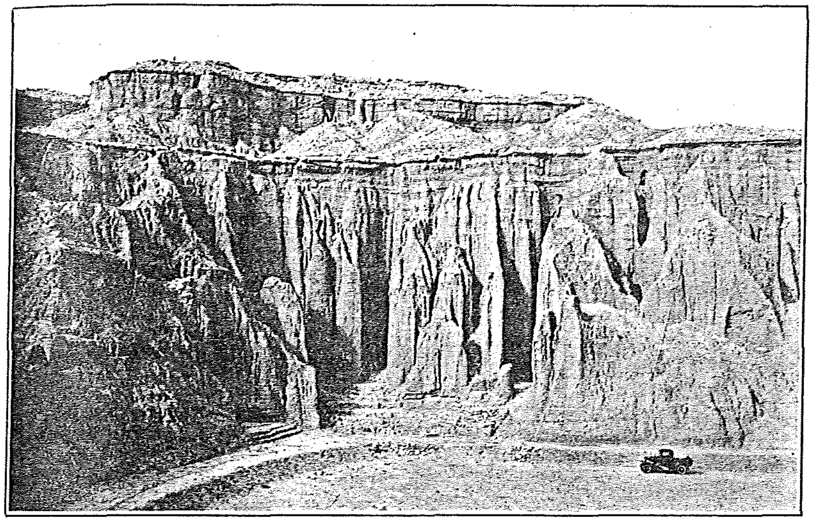
B. SAN SIMON CREEK NEAR TANQUE.



A. REMNANTS OF UPPER TERRACE ON FLANK OF GRAHAM MOUNTAINS.

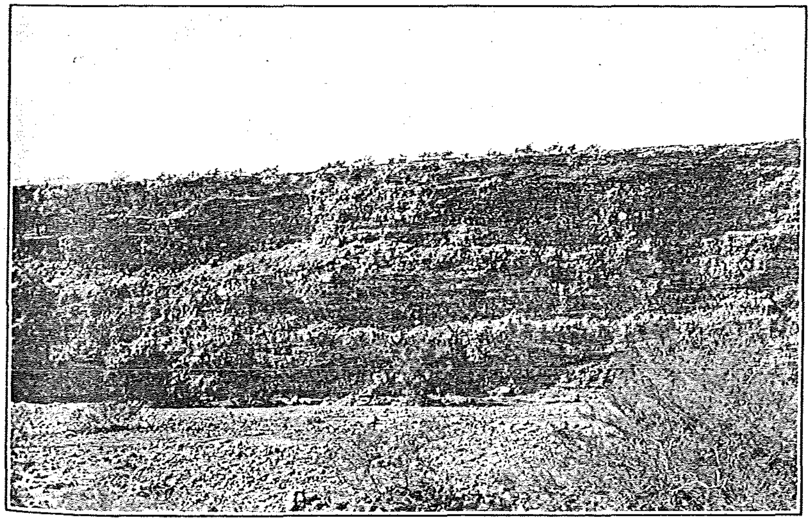


B. VIEW LOOKING SOUTH TOWARD GRAHAM MOUNTAINS FROM POINT NEAR THATCHER.
Upper terrace is seen at base of mountains.



A. LAKE BEDS EXPOSED AT RED KNOLLS "DESERT THEATER", IN VALLEY 1½ MILES SOUTHWEST OF ASHURST.

Two conspicuous hard layers near top are limestone containing fresh-water invertebrate fossils.



B. GILA CONGLOMERATE ON BIG SPRING WASH, NEAR CENTER OF T. 5 S., R. 25 E.

About 50 feet of conglomerate is exposed.

composed of the same materials as the fanglomeratic phase of the Gila conglomerate. The gravel is everywhere coarse, and the pebbles are poorly assorted in size. In sec. 27, T. 7 S., R. 25 E., 4 miles from the base of the Graham Mountains, boulders 2 feet in diameter occur in the conglomerate that caps a small mesa. The steep gradient, generally more than 30°, of the sloping escarpment of this terrace is due to the resistance to erosion that is offered by the hard capping layer of caliche and the ease of erosion in the underlying unconsolidated lake beds.

On the opposite side of the valley no terrace corresponding to this one seems to be present, unless it is indicated by a few caliche-capped mesas in sec. 31, T. 5 S., R. 25 E., the tops of which are about 3,330 feet above sea level, or about 100 feet above the surrounding upland. Possibly the upper terrace was formerly matched by a terrace sloping away from the Gila Mountains northeast of the present river and higher than the present surface there. At that time the Gila Valley was probably a broad trough resembling the present San Simon Valley in the neighborhood of San Simon, as described by Schwennesen.

LOWER TERRACE

A second dissected pediment surface, which may be called the "lower terrace", is bounded on the southwest side of the valley by the upper terrace and slopes gently downward toward the alluvial lowlands of the Gila Valley (pl. 49, *B*). Northeast of the Gila River it is matched by a similar terrace that rises to the base of the Gila Mountains. These two surfaces represent a second major episode in the erosional history of the valley since the lake disappeared, involving cutting by the Gila River down to a level about 100 feet above its present channel, at which it remained long enough to permit its tributaries to cut away large parts of the erosion surface represented by the upper terrace. Like the upper terrace, the lower terrace on each side of the valley is covered by a thin layer of coarse gravel cemented by calcium carbonate, and here also the cutting of the soft lake beds below the hard caliche capping has produced steeply sloping escarpments along the terrace faces. At this stage cutting extended up the San Simon Valley for more than 15 miles above Solomonsville.

ALLUVIAL PLAINS

The alluvial lowland plain along the Gila River (pl. 47, *A*) extends from the San Carlos Reservoir upstream and terminates at the narrows about 2 miles above Sanchez. This plain, which was built by the Gila River, is bordered on both sides by the steeply sloping escarpments at the foot of the lower terrace; its width is about 1 mile at Geronimo and Fort Thomas, about 2½ miles at Pima, 3 miles at Thatcher and Safford, 2 miles at Solomonsville, and 1½ miles at San

SEDIMENTARY ROCKS

GILA CONGLOMERATE

GENERAL FEATURES

Sedimentary deposits of lake and stream origin fill the valley of the Gila River and San Simon Creek to a depth of possibly 1,600 feet. The area occupied by these valley deposits in Graham County ranges from 10 to 20 miles in width, and they extend more than 100 miles up the valley from the Coolidge Dam. In the central part of the valley they are of lacustrine origin and are characteristically fine-grained, consisting of stratified red and gray clays and silts, with here and there layers of tuff and marly limestone. (See pls. 50, *A;* 51, *A*, *B*.) These prevailingly fine-grained materials grade laterally into fanglomerate (pl. 50, *B*), which is included in the Gila conglomerate as originally defined by Gilbert [29] and which extends in belts along the sides of the valley. This coarse material is of fluviatile origin and was no doubt deposited as alluvial fans and deltas by streams issuing from the mountains along the shores of the ancient lake. The pebbles and boulders of this lateral or shore phase of the formation are largest at the base of the mountains, where they are commonly a foot or more in diameter. On the southwest side of the valley they are composed chiefly of schist and coarse-grained igneous rocks derived from the Graham, Santa Teresa, and Turnbull Mountains. On the northeast side of the valley the pebbles are predominantly fragments of volcanic rock transported from the Gila Mountains. The belts of fanglomerate exposures are several miles wide in some places, but are absent in others. A broad belt skirts the Gila Mountains from the San Carlos Indian Reservation southeastward nearly to Sanchez, being interrupted only in the vicinity of Fort Thomas. A second broad belt skirts the Santa Teresa Mountains and extends a few miles southeast of the Fort Grant road. For several miles northwest and southeast of Frye Creek the belt of fanglomerate is not more than a mile wide. Belts in the upper San Simon Valley and in the lower Gila Valley are described by Schwennesen.[30] The fanglomeratic phase is absent along the base of the Whitlock Hills and in the vicinity of the 111 ranch, where the lake beds are composed of gray clays and beds of white diatomite and chert, shown in plate 52, *A*.

In the absence of detailed surveys no accurate estimate of the exposed thickness of lake beds in the valley is possible. It is probably not more than 200 feet, but the strata penetrated in at least the upper 1,600 feet in deep wells drilled at Safford, Pima, and Ashurst are apparently of lacustrine origin. The logs of the deep wells (pp. 202–204) show no large body of conglomerate older than the lake beds and underlying them at a depth of about 600 feet below the surface, as postulated by Schwennesen,[31] whose diagram, moreover, shows the "high marginal hilly belts" in the San Carlos Indian Reservation to be underlain exclusively by alluvial material. The writer found that the dissected upper surface of the high marginal belt or pediment (see p. 191) on the southwest side of the Gila Valley, along the base of the Graham Mountains, is underlain in part by lake beds, in part by fanglomerate, and, in an area of a few square miles, by the crystalline rocks of the Graham Mountains. Schwennesen's concept, in which the limits of the "belts of lower country" in the San Carlos Reservation are regarded as coincident with the outlines of the former lake, is thus contradicted, so far as the extension of the Gila Valley southeastward into Graham County is concerned. Furthermore, the transition from coarse detrital material in the basin deposits, as exposed along several arroyos near the margins of the valley, to predominantly fine-grained material in the central part of the trough occurs not abruptly but gradually. Interfingering of the two types of fill, as shown in figure 30, is inferred from well data and is supported by the hydrologic considerations set forth on pages 209–211. Such relations would scarcely be expected to exist if the fanglomerates and lake beds were deposited at separate times. The Gila conglomerate as a geologic formation must therefore include both lake beds and fanglomerates, the two phases having originated simultaneously. The late Pliocene age of the lacustrine phase of the Gila conglomerate in this area is known from fossil evidence obtained during the present investigation and set forth below. As the lacustrine deposits have been traced continuously to the mouth of Bonita Creek (see pl. 45), they may safely be regarded as lying within the type locality of the Gila conglomerate as given in the following quotation from Gilbert's original definition of that formation,[32] where the Gila and San Simon Valleys are referred to as the "Pueblo Viejo Desert."

> Beginning at the mouth of the Bonita, below which point their distinctive characters are lost, they follow the Gila for more than 100 miles toward its source, being last seen a little above the mouth of the Gilita.* * * Below the Bonita it [the Gila conglomerate] merges insensibly with the detritus of Pueblo Viejo Desert.

The character of the late Pliocene deposits in this valley is evidently very much the same as in the San Pedro Valley, to the southwest, which is described by Bryan [33] as follows:

> The conglomerate (fanglomerate) of the typical facies encircles unconsolidated fine-grained deposits laid down in the central areas of the original valleys. In

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[29] Gilbert, G. K., op. cit., pp. 540–541.

[30] Schwennesen, A. T., Ground water in San Simon Valley, Ariz. and N. Mex.: Geol. Survey Water-Supply Paper 425, p. 8, 1917; Geology and water resources of the Gila and San Carlos Valleys in the San Carlos Indian Reservation, Ariz.: Geol. Survey Water-Supply Paper 450, pp. 7–9, 1919.

[31] Schwennesen, A. T., Geology and water resources of the Gila and San Carlos Valleys in the San Carlos Indian Reservation, Ariz.: Geol. Survey Water-Supply Paper 450, pp. 7–10, 1919.

[32] Gilbert, G. K., op. cit., pp. 540–541, 1875.

[33] Bryan, Kirk, San Pedro Valley, Ariz., and the geographic cycle [abstract]: Geol. Soc. America Bull., vol. 37, p. 169, 1926.

the fine-grained deposits a large vertebrate fauna, determined by Gidley to be of late Pliocene age, has been found.

FOSSILS

Vertebrate fossils that were collected by the writer from the lake beds of the valley of the Gila River and San Simon Creek at two localities about 25 miles apart (111 ranch and Henry ranch) include camel bones, peccary teeth, a sloth bone, teeth and bones belonging to three genera of horses, and fragments of a large turtle. These, together with photographs and casts of part of a mastodon skull from a third locality, near Bear Springs, were referred for determination to C. L. Gazin, of the United States National Museum, whose preliminary report follows:

1. *Nannippus* locality, 111 ranch, sec. 27, T. 8 S., R. 28 E.:

    Hipparion (Nannippus) sp. (teeth and jaw fragments).
    Equid, large form (tooth fragments and foot bones).
    Camelid sp. (fragments of limb and foot bones).
    Platygonus sp. (teeth).
    Megalonychid sp. (ungual phalanx).

2. *Plesippus* locality, Henry ranch, NE¼ sec. 22, T. 5 S., R. 23 E.:

    Plesippus sp. (teeth and bone fragments).
    Camelid sp. (fragmentary foot bones).

3. Mastodon locality, Bear Springs, SE¼ sec. 9, T. 7 S., R. 23 E.:

    Rhynchotherium? sp. (portion of skull with teeth, identified from photographs and casts of the tooth crowns).

There is probably little or no difference in the age of the above three occurrences, as the presence of *Nannippus*, *Plesippus*, and a mastodon resembling *Rhynchotherium* in each locality indicates an upper Pliocene age. The part of the upper Pliocene represented is not clearly indicated, although the part represented appears to be less advanced than the *Plesippus* zone at Hagerman, Idaho,[34] and probably not greatly separated in time from the Blanco of Texas.[35] As compared with the horizons that carry mammalian remains in the San Pedro Valley of Arizona,[36] the horizons in the Gila and San Simon Valleys appear to be older than the late Pliocene or Pleistocene at the Curtis ranch, about 15 miles south of Benson, Ariz., and younger than or possibly equivalent to the upper Pliocene recognized near Benson.

The turtle remains were submitted to C. W. Gilmore for identification, and he reported them as undeterminable testudinate remains that gave no indication as to age.

Fossil invertebrates from a fourth locality, in the lake beds near Red Knolls, were studied by W. C. Mansfield, of the Geological Survey, who states:

4. *Planorbis* locality, Red Knolls, sec. 36, T. 5 S., R. 22 E. From a limestone about 40 feet higher than unidentified vertebrate bones:

    Lymnaea? sp. (only a fragment of a spire seen).
    Planorbis (species indeterminable; specimens badly crushed).

The fauna lived under fresh-water conditions. The age is indeterminable because of the poor state of preservation of the organisms; however, they do not look very old.

Fossil wood from locality 2 (*Plesippus* locality) has been studied by R. W. Brown, of the Geological Survey, who writes:

Among several specimens of silicified wood from sec. 22, T. 5 S., R. 23 E., Graham County, Ariz., only one was well enough preserved to show identifiable cellular elements. A transverse section of this wood exhibits distinct annual rings composed of about equal zones of spring and summer wood. The vessels of the spring wood are large and uniform; those of the summer wood, minute. The transition from the open spring wood to the dense summer wood is conspicuously abrupt. The medullary rays are narrow, barely visible to the naked eye, and lie between single, rarely double, rows of vessels. The radial and tangential sections reveal nothing definitive. This wood is clearly a ring-porous, dicotyledonous species, resembling in some respects the living *Sassafras variifolium*. I should hesitate, however, to identify it positively as a *Sassafras*. Its well-defined annual rings suggest regular seasonal changes, either wet to dry or warm to cold, or both. As to its geologic age I can offer only a guess that it may have lived in the middle or late Tertiary.

Diatomite collected by the writer from two localities was examined by K. E. Lohman, of the Geological Survey, whose report follows:

Geol. Survey diatomite locality 2054, 111 ranch, Ariz., SE¼ sec. 21, T. 8 S., R. 28 E.

This material consists chiefly of volcanic ash and some clastic material, diatoms constituting only about 30 percent of the total. It is useless for any purpose for which diatomite would be required. The following species of diatoms are present (C, common; F, frequent; R, rare):

Melosira italica (Ehrenberg) Kützing. F.
Podosira sp. R.
Stauroneis cf. S. phoenicenteron Ehrenberg. F.
Anomoeoneis sphaerophora (Kützing) Pfitzer. F.
Navicula cf. N. cuspidata Kützing. R.
Navicula amphibola Cleve. F.
Pinnularia major (Kützing) Cleve. C.
Pinnularia microstauron (Ehrenberg) Cleve. F.
Gomphonema longiceps Ehrenberg var. subclavata Grunow. R.
Denticula elegans Kützing. C.
Epithemia zebra (Ehrenberg) Kützing var. procellus (Kützing) Grunow. R.
Rhopalodia gibberula (Ehrenberg) Müller. F.
Nitzschia sp. R.
Campylodiscus clypeus Ehrenberg. R.

Geol. Survey diatomite locality 2055, opposite Fort Thomas, Ariz., SE¼ sec. 24. T. 4 S., R. 23 E.

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[34] Gidley, J. W., A new Pliocene horse from Idaho: Jour. Mammalogy, vol. 11, pp. 300-303, 1930; Continuation of the fossil-horse round-up on the old Oregon Trail: Smithsonian Inst. Explorations and Field Work in 1930, pp. 33-40, 1931. Boss, N. H., Explorations for fossil horses in Idaho: Smithsonian Inst. Explorations and Field Work in 1931, pp. 41-44, 1932.

[35] Gidley, J. W., The fresh-water Tertiary of northwestern Texas: Am. Mus. Nat. History Bull., vol. 19, pp. 617-635, 1903. Cope, E. D., A preliminary report on the vertebrate paleontology of the Llano Estacado: Texas Geol. Survey 4th Ann. Rept., pt. 2, pp. 47-74, 1893. Plummer, F. B., Cenozoic systems in Texas: Texas Univ. Bull. 3232, vol. 1, pp. 765-776, 1932.

[36] Gidley, J. W., Preliminary report on fossil vertebrates of the San Pedro Valley, Ariz., with descriptions of new species of Rodentia and Lagomorpha: U. S. Geol. Survey Prof. Paper 131, pp. 119-131, 1922; Fossil Proboscidea and Edentata of the San Pedro Valley, Ariz.: U. S. Geol. Survey Prof. Paper 140, pp. 83-95, 1926.

This material is an impure diatomite, the impurities, chiefly silt, amounting to approximately 15 percent. It would be suitable for such purposes as heat and sound insulation but would not be marketable in competition with even medium grades of diatomite from California, Oregon, Nevada, and other areas, because of impurities. Its economic use would depend on a local market. Heat insulation is suggested as the most likely purpose for which it might be used.

The following species of diatoms are present (A, abundant; C, common; F, frequent):

Cyclotella meneghiniana Kützing. C.
Mastogloia cf. M. smithii Thwaites. F.
Gomphonema cf. G. lanceolatum Ehrenberg. F.
Denticula elegans Kützing. A.
Surirella striatula Turpin. F.
Campylodiscus clypeus Ehrenberg. F.

The diatoms in both these samples suggest that they were deposited in warm, somewhat saline lake water. All the species are living at the present time, so that no evidence of age is offered, other than that the deposits can hardly be very old. All these species have been found in rocks of supposed Pliocene age, so that these deposits may be of Pliocene age or younger.

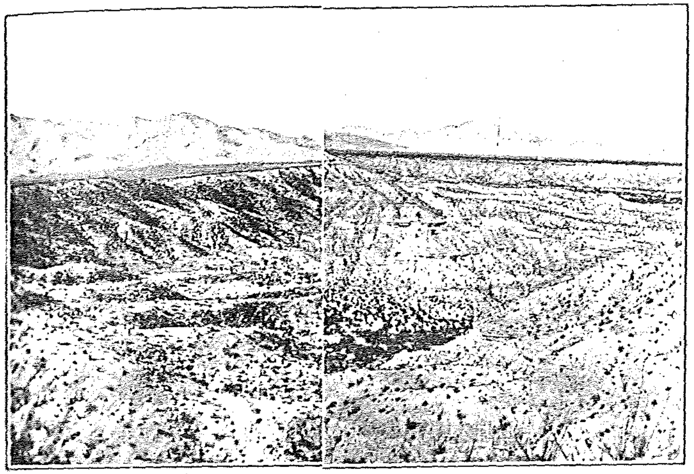
PLEISTOCENE (?) TERRACE GRAVEL

The middle and upper terraces of the valley of the Gila River and San Simon Creek are capped by caliche-cemented coarse gravel, the nature, origin, and stratigraphic relations of which are described on pages 190–193 of this report. As no fossils have been found in the gravel, its geologic age can only be inferred. Both the gravel capping the upper terrace and that capping the lower terrace, which is of later origin, are tentatively assigned to the Pleistocene because they rest unconformably on the upper Pliocene lake beds and were formed before the deposition of the alluvium that underlies the lowland plain along the Gila River.

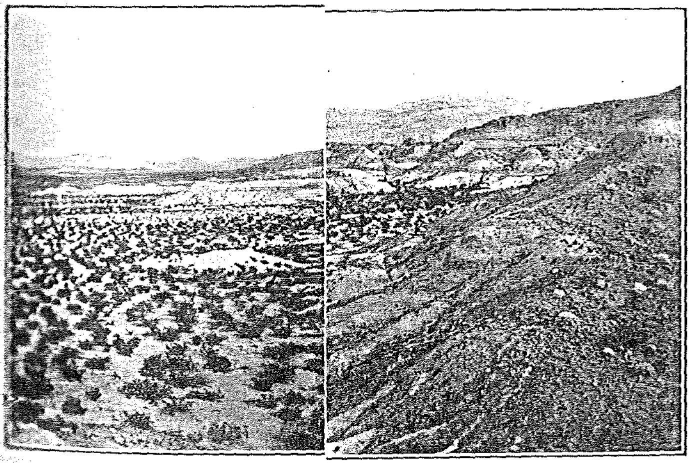
QUATERNARY ALLUVIUM

Alluvium, consisting of silt, sand, and gravel, underlies the lowland plain along the Gila River and less extensive areas along the tributaries of the river in Graham County. Deposition of this material probably began in Pleistocene time and has been in progress on the flood plain of the river until recently. The areal distribution of the alluvium, the history of its origin, its physiographic relations, and its economic value are briefly described on pages 187, 188, 193, 194, and 207.

The thickness of alluvium underlying the lowland plain differs from place to place but is probably nowhere much more than 100 feet. A general idea of the character of the alluvium as shown by wells may be obtained from the following sections:



A. F R. 23 E.



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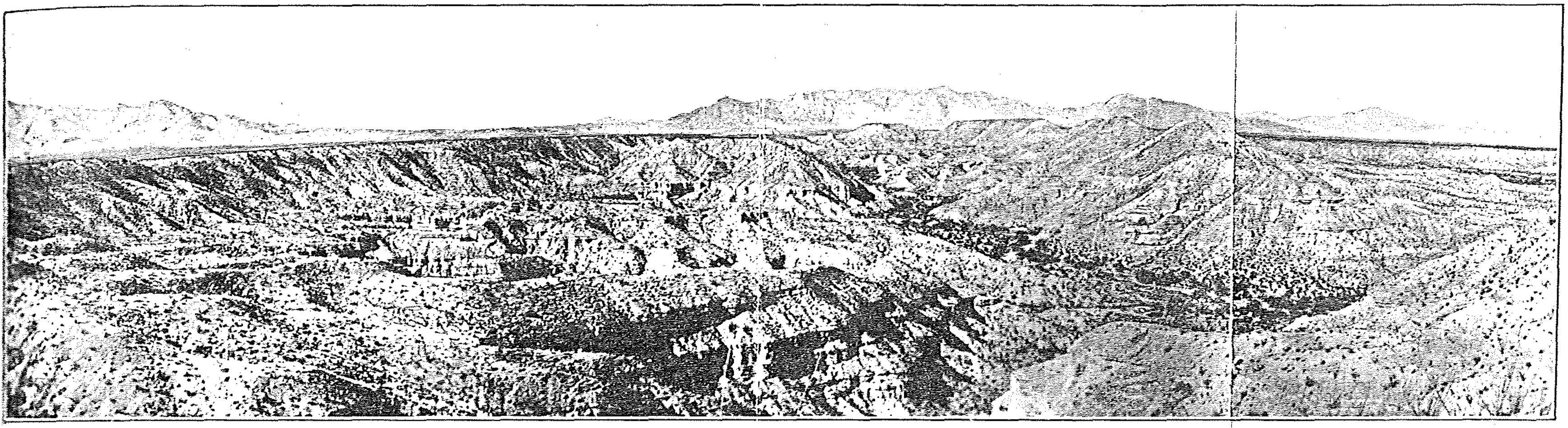
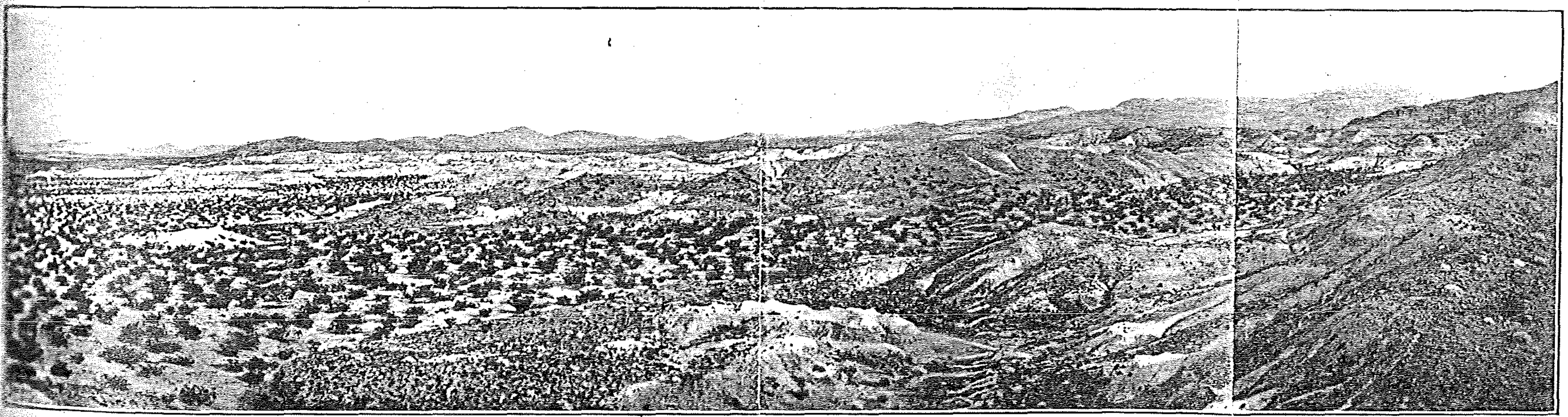
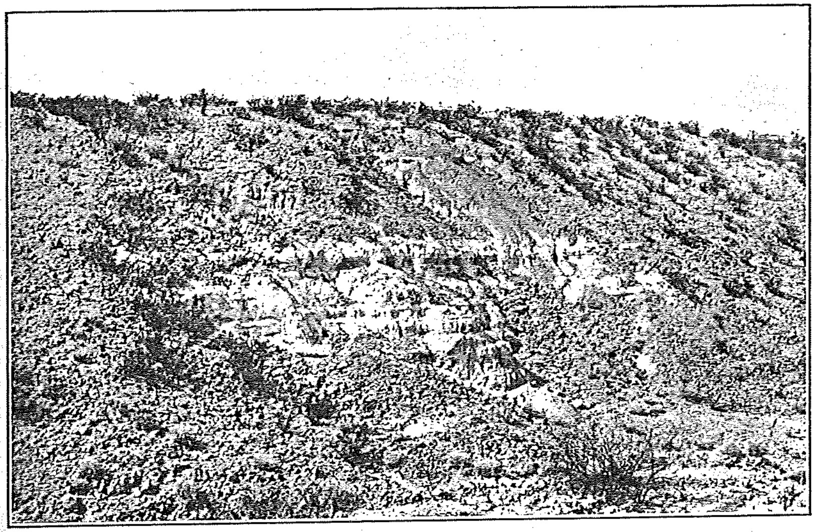


A. BADLANDS DEVELOPED IN FOSSILIFEROUS LAKE BEDS ABOUT 2 MILES WEST OF BEAR SPRINGS, T. 7 S., R. 23 E.

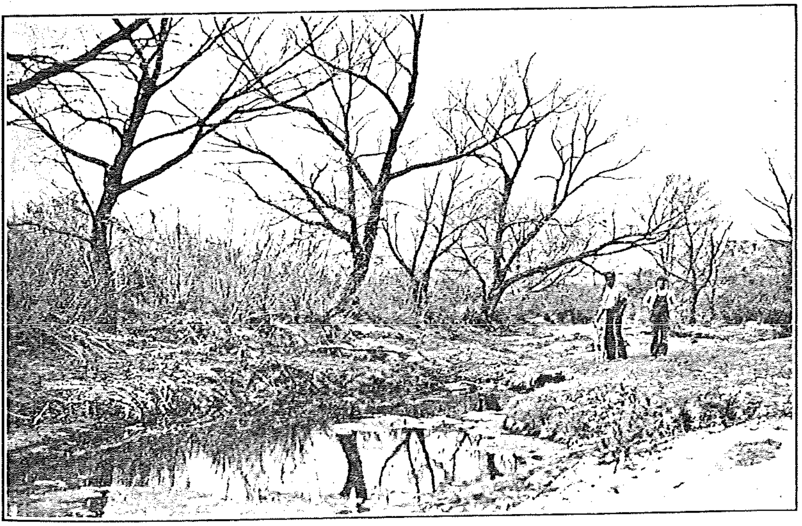
Santa Teresa and Turnbull Mountains in the distance; conspicuous terrace is a gravel-capped erosion surface.



B. FOSSILIFEROUS LAKE BEDS NEAR 111 RANCH, IN SEC. 27, T. 8 S., R. 28 E.



A. DIATOMITE WITH THIN CHERT LAYERS IN LAKE BEDS 1 MILE EAST OF 111 RANCH.



B. CIENAGA SPRINGS, IN JACOBSON WASH, EAST OF CACTUS FLAT.

Generalized section of alluvium from Solomonsville eastward

	Thickness	Depth	Remarks
	Feet	*Feet*	
Soil	5	5	
Gravel	35	40	Lower part of gravel contains water.
Unconformity			Contact between lake beds and overlying alluvium.
Red clay	10	50	
Hard black shaly clay with sand lenses.	50+	100+	Contains good water.

Approximate section from San Simon Creek to Safford

	Thickness	Depth	Remarks
	Feet	*Feet*	
Soil	18	18	
Sand and clay	18	36	Sand beds contain water.
Gravel	44	80	Water.
Unconformity			Contact between lake beds and overlying alluvium.
Red clay	20	100	

Log of E. G. Rogers well, NE¼ sec. 5, T. 6 S., R. 24 E.

	Thickness	Depth	Remarks
	Feet	*Feet*	
Sand	15	15	
Soft red clay	20	35	
Coarse sand	5	40	Small amount of water.
Red clay	5	45	
Coarse sand	5	50	Considerable water (nonartesian).
Red clay	10	60	
Sand	2	62	Do.
Hard red clay	18	80	
Gravel	2	82	Do.
Unconformity			Contact between lake beds and overlying alluvium.
Clay, with beds of limestone and tuff.	718	800	No sand or gravel and no water. Clean salt 6 feet thick at about 580 feet.

Log of E. W. Black well, NE¼NE¼ sec. 19, T. 4 S., R. 23 E.

	Thickness	Depth	Remarks
	Feet	*Feet*	
Sand and hard clay	27	27	
Sand	3	30	Water.
Hard red clay	24	54	
Quicksand	8	62	Much water, but sand is troublesome.
Sandy clay	13	75	Small amount of water.
Clay	25	100	
Sand	5	105	Large supply of good water.
Unconformity			Contact between lake beds and overlying alluvium.
Clay	20+	125+	Lake beds.

DEEP-WELL RECORDS

The following drillers' logs of four deep wells in the Gila Valley are given with no attempt to show the geologic age of the rocks penetrated. It is believed, however, that all the materials are of sedimentary origin, and it is possible that at least the upper 1,500 or 1,600 feet of the strata underlying the Quaternary alluvium belong to the lake beds.

Log of Southern Pacific Co.'s well at Tanque, Ariz.

[Pumping yield, 20,000 gallons in 24 hours]

	Thickness	Depth	Remarks
	Feet	*Feet*	
Hardpan	32	32	
Gravel	6	38	
Unconformity			Base of alluvium.
Yellow clay	52	90	
Sand and gravel	34	124	High water, 111 feet. Water level while pumping, 115 feet.
Yellow clay	8	132	
Gravel	12	144	Water.
Blue clay	96	240	Working barrel raised to 155 feet from ground surface, November 1911.
Blue clay and sand	14	254	
Gravel and sand	6	260	
Blue clay	24	284	
Sand	4	288	
Yellow clay	34	322	
Sand and clay	4	326	
Blue clay	70	396	
Sandstone	4	400	
Blue clay	192	592	
Gypsum and clay	143	735	Bottom of casing.
Gypsum	30	765	Bottom of well.

Log of Southern Pacific Co.'s well (dry) 17 feet south of center of main track, 124 feet east of center line of Central Avenue, Safford, Ariz.

[Drilled January 1906–March 1907. All water encountered was salty]

	Thickness	Depth	Remarks
	Feet	*Feet*	
Soil	8	8	
Gravel and boulders	82	90	
Unconformity			Base of alluvium.
Blue clay	100	190	
Yellow clay	70	260	
Blue clay	40	300	
Yellow stratified clay	400	700	
Yellow clay with streaks of gypsum	100	800	
Yellow clay with strata of hard rock	95	895	
Yellow and brown clay with streaks of gypsum	105	1,000	
Salty clay	820	1,820	Bottom of well.

Log of Mary S. Mack well in sec. 13, T. 6 S., R. 24 E., near Pima

	Thickness	Depth	Remarks
	Feet	*Feet*	
Sandy loam	3	3	
Sand	17	20	
Gravel; water	160	180	Base of alluvium; hole full of freshwater.
Unconformity			
Red sandstone	120	300	
Red sandy shale	160	460	
Brown shale	40	500	
Black shale	10	510	
Brown shale	50	560	
Gray shale	96	656	
Red sandstone	28	684	
Brown shale	56	740	
Gray shale	95	835	
Gypsum and shale	17	852	
Blue shale	18	870	
Hard shale	80	950	
Gray shale	10	960	
Blue shale	60	1,020	
Brown shale	250	1,270	
Gravel	30	1,300	
Brown shale	90	1,390	
Limy shale	2	1,392	
Red shale	58	1,450	
Sand	1	1,451	
Gravel	19	1,470	
Red shale	52	1,522	
Red sandstone	20	1,542	
Red shale	38	1,580	
Red sand	45	1,625	Well flowing 12,280 barrels of water in 24 hours.
Gravel	5	1,630	
Red sand	15	1,645	
Sand; water	75	1,720	Flow of water increased.
Gravel	10	1,730	
Red sand	18	1,748	
Sandy shale	40	1,788	
Gravel	15	1,803	
Red shale	17	1,820	
Red gravel	10	1,830	
Red sand	50	1,880	
Red shale	5	1,885	
Gravel	12	1,897	
Hard red sand	50	1,947	
Limy shale	5	1,952	
Red sand	191	2,143	
Sand; water	77	2,220	Do.
Red sand	30	2,250	
Red shale	55	2,305	
Sand; water	13	2,318	Do.
Red sand	81	2,399	
Red shale	76	2,475	
Gravel	5	2,480	
Limy shale	18	2,498	
Gravel	22	2,520	
Red shale	55	2,575	
Red sand	85	2,660	
Red shale	30	2,690	
Broken sand	12	2,702	
Hard lime	5	2,707	
Sandy shale	63	2,770	
Red sandstone	30	2,800	
Red shale	40	2,840	
Pink shale	10	2,850	
Red sandstone	155	3,005	
Red shale	89	3,094	
Hard lime	7	3,101	
Sand	39	3,140	
Red sand; water	70	3,210	
Gray lime	2	3,212	
Red sand	35	3,247	
Gray lime	3	3,250	
Gray sand	4	3,254	
Gray lime	4	3,258	
Gray sand	15	3,273	
Sandy lime	14	3,287	
Red sandstone	243	3,530	
Red sand	10	3,540	Flow of water increased to 50,000 barrels in 24 hours.
Red sandstone	180	3,720	
Red sandy shale	14	3,734	Hole caving very badly.
Gypsum	4	3,738	
Red sandstone	29	3,767	Bottom of well. Shut down Nov. 4, 1929. Pulled 6¼-inch casing and reamed hole to 10 inches to 3,300 feet and drilled 8¼-inch hole to depth of 3,767 feet.

Log of Gila Oil Syndicate's well in the SW¼NE¼ sec. 30, T. 5 S., R. 24 E., near Ashurst

	Thickness	Depth	Remarks
	Feet	*Feet*	
Alluvium	50	50	Water.
Clay	380	430	
Sand	15	445	Flow of water.
White limestone	145	590	Salt water.
Limy shale	30	620	
Gray sand	80	700	Flow of water.
Limy shale	50	750	Salt water.
Blue shale	55	805	
Gravel	30	835	
Gray shale	200	1, 035	
Brown shale	80	1, 115	
Blue shale	20	1, 135	
Brown shale	15	1, 150	
Blue shale	15	1, 165	
Brown shale	35	1, 200	
Sandy shale	35	1, 235	
Blue shale	20	1, 255	
Brown shale	80	1, 335	
Red shale	60	1, 395	
Sandy shale	40	1, 435	
Brown shale	80	1, 515	
Brown sandstone	480	1, 995	Flow of water.
Gravel	10	2, 005	
Dark-brown shale	70	2, 075	
Black sand	10	2, 085	
Brown shale	125	2, 210	
Dark-brown sandstone	70	2, 280	
Gray shale	15	2, 295	
Red shale	110	2, 405	
Dark-brown sandstone	80	2, 485	
Limestone	80	2, 565	
Sandy limestone	30	2, 595	
Blue shale	50	2, 645	Bottom of well.

The following section of the flowing well at Geronimo, in sec. 19, T. 4 S., R. 23 E., drilled for oil with cable tools in 1918–19, is furnished from memory by the owner, R. S. Knowles:

Log of flowing well at Geronimo

	Thickness	Depth	Remarks
	Feet	*Feet*	
Clay	28	28	
Sand and clay	17	45	Fresh water at several horizons; cemented off.
Hard clay	43	88	A little water.
Gravel	2	90	
Hard clay and lime	405	495	Artesian flow of salt water.
Sand	30	525	
Shale, lime, and clay	270	795	
Gravel	15	810	Bottom of well; no water was struck below 495 feet.

SUMMARY OF TERTIARY AND QUATERNARY HISTORY

The Tertiary and Quaternary history of the Gila-San Simon trough may be summarized as follows:

An enclosed basin, surrounded by mountains and occupied by a lake, was formed during late Tertiary time, possibly by block faulting. Lacustrine and fluviatile sediments were laid down in the basin to a thickness believed to be 1,600 feet or more. A part at least, if not all, of these beds were laid down in late Pliocene time. The presence of

active volcanoes in the neighborhood during the existence of the lake is proved by the layers of tuff that occur in the lake beds, and possibly part of the great succession of lava flows exposed in the Gila Mountains was extruded during that time. The lake was then drained, exposing the lacustrine and fluviatile sediments to erosion. Gravel-capped piedmont erosion surfaces, of the pediment type, cut in these upper Pliocene beds, were formed, probably in Pleistocene time, on both sides of the valley. At the end of this stage, which is now represented by the upper terrace, the Gila River was several hundred feet above its present level. The Gila later cut down a few hundred ~~feet~~ and then paused while new erosion surfaces, now represented by the lower terrace, were developed on both sides of the valley. The river next excavated a trench about 200 feet below the lower terrace and widened the trench by lateral cutting. The river channel then rose gradually by aggradation, depositing silt, sand, and gravel to form the alluvial lowland plain. It has recently cut down through the alluvium and has deposited the sand, silt, and gravel of its present flood plain.

WATER RESOURCES

SUMMARY

The water available for use in the valley of the Gila River and San Simon Creek may be classified as shown below, according to its mode of occurrence and development for use:

- Ground water:
  - Springs.
  - Wells:
    - Flowing wells.
    - Nonflowing artesian wells.
    - Nonartesian wells.
- Water flowing perennially in the Gila River.
- Water of intermittent streams tributary to the Gila.

The water is used principally for domestic supplies, for watering stock, and for irrigation. Individual wells and springs differ in the amount and temperature of the water they yield, in the amount and chemical character of minerals in solution, and in the depth of the sand and gravel from which the water is obtained. Shallow wells are generally dug by hand. Wells more than 40 feet deep are usually drilled by power-driven machinery. The water of nonflowing wells is pumped to the surface by windmills, by gasoline engines, or by hand or is brought up in buckets attached to ropes. The water of springs, flowing wells, and intermittent streams is commonly stored in reservoirs for use as needed.

MUNICIPAL WATER SUPPLIES

The municipal water-supply system of Safford and Thatcher is owned and operated by the Arizona Edison Co. The water is obtained from Frye Creek, which is fed in part by springs and rain but chiefly by melting snow in the Graham Mountains. The company's plant consists essentially of several miles of pipe and two storage reservoirs on Frye Creek. The upper reservoir, at the mouth of Frye Canyon, in sec. 7, T. 8 S., R. 25 E., has a capacity of 70,000,000 gallons. The dam, of variable-radius arch design, is 91 feet high and is constructed of reinforced concrete. The lower reservoir, 3½ miles downstream, in sec. 34, T. 7 S., R. 25 E., has a capacity of 5,000,000 gallons. When this supply fails, as occasionally happens during periods of drought, water is pumped from a well in the NE¼SE¼ sec. 13, T. 7 S., R. 25 E., on the outskirts of Safford.

The water supplied to the residents of Pima is piped from several flowing wells that lie along Cottonwood Creek in sec. 8, T. 7 S., R. 24 E. The water is stored in a small concrete reservoir in sec. 25, T. 6 S., R. 24 E. The plant is owned and operated by the City Utility Co. of Pima.

The water supply at Eden is partly obtained from a community-owned spring (see p. 214) and a small concrete reservoir about a mile northeast of the settlement.

All other settlements in the valley, including Solomonsville, Fort Thomas, and Geronimo, are supplied with water from local pumped wells, most of which are owned by individuals.

SURFACE-WATER IRRIGATION

The cultivated lands along the Gila River (pl. 47, *B*) are irrigated with water diverted from the river into ditches through which it is conducted to the users by gravity. The irrigation system is owned jointly by the users. The river water is well suited for irrigation, especially as it carries a large amount of silt that is reported to be rich in fertilizing material.

The following table shows that the amount of water available in the Gila River for irrigation is variable from year to year. The table gives the annual discharge and run-off for the years 1915–32 as recorded at a station 8 miles northeast of Solomonsville, above all diversions in the valley except that of the Brown Canal, and for 1933 as recorded at a station 3 miles farther upstream, above the Brown Canal.

Discharge of Gila River 8 miles northeast of Solomonsville, 1915–31, and 11 miles northeast of Solomonsville, 1933

[From records of U. S. Geological Survey]

Year ending Sept. 30	Discharge (second-feet)			Run-off (acre-feet)
	Maximum daily	Minimum daily	Annual mean	
1915	31,000	80	2,216	1,560,000
1916	73,600	110	1,810	1,320,000
1917	46,000	89	825	598,000
1918	1,110	75	171	124,000
1919	7,380	69	691	500,000
1920	6,370	78	671	488,000
1921	9,540	60	407	294,000
1922	1,720	42	176	128,000
1923	6,260	29	448	325,000
1924	9,940	56	534	388,000
1925	15,400	48	313	226,000
1926	4,380	58	448	325,000
1927	5,320	44	395	286,000
1928	1,390	40	227	165,000
1929	4,820	32	320	232,000
1930	5,500	41	339	245,000
1931	7,990	55	452	328,000
1933	4,290	90	344	249,000

The maximum daily discharge during the period of 18 years was 73,600 second-feet on January 19, 1916; the minimum was about 29 second-feet on July 4, 1923.

The farming areas at Artesia, Cactus Flat, Ash Creek, and Cottonwood Creek, which include about 1,000 acres, are irrigated by water from flowing wells, supplemented by stream water from the Graham Mountains. Well water for irrigation is commonly stored in small reservoirs for use when needed, and several large reservoirs, not all of which were in use at the time of examination, have been constructed on Cottonwood, Ash, and Marijilda Creeks for catching and storing the flood waters that issue rather infrequently from the mountains. A reservoir in Jacobson Wash, in the NW¼ sec. 6, T. 9 S., R. 26 E., stores a small perennial flow that is diverted from the creek into a pipe line at a point about 2 miles upstream.

GROUND WATER

WELLS IN ALLUVIUM

The Quaternary alluvium underlying the lowland plain along the Gila River in Graham County everywhere contains water at no great depth below the surface. Water is commonly obtained in wells at depths of less than 25 feet, and usually two or more water-bearing beds are found at less than 100 feet below the surface. The beds that yield water are nearly horizontal, are composed of sand and gravel, and are commonly overlain and underlain by relatively impermeable thick layers of silt and clay. The sand and gravel beds are numerous but irregular, and any one bed pinches out laterally in all directions and generally underlies only a small area. Consequently, the vertical spacing of water-bearing layers varies and the number of them encountered in sinking wells differs from place to place.

The water in the alluvium is doubtless derived mainly by infiltration of rain water, irrigation water, Gila River water, and water added by tributaries of the Gila during floods. Possibly some water enters the alluvium locally by upward seepage from the underlying Pliocene lake beds. The water in the alluvium does not rise to the surface in wells but is reported to be under small artesian pressure at a few localities, especially in the neighborhood of Thatcher.

Quaternary alluvium underlying the relatively narrow flood plains of tributaries of the Gila River also yields water to pumped wells at many places, especially along Black Rock, Cottonwood, Ash, Marijilda, and Stockton Washes.

WELLS IN FANGLOMERATE PHASE OF THE GILA CONGLOMERATE

Very few wells have been put down in localities underlain by fanglomerate of the Gila conglomerate, which crops out in large areas along the sides of the valley, and the writer knows of only one such well in which water was struck. At the Pursley ranch, in sec. 12, T. 6 S., R. 26 E., the drill went through coarse fanglomerate and clay to a depth of 345 feet, where it encountered hot water that rose under artesian head about 200 feet, to a level about 145 feet below the surface. Near Big Spring Wash, in secs. 11 and 14, T. 5 S., R. 25 E., two unsuccessful wells were put down. One of these wells was drilled without reaching water through 375 feet of very coarse conglomerate followed by 40 feet of basalt and 100 feet of clay. It is probable, however, that in some areas underlain by the fanglomerate the water table lies within a few hundred feet of the surface. Otherwise it would be difficult, if not impossible, to explain the pressure head of the artesian water in the lake beds.

WELLS IN LAKE BEDS OF THE GILA CONGLOMERATE

The upper 1,600 feet of beds in the central part of the valley trough, consisting mainly of clay and silt, which are tentatively regarded as belonging to the lake beds, yield water from sandy beds at various depths. Nearly all the wells that obtain water from the lake beds have artesian flows or at least water under considerable artesian head. The number of water-bearing sands and the intervals between them differ from place to place. In some parts of the valley, as at Cactus Flat and Artesia and along Ash Creek, several water-bearing beds are separated by thicknesses of only a few hundred feet of clay and silt. In some other places wells drilled many hundred feet deep have failed to yield water. The 800-foot Rogers well, in sec. 13, T. 6 S., R. 24 E., yielded no water below the Quaternary alluvium in which it was started. In drilling at the 111 ranch no water was encountered above 720 feet.

The principal area of artesian wells in Graham County is in the west half of T. 8 S., R. 26 E., in the vicinity of the farming communities at Artesia and Cactus Flat. The western edge of this area is 1½ to 2½ miles east of the contact between the valley fill and the rocks exposed at the base of the Graham Mountains. Small areas of

artesian flow have been developed along Ash Creek in the east half of T. 7 S., R. 24 E.; along Cottonwood Creek in the west half of T. 7 S., R. 24 E.; and near Bear Springs in secs. 1 and 2, T. 7 S., R. 23 E. All flowing wells in these areas are within 4 miles of the base of the Graham Mountains. A few flowing wells have been obtained between these areas and at other places in the valley. Flowing wells in the San Simon Valley to the southeast, in Cochise County, Ariz., have been described by Schwennesen.[37]

The drilling of wells in the lake beds of Graham County began about 1900. Some adequately cased wells are reported to have flowed fairly uniformly for many years. Others that were not cased yielded copiously at first but later dwindled in flow, and many ceased flowing. Drillers have usually failed to keep logs, and the writer could measure the depths of but few drilled wells.

The discussion by Meinzer[38] of artesian conditions in the valley fill of Sulphur Spring Valley, Ariz., is believed to be applicable, with slight modification, to the late Tertiary fill in the valley of the Gila River and San Simon Creek. He writes:

> The sediments in Sulphur Spring Valley are saturated practically to the level of the lowest parts. New supplies of water are from time to time poured into the valley and sink into the gravelly upper parts of the stream-built slopes. The water beneath the slopes has accumulated till it stands above the level of the central flats and consequently moves slowly toward these low areas, where it reappears at the surface and evaporates. In the upper parts of the slopes the valley fill consists largely of gravel, but farther down in the valley the gravel gives way to alternating beds of clay and sand. Beneath the center of the valley these beds are nearly level, but beneath the slopes they curve upward. The gravel and sand are porous and therefore allow water to percolate through them, but the clay is so dense that it is relatively water-tight. The water which sinks into the gravel in the upper parts of the slopes and travels toward the central axis becomes confined below the layers of clay, and the water which accumulates back of it places it under pressure. This pressure may become so great that when the clay layers are punctured by the drill the confined water will escape to the surface, forming flowing wells. If the clay layers were perfectly impervious the head of water would probably be great enough to produce flows with strong pressure over considerable areas, but in fact they allow so much water to escape that flowing wells have been struck in only a few specially favorable localities, and in most of these the pressure is slight.

A detailed structural survey would probably show that the lake beds in the valley of the Gila River and San Simon Creek also curve gently upward toward the sides of the valley, although the strata appear horizontal at most places. The upward curving, however, may not be required to explain the artesian pressure under conditions believed to

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[37] Schwennesen, A. T., Ground water in San Simon Valley, Ariz. and N. Mex.: Geol. Survey Water-Supply Paper 425, pp. 12-14, 1917.

[38] Meinzer, O. E., Geology and water resources of Sulphur Spring Valley, Ariz.: Geol. Survey Water-Supply Paper 320, pp. 130, 131, 1913.

exist here, as illustrated in figure 30. The water beneath the highest terrace near the Graham Mountains evidently accumulates in the porous gravel and sand of the underlying fanglomeratic phase of the Gila conglomerate and stands at or below the level of the highest lake beds, which are composed largely of clay. Nearer the middle of the valley the upper part of the lake beds has been removed by erosion, and the land surface is lower than the level of the water table in the fanglomerate. Beds of sand, which lie almost horizontal, extend basinward from the fanglomerate into the dense lake beds underlying the lower lands. Most of the sand beds pinch out within 3 or 4 miles of the mountains. The water in these permeable sands is subject to the pressure of water standing at higher levels in the fanglomerate and is confined by relatively water-tight clays above and below and is also confined in a direction normal to the axis of the valley. In Graham County these conditions may account for the localization in a relatively narrow belt not far from the Graham Mountains of nearly all flowing wells that reach water in the lake beds.

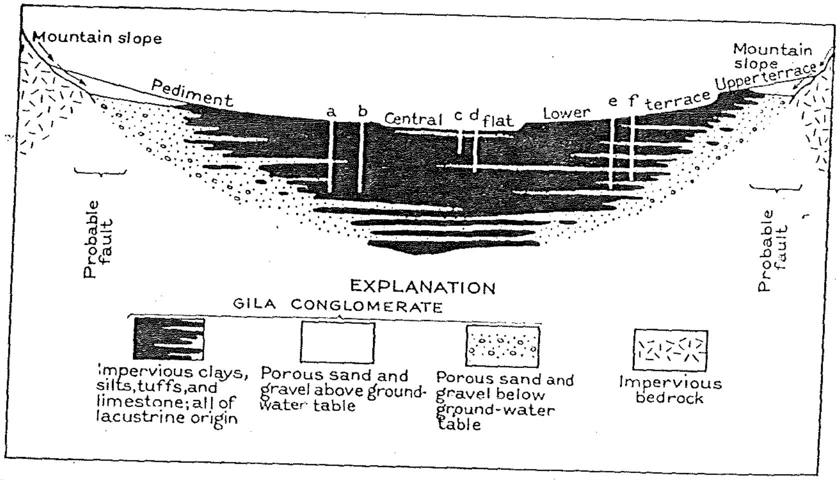

FIGURE 30.—Section showing artesian conditions in the lake beds of the valley of the Gila River and San Simon Creek. (See text for further explanation.)

The fanglomerate phase of the Gila conglomerate does not crop out between the 111 ranch and the mountains to the east, the sedimentary rocks locally exposed being dense Pliocene clay and diatomite, capped by a thin layer of Pleistocene (?) gravel. It is obvious, therefore, that this locality is not the intake area for the water-bearing sand at a depth of 720 feet tapped by the well at the 111 ranch, the water in which rises under pressure and stands at a depth of 70 feet below the surface. The water probably comes from areas farther up the valley or across the valley.

Under the conditions illustrated at *a*, in figure 30, the water table beneath the intake area near the edge of the valley, although higher than the mouth of the well, might be so low that the theoretical head represented by difference of altitude at the surface is less than the head lost underground in the intervening distance. The loss of head might be due to escape of water through the confining layers, which are not perfectly water-tight, and also to resistance to flow in the sand and gravel through which the water must pass before entering the well. The loss should increase with the distance from the intake area, and therefore the pressures at a given horizon might effect an artesian flow from a well near the intake area (*e*, fig. 30) but might fail to force

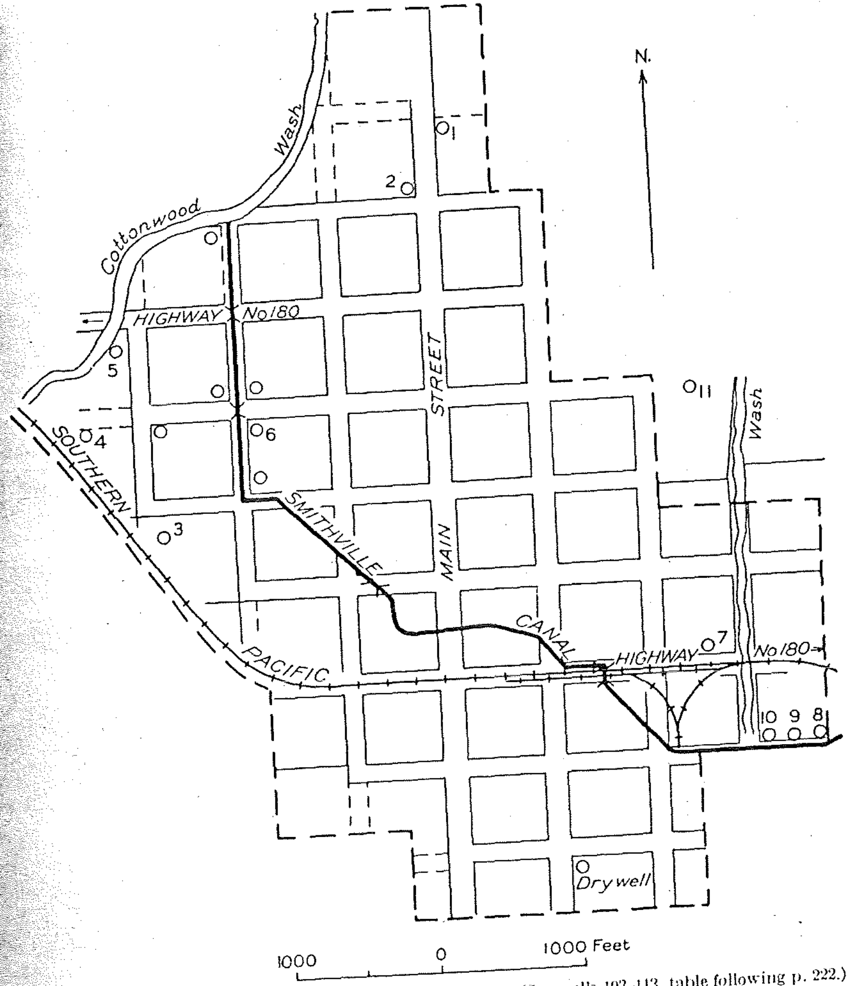

FIGURE 31.—Map of Pima, showing location of wells, 1934. (See wells 103-113, table following p. 222.)

water to the surface in a second well (*d*, fig. 30) having its mouth at or below the level of the first but farther from the intake area.

The favorable geologic conditions in the lake beds and the successful drilling for artesian water that has been carried on over a period of several decades warrant the belief that artesian water is present in nearly all parts of the Gila and San Simon Valleys that are underlain by these beds, at depths within easy reach of drilling equipment.

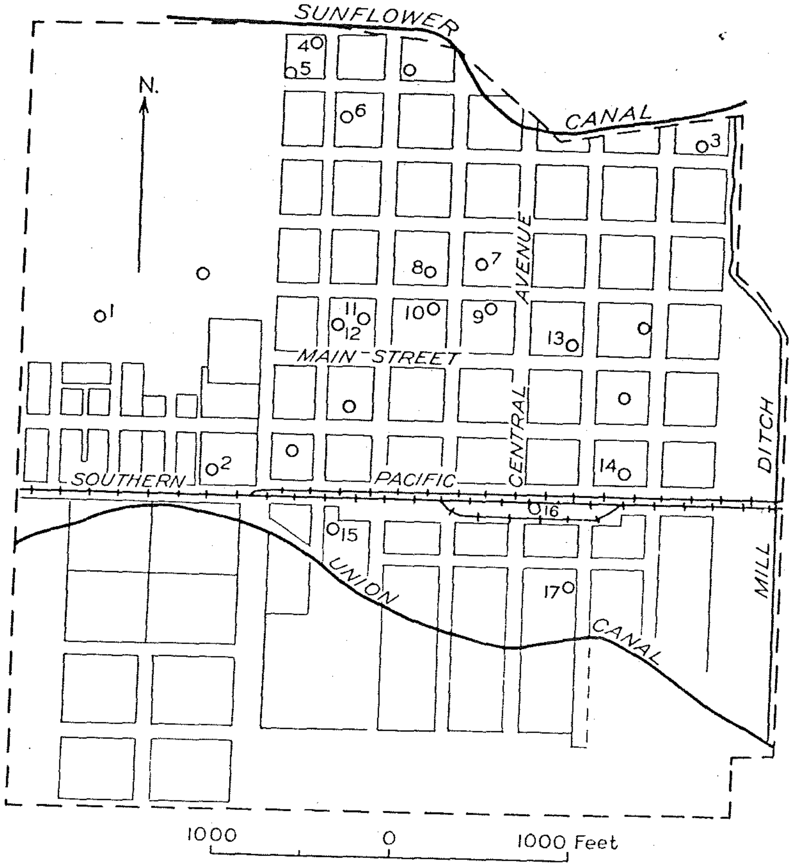

FIGURE 32.—Map of Safford, showing location of wells, 1934. (See wells 189–203, table following p. 222.)

WELLS IN THE DEEP SANDS

The deepest well in Graham County is the 3,767-foot Mack well, in sec. 13, T. 6 S., R. 24 E., near Pima. This well penetrated five water-bearing sands below 1,600 feet, the deepest one at 3,530 feet. The geologic age and structure of the deeply buried sediments containing these sand beds is not known, and no explanation of the occurrence of water in them is offered. It is possible that they are marine sediments and are much older than the lake beds.

A well that was abandoned before 1933 was drilled to a depth of 2,645 feet near Ashurst, in sec. 30, T. 5 S., R. 24 E., about 2¼ miles southwest of Indian Hot Springs. It is reported to have yielded strong artesian flows at depths of 430, 620, 1,515, 2,075, 2,210, and 2,405 feet below the surface. The water of the deeper flows was highly mineralized and hot. The relation of the hot water encountered in this well to that of Indian Hot Springs (pp. 216 and 217) is not known, but possibly the deep water-bearing beds are the same in both places. In February 1934 a well was being drilled by E. G. Rogers in the NE¼ sec. 5, T. 6 S., R. 24 E., in the expectation of striking artesian flows of hot water comparable with those obtained at Indian Hot Springs and the Mack well and formerly at the Ashurst well.

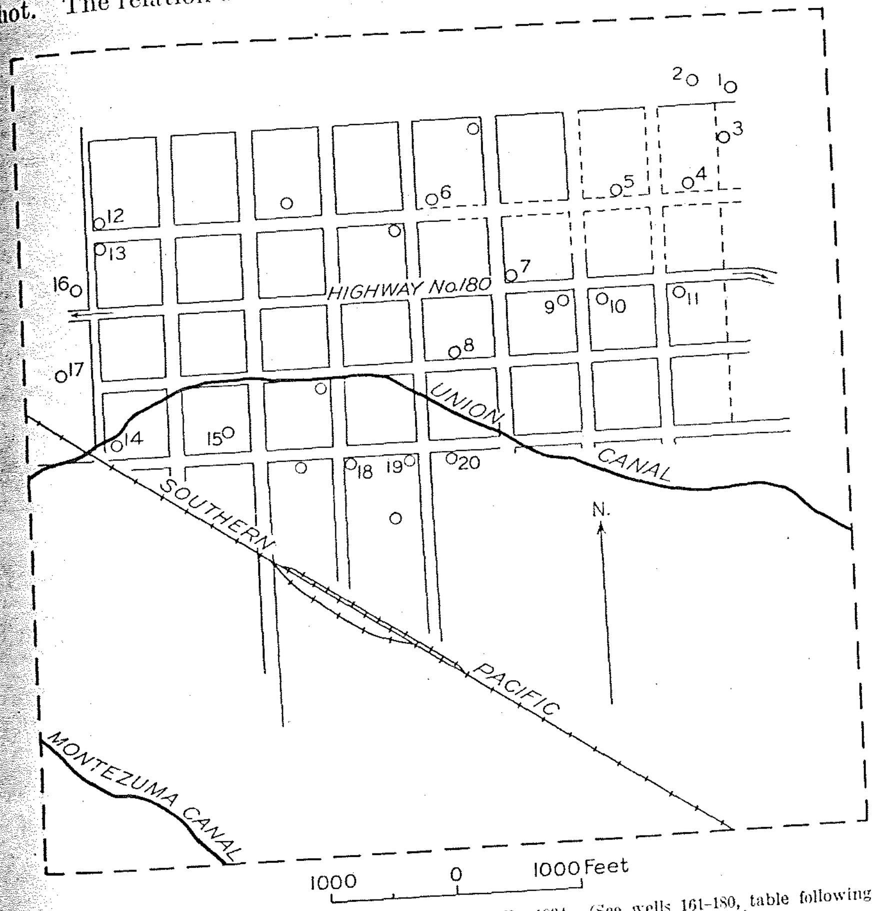

FIGURE 33.—Map of Thatcher, showing location of wells, 1934. (See wells 161–180, table following p. 222.)

The Southern Pacific Co.'s well at Safford, at the place where the elevated water tank stood in 1934, was drilled in 1906–7 to a depth of 1,820 feet. (See log, p. 202.) This well is reported to have flowed warm salt water for a short time. No record was kept of the temperature or of the depth at which the water stood in the well, and no chemical analysis of the water is available.

In the southeastern part of T. 10 S., R. 28 E., two flowing artesian wells, the Whitlock Nos. 1 and 2 of the Pinal Oil Co., were obtained in drilling unsuccessfully for oil. The Whitlock No. 1 well, shown in plate 53, *A*, was drilled in 1927–28. It yields a strong flow of soft, warm water (temperature 105° F.) from conglomerate at a depth of 1,445 feet, above which only clay and sand, probably lake beds, were encountered. A flow of sulphur water was struck at a depth of 1,750 feet. "Limerock" was encountered at a depth of 1,500 feet, and the well was drilled through this to a depth of 1,925 feet and finished in "sandy lime." When the well was completed the discharge was estimated by the drillers to be about 12,000 barrels (500,000 gallons) in 24 hours. The discharge is controlled by a valve at the casing head. The Pinal Oil Co.'s Whitlock No. 2 well, was drilled with cable tools to a depth of 1,555 feet. It discharges a "2-inch pipe full" of lukewarm water. The depths to the water sands in this well were not ascertained.

The location of wells in the towns of Pima, Thatcher, and Safford in 1934 is shown in figures 31, 32, and 33. The data collected by the writer on these and other wells in the valley are presented in the table at the end of this paper.

SPRINGS

The Goodwin Spring, in Goodwin Wash, sec. 35, T. 4 S., R. 22 E., near the east boundary of the San Carlos Indian Reservation, is a seepage from the alluvial gravel of the creek bottom. The discharge on January 10, 1934, was about 8 gallons a minute. This spring is reported to have yielded much more copiously some years ago.

Several springs, yielding less than 100 gallons a minute in total discharge, issue along the sloping terrace escarpment that rises about 100 feet above the alluvial lowland plain in secs. 21 and 22, T. 4 S., R. 23 E. The water seems to come from the base of porous Pleistocene (?) gravel, several feet thick, which caps about 90 feet of dense lacustrine clays of Pliocene age exposed on the hillside. The water is highly mineralized and is used only for watering stock.

A spring about 1 mile northeast of Fort Thomas, near the southwest corner of sec. 25, T. 4 S., R. 23 E., yields about 6 gallons a minute. The water issues from the base of Pleistocene (?) terrace gravel overlying dense clays of the Pliocene lake beds. The spring is used to water stock.

The residents of Eden, in secs. 28 and 33, T. 5 S., R. 24 E., normally obtain their water supply from a small spring of seasonally variable yield about 1 mile northeast of the settlement. The spring issues from a small excavation in the porous gravel bottom of a minor reentrant in the face of the lower terrace. The water is stored near the spring in a small concrete reservoir, from which it is piped by gravity to the settlement. The spring dries up during several months of each year, and drinking water is then hauled from the Rhodes well, about 5½ miles to the northwest. The water of nearer wells is regarded by local residents as poor in quality.

A small spring in sec. 5, T. 6 S., R. 25 E., about 1½ miles northeast of Bryce, flows from the base of porous conglomerate that caps impermeable Pliocene lake beds. The spring yields about 12 gallons a minute of water at a temperature of 68° F. and is used to water stock. (See analysis F, p. 222.)

At Bear Springs, in secs. 1 and 2, T. 7 S., R. 23 E., two springs yield water from sand in the Pliocene lake beds where these are dissected by the heads of small streams. The spring in sec. 1 yields about 2 gallons a minute but has not been used. The water has a temperature of 54° F. (See analysis G, p. 222.) The spring in sec. 2 yields about half a gallon a minute of rather salty water.

A spring yielding less than half a gallon a minute in Cottonwood Wash, in the SE¼ sec. 5, T. 7 S., R. 24 E., issues from the base of a thin layer of gravel capping Pliocene lake beds.

A spring on the Pace estate, in the SW¼ sec. 3, T. 7 S., R. 25 E., about a mile west of Thatcher, at the southern edge of the alluvial lowland, yields about 5 gallons a minute of rather alkaline water. The water of this spring probably issues from a sandy layer in the Pliocene lake beds.

A spring known as the Porter Spring, in the southeastern part of T. 7 S., R. 25 E., which yields less than a gallon of water a minute, probably issues from a sandy layer in the Pliocene lake beds. It is used for watering stock.

A spring in the NW¼ sec. 5, T. 7 S., R. 26 E., which yields less than half a gallon of water a minute, issues from the base of gravel capping the Pliocene lake beds, on the face of the lower terrace about 30 feet above the alluvial plain.

A small seepage of water in the bottom of Stockton Wash east of Cactus Flat, in T. 8 S., R. 26 E., issues from alluvium where formerly there was sufficient water to create a marsh covering many acres. This seepage was known as the Lower Cienaga, or Solomon Spring. The water was used for irrigation until the supply failed. The decrease in discharge is reported to have taken place shortly after the drilling of four flowing wells at Artesia in 1929–30, and the possibility is therefore suggested that the seepage rises from the artesian water sands underlying this part of the valley. The same explanation may be applicable to several small springs known as Cienaga Springs (pl. 52, *B*), in Jacobson Wash, in sec. 9 of the same township, and Mud Spring, in sec. 17. Several former "mud springs" in the vicinity of Cactus Flat and Artesia have become dry since artesian wells have been drilled. Abundant fragments of pottery near these springs give evidence that the aborigines camped in their neighborhood.

The health resort and hotel known as Indian Hot Springs (pl. 53, *B*),[39] in sec. 17, T. 5 S., R. 24 E., is at the base of the middle terrace, about 5 miles from the base of the Gila Mountains and 8 miles northwest of Pima. Within the grounds five springs and a flowing well (87 in table following p. 222) have a combined discharge of about 320 gallons a minute. Most of the water runs in ditches directly to the Gila River and makes a small contribution to the amount of water available for irrigation. A relatively small amount of water is used at the resort, where it is the supply for several Roman baths, a large swimming pool, and the hotel.

The springs and flowing well 87 are all within 300 feet of the hotel, in a small reentrant in the face of the middle terrace. The rocks near the surface are late Pliocene sedimentary beds of lacustrine origin. Their structure could not be determined directly, because of an obscuring mantle of gravel and soil, but faulting in them is suspected, as explained below.

Well 87 is about 600 feet deep and discharges 156 gallons a minute of water at a temperature of 119° F. Spring B yields 145 gallons of water a minute at 116°; spring D yields 10½ gallons at 116°; spring A, 6½ gallons at 118°; and spring C, three-fifths of a gallon at 81°. Spring E is a slow seepage of water at 107°.

Samples of water for analysis were collected from the well and from springs A, B, and C. The analyses (p. 222) show that all the samples contained a comparatively large amount of dissolved solids. The different mineral constituents were present in each sample in about the same amounts and proportions and in nearly the same amounts and proportions as in a sample of water collected from the deep Mack well 97, 7 miles to the southeast, near Pima. From the similarity in the chemical composition of the waters at Indian Hot Springs and the fact that the water of well 87 and the three springs that flow most copiously show a variation in temperature of only 2°, it may be inferred that all the water issues from the same horizon. The other springs, C and E, are cooler, and the water of the Mack well is 20° hotter.

The temperature of spring C is 35° lower than that of spring B, which is less than 20 feet distant. As these springs yield water of similar mineral content and are therefore probably supplied from the same source, the difference in their temperatures is probably due to the great difference in their rates of flow, the water from spring C being cooled to a temperature lower than that of spring B because it rises more slowly to the surface. This implies, of course, that all or a part of the ascent is made through independent openings. This

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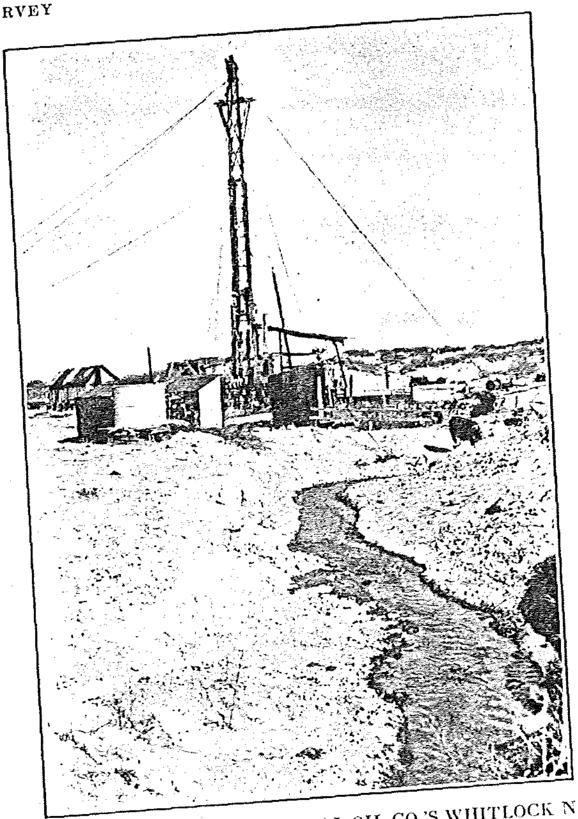
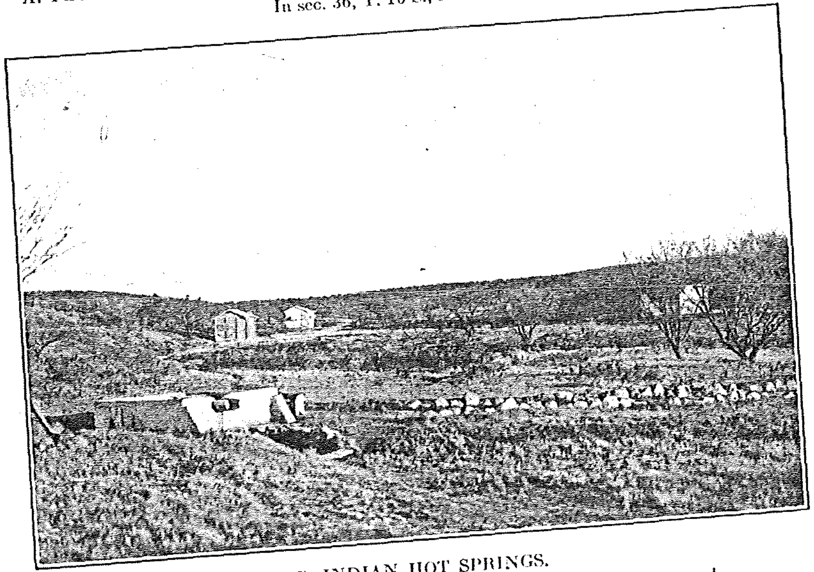
[39] Knechtel, M. M., Indian Hot Springs, Graham County, Ariz.: Washington Acad. Sci. Jour., vol. 25, no. 9, pp. 409-41[illegible] Sept. 15, 1935.



A. FLOW OF WARM WATER FROM PINAL OIL CO.'S WHITLOCK NO. 1 WELL.

In sec. 36, T. 10 S., R. 28 E.



B. INDIAN HOT SPRINGS.

Springs are in background; flowing well is at concrete tank in foreground.

explanation also applies to the temperature of spring E, which is 9° lower than that of spring B.

The temperature of the well water and the three principal springs at Indian Hot Springs averages about 117°. If it is assumed that the water rises from a depth of only 600 feet, the depth of the well, then local unusual thermal conditions must be invoked to explain the high temperature at this comparatively shallow depth below the surface. It is probable, however, that the water comes to the surface through fractures, perhaps caused by faulting, from an artesian source much deeper than 600 feet and that the well merely taps the upward-moving streams. If there were an increase of 1° in temperature for about each 57 feet of increase in depth, as suggested in the following paragraphs, the water would rise from a depth of about 2,500 feet.

DEPTH-TEMPERATURE RELATIONS

Most of the depths of wells, especially of the deeper wells, given in the table of well records (following p. 222), were reported to the writer from memory by various persons, some of whom had in turn acquired their information by hearsay. Most of the water temperatures are those observed by the writer at the mouths of flowing wells and probably are slightly lower than the temperatures of the water at depth. Some heat is lost by the water in its ascent to the surface, especially in wells that have only small flows, and as many of the wells are not cased the water issuing from a given well may come from several horizons at which the temperatures differ. In general, however, by far the greatest discharge is from the bottom of the well, and the cooling effect of water from higher levels is small.

A depth-temperature study of the field data on 78 wells was made by H. C. Spicer, of the Geological Survey, and his computations, which with one exception were based on wells ranging in depth from 100 to 1,450 feet, indicate a rise in temperature of 1° F. for each 57 feet of depth. The temperature of about 135° F. for a depth of 3,540 feet, as computed from this gradient, checks surprisingly well with the measured temperature, 138° F., of the water flowing from the mouth of the Mack well, in sec. 13, T. 6 S., R. 24 E., most of which comes from a horizon at that depth.

CHEMICAL CHARACTER OF THE GROUND WATER

By E. W. Lohr

The chemical character of ground water in the valley of the Gila River and San Simon Creek is indicated by partial analyses of samples from 5 springs and 44 wells. The analyses made by the Geological Survey indicate the suitability or unsuitability of water for industrial use, for irrigation, and for domestic use so far as such use is affected by the dissolved mineral matter. They do not show the sanitary condition of the waters examined.

The chemical constituents determined (see table of analyses, p. 222) are iron, calcium, magnesium, carbonate, bicarbonate, sulphate, chloride, fluoride, and nitrate. Sodium and potassium were calculated as sodium. The total hardness was calculated when both the calcium and magnesium were determined; otherwise it was determined by the soap method. Silica was not determined, and iron only when an amount in excess of 0.1 part per million was noted to be present. The silica present in the waters will probably average less than 20 parts per million, and the iron less than 0.1 part per million. The figure for total dissolved solids was obtained by summation of the mineral constituents, both calculated and determined, silica not being included. The usual methods of analysis [40] were used. The fluoride was determined colorimetrically.

The 49 samples examined are mainly sodium chloride, sodium carbonate, and sodium sulphate waters and are rather highly mineralized. There are only three calcium carbonate waters and a few that are of mixed type. Sodium is the chief basic constituent in 46 of the waters. Chloride is the main acid constituent in 32 of the samples, carbonate in 12, and sulphate in 5. The concentration of these three acid constituents is rather high in nearly all the waters.

The high mineralization of the ground waters is due chiefly to the aridity of the area and to the lacustrine origin of the geologic formations through which the waters largely percolate and from which most of them flow or are pumped. The rapid evaporation of the water from the surface causes a concentration of soluble salts in the top layers of the soil, and the water that percolates downward to become ground water is therefore more highly charged with mineral matter than percolating water in a humid area. Moreover, sediments which are deposited in lakes that do not overflow are commonly impregnated with soluble salts, and the lacustrine origin of the principal sedimentary deposits of the Gila and San Simon Valleys may therefore account for the rather highly mineralized waters of the region.

The quality of water that may be considered satisfactory for drinking and for domestic use depends on the locality and the individual. The limits adopted by the United States Treasury Department to govern the quality of water used for drinking on interstate carriers [41] have been widely used as general standards for domestic water supplies. The published standards indicate that the limits are not expected to be very rigidly enforced. It is common experience that many waters exceeding the limits in some respects have been used for long times without any apparent harmful effects. The limits suggested by the

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[40] Collins, W. D., Notes on practical water analysis: Geol. Survey Water-Supply Paper 596, pp. [illegible] 266, 1928. Foster, M. D., Colorimetric determination of fluoride in water, using ferric chloride: Ind. [illegible] Eng. Chemistry, anal. ed., vol. 5, pp. 234-236, 1933.

[41] Drinking-water standards; standards adopted by the Treasury Department June 20, 1925, for [illegible] and culinary water supplied by common carriers in interstate commerce: Public Health Repts., [illegible] 1029, April 10, 1925.

Treasury Department are total solids 1,000 parts per million, iron 0.3 part, magnesium 100 parts, sulphate 250 parts, and chloride 250 parts. Of the samples examined from the Gila and San Simon Valley only 25 were within the limits suggested by the Treasury Department, but several others were not far from the limits and are reported to have been used without injurious effects.

Water that is satisfactory for domestic use may be unsuitable for industrial use. For industrial use hardness is the most generally objectionable characteristic. Water with a hardness of 100 parts per million is neither satisfactory nor economical for use in laundries nor for use without treatment in steam boilers. Hardness is chiefly caused by salts of calcium and magnesium. These constituents, with silica and iron, make up practically all the scale found in steam boilers and cause much of the trouble encountered in steam-boiler plants.

The waters analyzed from the valley of the Gila River and San Simon Creek do not contain large quantities of calcium and magnesium or iron, and in this respect they would be satisfactory for most industrial purposes. About 60 percent of the waters have hardness less than 100; about 30 percent have hardness between 100 and 300; and the remainder have hardness greater than 300.

Although these waters do not contain scale-forming constituents in large quantities, most of them contain large amounts of sodium salts and would be likely to cause foaming in boilers. Some might even cause corrosion if used in boilers operated at high ratings.

The successful use of water for irrigation depends on a number of factors in addition to the composition of the water. Among these are the character of the soil, the amount of water used, rainfall, and drainage. Scofield [42] in 1933 suggested limits for certain characteristics of irrigation waters. In general, waters within the range specified in the lower set of limits are not likely to be harmful when used in ordinary irrigation. The upper limits, however, represent concentrations that are very likely to render the waters unfit for irrigation, either because of their effects on the plants or because of their effects on the soil. Concentrations between the upper and lower limits may not cause injury to crops and soil, depending on the composition of the water, the characteristics of the land, and the manner in which the water is used. The following table shows the suggested limits:

Suggested limits for safe and unsafe waters for irrigation

Constituents		Safe: Less than—	Unsafe: More than—
Total dissolved solids	parts per million	700	2,000
Sodium (Na)	percent	50	60
Sulphate (SO_4)	parts per million	192	480
Chloride (Cl)	do	142	355

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[42] Scofield, C. S., Quality of irrigation waters: California Dept. Public Works, Div. Water Resources,

The percentage of sodium is obtained by dividing 100 times the figure for sodium by the sum of the milligram equivalents of calcium, magnesium, and sodium:

$$\frac{Na \times 100}{Ca+Mg+Na}=\text{percent Na}$$

With these limits as a standard for classification, about one-third of the waters analyzed from the valley of the Gila River and San Simon Creek would be classed as safe for irrigation, one-third as not determinable from the factors in the table, and the remaining third as unsafe.

The presence of fluoride in natural waters has been known for some time, but the relation of the occurrence of fluoride in water to the dental defect known as mottled enamel has only recently been generally recognized. Residents of the Gila and San Simon Valley, especially natives, are commonly afflicted with this dental defect, which is thus described by Smith and Smith:[43]

> There are certain sections in Arizona and many parts of the world where every native-born inhabitant has the peculiar defect of permanent teeth known as mottled enamel. Mottled enamel is frequently referred to as "brown stain", or simply "stained teeth", but the staining is a secondary phenomenon and should not be confused with the defect itself. The most outstanding characteristic of mottled enamel is its dull, chalky-white appearance. Sometimes the whole tooth has lost its translucency and presents an unglazed appearance, but in milder cases paper-white areas are distributed more or less irregularly over the surface of the tooth. The enamel may or may not stain later, the color of the stain varying from almost black through orange-red to yellow, hence the name "brown stain." Usually all of the teeth, though they may be mottled, are not stained the stain being more pronounced on the upper central incisors. The general tendency is for the stain to follow the lip line, and this fact suggests that exposure to air and light may be a factor in its production. In severe cases of mottled enamel, the enamel is so defective that it is badly pitted and corroded and the teeth are structurally weak, the enamel tending to chip off. Mottled teeth, though perhaps no more subject to decay than normal teeth, do not hold fillings well and deteriorate more rapidly. False teeth among young adults in a community in which mottled enamel occurs are not uncommon. Mottled enamel is primarily a defect of the second or permanent set of teeth, for only rarely have cases of mottled enamel of the temporary or deciduous teeth been observed.

As to the toxic concentration of fluorine in drinking water, Smith[44] has stated:

> No Arizona water has yet been found containing as much as 1.0 part per million of fluorine which has not been demonstrated to cause mottled enamel, and no water with a fluorine content less than 0.8 part per million has been found to be associated with mottled enamel.

The presence of toxic quantities of fluorides in waters in Graham County appears to be associated with a high content of sodium salts and with soft water rather than hard.

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[43] Smith, H. V., and Smith, M. C., Mottled enamel in Arizona and its correlation with the concentration of fluorides in water supplies: Arizona Univ., College Agr., Tech. Bull. 43, p. 284, 1932.

[44] Smith, H. V., Determination of fluorine in drinking water; comparison of [illegible] lishment of toxic concentration by these methods [illegible]

The fluoride content of the waters analyzed from the valley of the Gila River and San Simon Creek ranged from 0 to 15 parts per million. Only 2 samples gave no test for fluoride, 9 had 1 part per million or less, and 20 samples had more than 5 parts. In the samples that were examined the smallest quantities of fluoride generally were found in water from wells less than 200 feet deep, and the largest quantities were found in water from wells more than 800 feet deep.

There is at present no cheap and efficient method known for removing fluoride from water for domestic use.

It seems obvious that drinking-water supplies that will be used by young children should be taken only from wells whose analyses indicate very small amounts of fluoride. Probably in most neighborhoods at least one convenient well supply will meet this requirement.

ANALYSES AND WELL RECORDS

The accompanying tables present data that were collected concerning 435 wells in the area examined. Analyses of some of the waters are given in the one on page 222.

Analyses of water from wells and springs in the valley of the Gila River and Sa Simon Creek, Graham County, Ariz.

[Parts per million. Numbers correspond to well numbers in following table. Letters A, B, C, F, and G refer to springs described on pp. 214-217. E. W. Lohr, analyst]

No.	Date of collection	Total dissolved solids (calculated)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K) (calculated)	Bicarbonate (HCO$_3$)	Sulphate (SO$_4$)	Chloride (Cl)	Fluoride (F)	Nitrate (NO$_3$)	Total hardness as CaCO$_3$ (calculated)
2	Nov. 22, 1933	531	47	12	140	244	80	130	2.0	0.0	[illegible]
3	Nov. 23, 1933	296	33	6.5	71	152	50	59	1.2	.70	109
16	Nov. 22, 1933	14,035	133	85	5,076	492	1,838	6,656	4.5	--------	682
59	Nov. 23, 1933	[1] 192	42	12	11	144	50	6.0	.2	.0	154
73	Apr, 7, 1934	136	28	5.1	15	100	[2] 34	4.0	.4	.50	91
87	Nov. 20, 1933	2,568	78	10	878	106	357	1,190	3.3	.0	236
A	do	2,996	78	9.0	1,043	98	404	1,410	3.7	.0	232
B	do	3,016	80	9.4	1,048	100	405	1,420	4.1	.0	239
C	do	3,455	102	12	1,182	114	518	1,580	4.3	.50	304
97	Nov. 30, 1933	3,351	73	7.2	1,190	96	419	1,610	4.9	.0	212
F	Feb. 9, 1934	1,715	62	27	540	178	319	675	3.3	1.2	266
G	Nov. 9, 1933	228	44	7.2	38	240	[2] 10	10	.8	.20	[illegible]
130	do	500	39	5.0	142	124	84	168	.0	.50	118
131	do	1,124	97	9.2	305	102	211	450	1.6	.0	280
132	do	411	[2] 2	--------	167	163	77	96	7.1	.20	([3] [4])
135	do	1,282	90	8.5	369	112	269	490	.0	.0	260
143	Dec. 27, 1933	217	[2] 1	--------	87	[5] 91	[2] 50	38	5.0	.10	([3] [4])
154	Feb. 16, 1934	2,880	[2] 36	--------	1,085	60	564	1,265	7.1	.50	[4] [illegible]
155	do	2,352	[2] 26	--------	891	66	521	970	7.3	.50	[4] 48
182	July 23, 1934	1,672	158	51	388	507	325	480	.2	20	604
189	Apr. 11, 1934	1,045	129	26	231	446	115	305	.8	18	429
190	July 21, 1934	1,133	141	27	252	513	121	315	.6	24	463
224	Apr. 3, 1934	1,081	77	23	305	486	158	260	3.3	15	287
225	do	1,080	78	25	301	486	150	265	3.2	18	298
245	Dec. 19, 1933	941	[2] 11	--------	358	276	270	195	9.3	.70	[4] 28
246	do	1,166	60	17	367	526	192	260	5.8	4.7	220
253	Jan. 22, 1934	1,873	201	62	387	484	437	500	1.6	46	757
257	Feb. 13, 1934	1,881	[2] 10	--------	738	220	262	830	1.2	.50	[4] 22
258	do	[6] 771	[2] 17	--------	286	218	211	181	1.6	.50	[4] 36
271	Nov. 17, 1933	718	[2] 5	--------	280	[7] 65	164	251	15	.0	[4] 8
273	do	1,488	40	2.2	509	48	349	550	14	.0	109
278	Nov. 18, 1933	807	[2] 10	--------	313	460	180	87	5.3	15	[4] 32
285	Nov. 16, 1933	1,682	[2] 2	--------	658	243	370	590	7.8	1.0	[4] 8
286	do	857	[2] 7	--------	332	176	193	268	5.3	.0	[4] 16
295	do	1,479	30	2.2	512	46	389	510	13	.0	84
296	do	536	[2] 5	--------	209	122	134	143	8.7	.10	[4] 9
305	Nov. 15, 1933	577	[2] 5	--------	221	116	136	173	6.1	.0	[4] 16
308	Nov. 18, 1933	944	[2] 10	--------	361	60	223	345	14	.0	[4] 20
309	Nov. 17, 1933	708	[2] 6	--------	275	[7] 85	172	230	13	.10	[4] 9
314	Nov. 16, 1933	1,977	[2] 28	--------	725	[8] 66	512	740	10	.0	[4] 81
320	do	1,308	[2] 22	--------	489	56	333	480	13	.0	[4] 40
328	Nov. 18, 1933	651	[2] 10	--------	231	170	211	125	6.1	.90	[4] 50
332	Nov. 17, 1933	225	[2] 7	--------	88	122	[1] 30	45	4.4	.10	[4] 14
356	Nov. 18, 1933	163	[2] 16	--------	42	130	[2] 20	16	.4	.0	[4] 60
358	Nov. 17, 1933	786	[2] 6	--------	310	96	176	280	10	.0	[4] 10
392	Feb. 2, 1934	[9] 639	[2] 18	--------	239	152	174	150	13	.75	[4] 33
409	Nov. 13, 1933	549	[2] 33	--------	167	128	171	124	1.2	1.1	[4] 90
430	Nov. 7, 1933	1,024	[2] 8	--------	389	205	347	215	11	.0	[4] 16
432	do	940	[2] 6	--------	359	186	319	197	12	.0	[4] 14

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[1] Iron (Fe) 0.65 part per million.
[2] By turbidity.
[3] Less than 5 parts per million.
[4] Determined.
[5] Includes equivalent of 30 parts of carbonate (CO$_3$).
[6] Includes 0.8 part of borate (BO$_3$).
[7] Includes equivalent of 18 parts of carbonate (CO$_3$).
[8] Includes equivalent of 12 parts of carbonate (CO$_3$).
[9] Includes 1.4 parts of borate (BO$_3$).

Following this article there
several "Records of Wells" whic
to position in book and age o
paper, wouldn't xerox well. The
may be found following page 2
in USGS, WSP, 796-F (1936

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