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UNITED STATES DEPARTMENT OF THE INTERIOR

GROUND-WATER RESOURCES OF THE HOLBROOK REGION, ARIZ.

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 836-B

UNITED STATES DEPARTMENT OF THE INTERIOR
Harold L. Ickes, Secretary
GEOLOGICAL SURVEY
W. C. Mendenhall, Director

Water-Supply Paper 836-B

GROUND-WATER RESOURCES OF THE HOLBROOK REGION ARIZONA

BY
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Contributions to the hydrology of the United States, 1938
(Pages 19-105)

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1939

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GROUND-WATER RESOURCES OF THE HOLBROOK REGION, ARIZONA

By Marshall A. Harrell and Edwin B. Eckel

ABSTRACT

The Holbrook region, as described in this report, occupies a portion of the Colorado Plateau of northeastern Arizona and is roughly bounded by meridians 109° and 111° west and parallels 34° and 35°30′ north. It includes most of the drainage area of the Little Colorado River in Arizona, exclusive of the Navajo country.

Semiarid conditions prevail except in the mountainous areas to the south. Dry farming has been unsuccessful; irrigation is practiced to a very slight extent, its chief restrictions being the lack of water of proper quality and quantity. Cattle and sheep grazing have been conducted successfully and are the chief industries. Sufficient well-water supplies may be developed for present herds, but the region as a whole seems not adapted to further expansion of the grazing industry under present conditions of vegetative cover and its use. Mineral and other resources appear to be meager. There is some timber. The Petrified Forest, Painted Desert, and Crater Mound are natural features that attract visitors, and the White Mountain country has become a summer resort area.

The sedimentary rocks exposed within the region range from the Supai formation, of Permian age, to Recent gravel. Extrusive lava flows and cinder beds of Tertiary or Quaternary age mantle large tracts in the southeastern and western parts of the region. A great number of small dikes and plugs of intrusive igneous rock occur in the north-central part, and others are probably present beneath the lava flows, but they have little effect on the occurrence of ground water.

The principal aquifers of the region are the Coconino sandstone, the lava flows, and the Recent sand and gravel deposits along major streams. The Coconino sandstone yields abundant supplies of fresh water to many wells in the western and central parts of the region. Salt water is reported to occur in the Coconino at Winslow and at the Petrified Forest National Monument, although there appears to be doubt as to its source.

The contact of the extrusive igneous rocks with underlying impervious sedimentary beds is an important spring horizon, and a few wells obtain water at the same horizon. Many wells are situated in the alluvial flats along most of the major streams. The water obtained from these wells is not of good quality but is usable. A large number of wells and springs in Apache County obtain relatively small but useful supplies of water at the contact of unconsolidated Tertiary sands with underlying Chinle or Cretaceous formations. Warm springs, which yield large quantities of highly mineralized water, issue from deposits of travertine along the Little Colorado River near Hunt and south of St. Johns.

The rocks of the Holbrook region dip in general toward the north and northeast, away from the high mountainous area on the south. Local folds interrupt the gentle regional dip, and a few faults are present. Some of the folds, such as the Holbrook dome, are important factors in causing artesian conditions in certain areas where other factors are favorable. Details of the structure are only imper-

fectly known, and it is difficult to predict the presence or absence of artesian conditions in advance of drilling.

Local structural features associated with the Holbrook dome are among the more interesting geologic phenomena of the region. They include open tension cracks near the crest of the anticline, tepeelike ridges due to compression in synclinal areas, and numerous sinks, whose origin is here tentatively ascribed to block faulting rather than to solution of underlying beds.

Samples of water from 118 wells and springs were analyzed in the laboratory of the Geological Survey. The results of the analyses, which are included in this report, show that the total dissolved solids in the waters range from 80 to 6,197 parts per million. Waters from Recent alluvial materials, the Moenkopi formation, and the Chinle formation are commonly high in dissolved mineral matter. The best waters come in large part from the base of the lava flows or of the Tertiary sands and from the Coconino sandstone.

Data on nearly all the springs and wells in the region are presented in the text, in tables, and on maps, and suggestions relative to future water supply developments are included.

Winslow, which contains about 15 percent of the inhabitants of the region, obtains water for domestic use from a reservoir on Clear Creek. Joseph City, Snowflake, Taylor, St. Johns, and Hunt use impounded surface waters for irrigation. Domestic and public supplies of water for these and other towns are obtained in large part from wells or springs. The Atchison, Topeka & Santa Fe Railway uses ground water from wells except at Winslow, where impounded surface waters are used.

INTRODUCTION

Location and extent of the region.—The region described in this report is a part of the Colorado Plateau. It covers about 10,000 square miles and includes portions of Coconino, Navajo, and Apache Counties. (See fig. 3.) As nearly as could be estimated from the 1930 census report, it has a population of about 27,000.

Field work.—In the late summer of 1933 the Public Works Administration allotted funds to the Geological Survey of the United States Department of the Interior, for investigation of the ground-water resources of the Colorado Plateau region. The present report is one of a series of reports resulting from these investigations. The field work on which this report is based was begun on November 1, 1933, and completed on March 1, 1934. Fortunately the winter of 1933–34 was exceedingly mild, and no loss of time was caused by inclement weather.

Information was obtained from well owners, drillers, and other responsible persons in regard to many wells and springs throughout the region. Every effort was made to obtain all available information on each well, but as many of the wells are isolated it was difficult to locate them correctly or to obtain their complete histories. Windmills are conspicuous landmarks in this sparsely settled region, however, and many of them can be seen for miles. By taking careful notes and making inquiries of land owners it was generally possible to locate the wells at least approximately. Data relative to the depths of the wells, the depths to water levels in the wells, and the yields of the wells, as here presented, are for the most part those given from memory by informants, although a few written records were obtained. Many statements as to yield of water from wells were

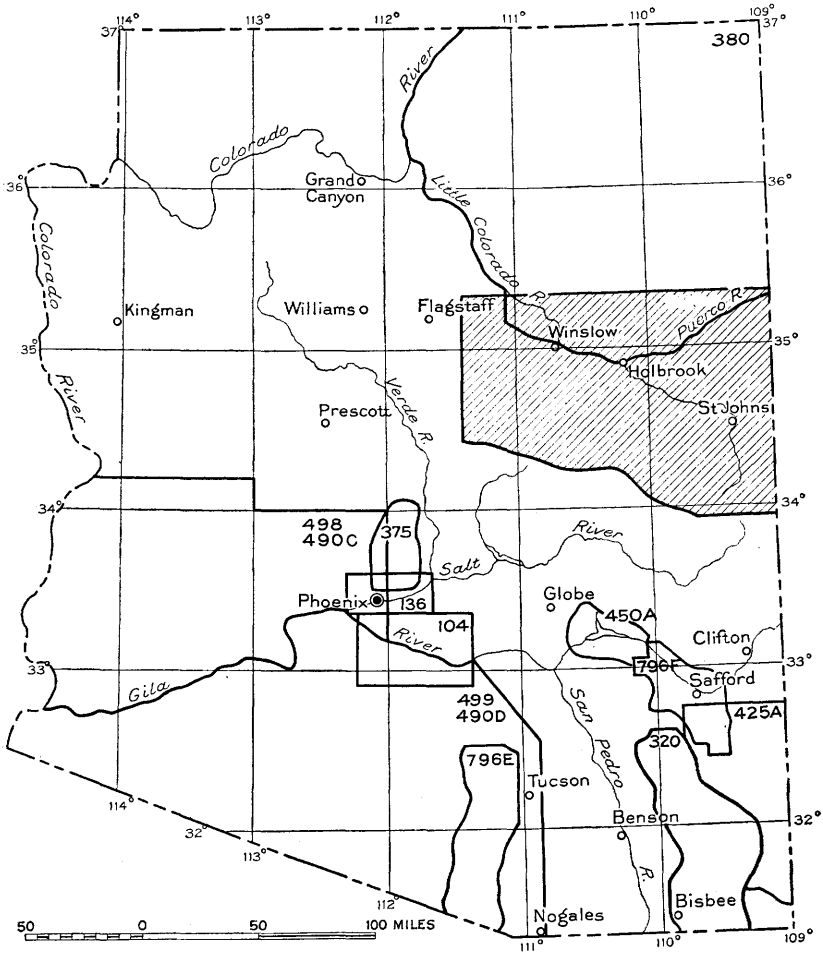

FIGURE 3.—Index map of Arizona showing areas considered in this report (shaded area) and other water-supply papers of the Geological Survey (indicated by numbers).

vague or otherwise unsatisfactory. For instance, the information was frequently given that a well supplied sufficient water for a "band of sheep" or "enough for the cattle in the winter time." At many wells no pumping test could be made, because the pump was out of commission, there was not enough wind to operate the windmill, or there was some physical barrier, such as an outlet into a closed tank.

Samples of water were collected from 118 wells and springs. An effort was made to have these samples representative of the different aquifers and of types of water supply. The samples were analyzed in the laboratory of the Geological Survey in Washington, D. C., and the results are tabulated on pages 88–90.

Geologic and hydrologic maps.—The surface geology of the region covered by this report is shown on plate 2. Except for certain minor changes in details of extent of formations, this map is taken from the geologic map of Arizona, edition of 1924, prepared by the Arizona Bureau of Mines in cooperation with the Federal Geological Survey. The chief modifications given on the present map consist of more accurate boundaries for the Tertiary sands, extension of the Moenkopi formation up the Little Colorado River to St. Johns, and elimination of the Shinarump conglomerate from the Petrified Forest National Monument area.

The location of the wells described in the text and listed in the tables is shown on plate 3. The wells are numbered consecutively. Wells in Coconino County are numbered from 1 to 28 and 393, 394, 432, and 438, those in Navajo County from 30 to 127, and those in Apache County from 130 to 313. In each county the township subdivisions are arranged from west to east as in following the lines of the printed page. Within the townships the United States land-survey system of numbering sections has been followed in arranging the tables. Efforts were made to locate wells by quarter sections, but those whose exact locations are unknown are plotted in the centers of the sections on the map.

Three county maps were generously made available by the county officials—the 1931 revision of the map of Coconino County, by J. B. Wright, county engineer, which is on the scale of 1 inch to 4 miles; the map of Navajo County, made by K. L. Hudson in 1931, scale 1 inch to 4 miles; and the map of Apache County, made in 1918, scale 1 inch to 2 miles. The county maps show sections and townships and, with the maps of the Apache, Coconino, and Sitgreaves National Forests and the geologic and topographic maps of the State of Arizona, helped greatly in obtaining accuracy in field mapping. Many revisions were required in the alinement of the roads as shown on the county maps, but the drainage and natural features were found to be in general approximately correct. In Coconino and Navajo Counties section markers established by the General Land Office were useful in locating wells and other features accurately on field maps.

Acknowledgments.—A helpful spirit of cooperation was shown by the citizens of the area covered, and grateful acknowledgment is made of their efforts. In particular, the assistance of the following individuals and units is appreciated: J. B. Wright and Herbert Babbitt, of Flagstaff; officials of Navajo, Apache, and Coconino Counties; the superintendents of the Coconino, Sitgreaves, and Apache National Forests; the officials of the National Park Service, the Office of Indian Affairs, and the Atchison, Topeka & Santa Fe Railway. Much valuable information was given by the late Arthur Saunders, of Holbrook; A. B. Randall and Frank Richards, of Joseph City; Wayne Thornburg, of Phoenix; Robert Grantham, of Winslow; Jacob Barth, J. M. Shepherd, Graham Cowley, Judge Levi Udall, and Grover Udall, of St. Johns; Ray F. Durfee, of Holbrook; Burr Porter, of Navajo; Glenn Jacobs, of Concho; Spencer Balcomb, of Sanders; and the Beckers, of Springerville. Information was also given freely by the officials of the Lyman Irrigation Co., the Joseph City Irrigation Co., and the Zion Reservoir Irrigation Co. The University of Arizona supplied some of the data incorporated in this report.

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GEOGRAPHY

CLIMATE

General conditions.—Climatic data have been collected in the Holbrook region and adjacent areas for many years. The reports of scientific expeditions and railroad surveys made some 80 years ago contain miscellaneous observations. The War Department obtained records at military posts, none of which however, were located within the Holbrook region. The United States Weather Bureau has obtained records at Holbrook since 1886, at Winslow since 1888, at St. Johns since 1889, and at Springerville since 1890.

The climate of the Holbrook region is arid or semiarid. Because of a range in altitude from about 4,850 feet at Winslow to 9,843 feet on Greens Peak, in southern Apache County, there is considerable variation in climate from place to place within the region. The general effect of altitude is locally modified by secondary topographic features. Even local effects of shaded or sunny areas make considerable differences in the weather. The percentage of sunshine is very high, especially during April, May, June, and October. During the summer thunderstorms occur frequently, especially on the plateaus above the 4,500-foot level. The 6,000-foot level receives snows in winter that range from 6 inches to 2 feet in depth; above the 8,500-foot level the snow often remains from December until June. The heat of summer and the cold of winter are tempered by the dryness of the air.

The mean annual temperature ranges from about 47° F. at Heber to about 55° F. at Winslow. Recorded extremes of temperature within the whole region are 108° F. and −28° F. The following table summarizes the temperature records of the United States Weather Bureau in or near the Holbrook area.

Summary of temperature records of United States Weather Bureau to 1930 for stations in or near the Holbrook region

Station	Altitude (feet)	Years of record	Temperature (°F.)		
			Average	Highest	Lowest
Greer	8,500	7	44.0	86	−16
Lakeside	7,054	15	47.2	105	−23
Flagstaff	6,907	34	45.5	99	−25
Springerville	6,862	17	48.0	96	−28
Pinedale	6,500	14	48.7	97	−26
Heber	6,484	9	47.1	97	−28
Pinto	5,660	6	51.9	108	−24
St. Johns	5,650	23	52.2	104	−22
Snowflake	5,644	23	51.4	102	−24
Holbrook	5,069	40	54.5	106	−21
Winslow	4,848	22	55.0	107	−19
Leupp	4,150	9	53.3	105	−12

Precipitation.—The following table is a summary of data on precipitation at stations of the United States Weather Bureau in or near the Holbrook region:

Average monthly and annual precipitation and annual snowfall, in inches, at stations in or near the Holbrook region, arranged in the order of altitude

[From records of the U. S. Weather Bureau]

Station	Altitude (feet)	Years of record	January	February	March	April	May	June
Greer	8,500	18						
Lakeside	7,054	18	1.99	1.97	1.98	1.37	0.61	0.56
Flagstaff	6,907	43	2.49	2.06	2.36	1.30	1.00	.45
Springerville	6,862	22	.50	.53	.49	.46	.46	.57
Bly Ranger Station	6,800	15	2.31	1.67	2.03	1.81	.53	.52
Pinedale	6,500	18	1.49	1.57	1.52	1.21	.55	.78
Heber	6,484	15	1.77	1.48	1.23	1.17	.59	.65
Showlow	6,300	29	1.78	1.38	1.81	.79	.49	.46
Pinto	5,660	19	.91	.94	.77	.70	.29	.51
St. Johns	5,650	31	.67	.57	.78	.53	.42	.45
Snowflake	5,644	31	.69	.84	.85	.68	.45	.62
Holbrook	5,069	42	.62	.61	.60	.54	.27	.40
Winslow	4,848	30	.56	.40	.47	.46	.26	.36
Leupp	4,150	12	.53	.42	.29	.70	.19	.24

Station	July	August	September	October	November	December	Annual	Annual snowfall[1]
Greer							22.2	86.2
Lakeside	4.36	2.98	1.72	1.78	1.39	1.73	22.44	61.0
Flagstaff	3.12	2.69	1.63	1.37	1.40	2.05	21.92	78.4
Springerville	3.23	2.84	1.33	.78	.62	.66	12.47	22.8
Bly Ranger Station	2.89	2.73	1.99	1.51	1.55	2.85	22.39	80.5
Pinedale	3.64	2.68	1.64	1.59	1.48	1.84	19.99	50.7
Heber	3.63	2.91	1.84	1.17	1.12	1.38	18.94	45.1
Showlow	2.47	2.38	1.73	1.23	1.41	1.71	17.64	45.4
Pinto	2.11	1.78	.91	1.09	.83	.99	11.83	27.2
St. Johns	2.27	2.23	1.30	.66	.56	.75	11.19	22.9
Snowflake	2.39	2.57	1.35	.89	.61	.68	12.62	21.8
Holbrook	1.85	1.42	.94	.69	.72	.59	9.25	13.5
Winslow	1.62	1.71	.78	.52	.52	.93	8.60	13.0
Leupp	1.28	1.14	.79	.57	.35	.57	7.07	8.2

[1] As unmelted snow.

As shown in the table, the heaviest precipitation occurs in the summer, and the driest season is the spring. The table also shows that in general the precipitation increases with the altitude. Thus, all stations at altitudes of more than 6,500 feet, except Springerville, receive an average of more than 20 inches of precipitation a year, whereas all stations at lower altitudes receive less than 20 inches, and the three stations at altitudes of less than 5,500 feet receive less than 10 inches. The location of Springerville, on the leeward side of a high mountainous area, is apparently the cause of its relatively low precipitation. It is clear, however, that in other parts of the region the altitude is not the only factor, and that physiographic position is an influential factor in causing rainfall from storm clouds that come from the southeast. Considerable variation in the precipitation occurs from year to year. Thus, at Holbrook, which has the longest record of all the stations within the region, the recorded annual precipitation ranged from 3.4 inches in 1922 to 17.63 inches in 1905.

The precipitation in the Holbrook region is generally insufficient for agriculture and inadequate in many respects for grazing. The average growing season at Holbrook is from May 4 to October 16, a total of 165 days. The first 2 months of the growing season are very deficient in rainfall, but the relatively heavy rainfall later in the season is favorable for producing grass on the range. The annual distribution of the precipitation is not favorable for replenishment of the water supplies for springs and wells, because the water derived from the summer rains is largely lost on account of rapid surface runoff, which is characteristic of the region, or returned to the atmosphere by evaporation from the soil and transpiration of the plants.

VEGETATION

The principal vegetative groups in the Holbrook region as described by Shantz and Zon,[1] consist of sagebrush (northern desert shrub), short grass (plains grassland), piñon-juniper association (southwest coniferous woodland), and yellow pine-Douglas fir (forest) association.

The sagebrush (northern desert shrub) types of vegetation grow mainly in the Little Colorado River Valley. The principal associations are sagebrush, shadscale, and salt sage. The individual species of sagebrush are small sage (*Artemisia mova*), scabland sage (*Artemisia rigida*), little rabbitbrush (*Chrysothamnus stenophyllus*), bitterbrush (*Purshia tridentata*), big rabbitbrush (*Chrysothamnus nauseosus*), coleogyne (*Coleogyne ramosissima*), chamiso (*Atriplex canescens*), and matchweed (*Gutierrezia sarothrae*). The shadscale species are winterfat (*Eurotia lanata*), hop-sage (*Grayia spinosa*), and bud sage (*Arte-*

[1] Shantz, H. L., and Zon, Raphael, Atlas of American agriculture, part 1, The physical basis of agriculture, section E, Natural vegetation, grassland, and desert shrub, by H. L. Shantz, and Forests, by Raphael Zon: U. S. Dept. Agr., Bur. Agr. Economics. Advance sheet 6, 1924.

misia spinescens). The salt sage (*Atriplex corrugata* and *Atriplex muttallii*) includes white sage (*Kochia americana vestita*).

The short-grass or plains-grassland vegetation may be subdivided into several associations, as follows:

Grama grass.	Grama-buffalo grass.
Grama-mountain sage.	Wire grass.
Grama-Muhlenbergia.	Western wheat grass.
Galleta grass.	Grama-western needlegrass.

The grassland type is extensive on the plains and mesas at altitudes of 5,000 to 6,500 feet. Grama, ring grass, needlegrass, triple awa (*Aristida longisata*), and galleta grass are the dominant species. Sagebrush, matchweed or yellowtop (*Gutierrezia* sp.) and soapweed (*Yucca glauca*) are brush species scattered intermittently throughout the area.

The woodland or piñon-juniper type occupies mesas, lower mountain slopes, and breaks and is fairly well developed in the Holbrook region. Piñon is the dominant species, with one-seeded and Utah juniper also widely distributed. The piñon is represented by two species, *Pinus edulis* and *Pinus monophylla*, the juniper species are *Juniperus scopulorum*, which is Rocky Mountain red cedar, *Juniperus utahensis*, and *Juniperus monosperma*, also *Juniperus pachyphloea*, the last sometimes known as the alligator juniper. The piñon-juniper type occupies rough, broken country and shallow stony soil. In many places the piñon-juniper type is associated with western yellow pine and locally with stunted Douglas fir (*Pseudotsuga taxifolia*) at higher altitudes and with so-called scrub oaks (*Quercus gambelii* and *Quercus undulata*). The undergrowth contains grama, galleta, needle, and ring grasses. Sagebrush, four-wing saltbrush or chamiso (*Atriplex canescens*), birch-leaf mahogany, and hawthorn (*Crataegus*) are the dominant shrubs.

The forest vegetation comprises chiefly the yellow-pine forests of the higher mountains and plateau. Western yellow pine is the principal species at 6,000 and 7,500 feet, and Engelmann spruce dominates the stand at about 9,000 feet. There are many grassy parks in which Arizona fescue (*Festuca arizonica*) is the most prominent species.

SURFACE FEATURES

Northeastern Arizona occupies a portion of the Colorado Plateau province of the great intermontane plateaus of the western United States. The Colorado Plateau is frequently called the High Plateau or the High Desert Plateau. The Holbrook region has been referred to by various writers as the Mogollon Plateau, the San Francisco Plateau, or the Arizona Plateau. Fenneman[2] has listed the distinguishing features of the Colorado Plateau as the approximate horizontality of its rocks; the great altitude above the sea; and the remarkable development of canyons.

[2] Fenneman, N. M., Physiography of western United States, p. 274, 1931.

The surface of the Holbrook region, although considerably diversified, consists essentially of a plateau which has been dissected by a major stream and its tributaries. The Little Colorado River is the main watercourse for the entire area. The altitude near Leupp, on the Little Colorado River, is about 4,150 feet, and at Greens Peak, west of Springerville, it is over 9,800 feet. The 2,000-meter contour as shown on the State topographic map (6,562 feet above sea level) roughly marks the boundary between the mountains that characterize the high parts of the area to the south and the foothills and gentle northward slopes north of the mountains.

According to Fenneman's map [3] showing the physical divisions of the United States, the Holbrook region includes portions of the Navajo, Grand Canyon, and Datil sections of the Colorado Plateau province. The Navajo section of the Holbrook region is bounded on the south by the Little Colorado River and the Zuñi River. Badlands, travertine cones, dry stream channels, barren rock surfaces, sand accumulations on ridges, volcanic tuff, igneous necks, canyons, and buttes occur in this section.

The Grand Canyon section of the Holbrook region is largely a plateau floored by the Kaibab limestone. Several streams have cut deep canyons into the Kaibab and underlying formations.

The Datil section, which lies east of Silver Creek and south of the Zuñi River, consists of mesas, buttes, cinder cones, stream valleys, and foothill areas. It is an area of extrusive igneous rocks. The underlying sedimentary formations dip eastward or northeastward.

STREAMS AND STREAM FLOW

The Holbrook region lies in the drainage basin of the Colorado River. The major streams within the region are the Little Colorado River and its three main tributaries—the Rio Puerco, the Zuñi River, and Silver Creek. In its upper portions the Little Colorado River is perennial, but below Holbrook it is intermittent. All its tributaries are intermittent except the Nutrioso River and Silver Creek. The Little Colorado River heads in the White Mountains, in the southeast corner of the Holbrook region, and flows in a northwesterly direction, bisecting the region. Below Holbrook the river flows through a broad valley in an anastomosing channel several hundred feet wide. In dry seasons the river bed is dry and movement of water is confined to subsurface flow. The average gradient of the Little Colorado River for a distance of 200 miles is about 13 feet to the mile. Between Black Falls and Woodruff, a distance of 115 miles, the average gradient is 7.6 feet to the mile; between Woodruff and St. Johns, a distance of 55 miles, it is 10 feet to the mile; and between St. Johns and

[3] Fenneman, N. M., Map showing physical divisions of the United States, prepared in cooperation with the Physiographic Committee of the Geological Survey, edition of 1930.

Springerville, a distance of 33 miles, it is 37.6 feet to the mile. Above Springerville the gradient becomes even steeper

The Rio Puerco is an ephemeral stream. From its source, in New Mexico, to its mouth, near Holbrook, it is characterized by dry stretches, except after heavy rains and the spring thaws. It is reported that during certain seasons it carries no water below Lupton, where it enters Arizona.

Fenneman [4] has described the Rio Puerco as a typical youthful stream on a desert plateau. It is entrenched throughout its course between vertical banks that range from 10 to 50 feet in height. At the present time the stream is actively cutting downward through alluvial materials and in places into the underlying sandstones and shales, though records of wells in the Rio Puerco Valley indicate that at one time it deposited materials over a wide flood plain. The only tributaries on the south side of the Rio Puerco in the Holbrook region are Whitewater Creek and a few other small dry washes. A large number of ephemeral streams drain the country north of the Rio Puerco.

The Zuñi River, also an ephemeral stream, rises in New Mexico and joins the Little Colorado near Hunt, in Apache County, Ariz. In places it flows between steep banks, but elsewhere it meanders over a broad floodplain.

Cottonwood Wash, which is crossed on U. S. Highway 66 about 5 miles east of Winslow, heads some 100 miles or more to the northeast, where it is known as Pueblo Colorado Wash. From its head, near Ganado, the wash drops about 1,700 feet in a distance of 90 miles. Except near its head the stream carries water only after heavy rains, but during the rainy season it is sometimes a veritable torrent. Until modern bridges were built the crossing of Cottonwood Wash was one of the problems of transportation in this region. Even today the sandy bottom and quicksands make crossings for cattle and horses precarious. Leroux Wash, which is crossed on U. S. Highway 66 about 1 mile west of Holbrook, is similar to Cottonwood Wash. Both Leroux and Cottonwood Washes carry subsurface water and are therefore important as sources of stock water.

The Nutrioso River heads in the White Mountains and flows into the Little Colorado below Springerville. So far as known to the writers this is a perennial stream. Storage dams for irrigation water have been constructed on both the Nutrioso River and the headwaters of the Little Colorado River.

Silver Creek, which originates at Silver Creek Spring, southeast of Shumway, and which joins the Little Colorado about 4 miles south of the village of Woodruff, is a perennial stream. There are no

[4] Fenneman, N. M., Physiography of western United States, p. 315, fig. 114, New York, McGraw-Hill Book Co., 1931.

reports that this spring has failed even in the most severe droughts. Old-time residents of southern Navajo County state that Silver Creek Spring continued to flow when all other springs in the region had gone dry. Water is diverted from Silver Creek for irrigation by the Snowflake-Taylor irrigation project.

The streams west of Silver Creek and south of the Little Colorado River are all dry during most of the year, except for water holes in some places and artificial reservoirs on Clear Creek and on Chevelon Fork. The canyons cut by these streams in the Kaibab limestone and Coconino sandstone, some to a depth of 300 feet and a width of 500 feet, are very impressive (pl. 4, *A*). In many places the rim of the canyon is level with the general surface of the plain, and no evidence of the presence of a vast chasm is visible until the brink is reached.

Six stations for the measurement of stream flow have been established in the Holbrook region by the Geological Survey. The location of these stations is as follows:

Little Colorado River at St. Johns: Water-stage recorder in sec. 27, T. 13 N., R. 28 E., at high bridge at eastern edge of St. Johns.

Little Colorado River near Hunt: Water-stage recorder in sec. 4, T. 14 N., R. 25 E., 3 miles below Zuñi River and 5 miles northwest of Hunt.

Little Colorado River near Woodruff: Water-stage recorder in sec. 7, T. 16 N., R. 22 E., 4 miles below Silver Creek and 1½ miles northwest of Woodruff.

Silver Creek near Woodruff: Water-stage recorder in sec. 32, T. 16 N., R. 22 E., half a mile above mouth and 3 miles south of Woodruff.

Chevelon Fork near Winslow: Water-stage recorder in sec. 27, T. 18 N., R. 17 E., 3 miles above mouth and 12 miles southeast of Winslow.

Clear Creek near Winslow: Water-stage recorder in SE¼ sec. 9, T. 18 N., R. 16 E., 1½ miles above mouth and 5 miles southeast of Winslow.

In the following summary table the data for the stream-gaging station on the Little Colorado River at Grand Falls are given for comparison. Grand Falls is northwest of the Holbrook region, about 10 miles downstream from Leupp. The average annual run-off from the drainage area of 22,100 square miles of the Little Colorado River above the Grand Falls station, as measured during an 8-year period, is 264,325 acre-feet.

Run-off as measured at stream-gaging stations in the Holbrook region and on the Little Colorado River at Grand Falls, 1926–33

[Records for years ending Sept. 30; taken from Geol. Survey Water-Supply Papers 629, 649, 669, 689, 704, 719, 734, and 749]

Stream-gaging station	Drainage area (square miles)	Annual run-off (acre-feet)			
		1926	1927	1928	1929
Little Colorado River at St. Johns	938				2,820
Little Colorado River at Hunt	7,240				63,000
Little Colorado River at Woodruff	9,040				106,000
Silver Creek near Woodruff	942				23,600
Chevelon Fork near Winslow	1,010				33,000
Clear Creek near Winslow	607				77,800
Little Colorado River at Grand Falls	22,100	173,000	394,000	87,600	511,000

Run-off as measured at stream-gaging stations in the Holbrook region and on the Little Colorado River at Grand Falls, 1926–33—Continued

Stream-gaging station	Drainage area (square miles)	Annual run-off (acre-feet)			
		1930	1931	1932	1933
Little Colorado River at St. Johns	938	5, 280	3, 120	15, 600	5, 050
Little Colorado River at Hunt	7, 240	14, 000	27, 600	48, 700	15, 900
Little Colorado River at Woodruff	9, 040	42, 700	64, 200	117, 000	51, 600
Silver Creek near Woodruff	942	21, 700	19, 000	59, 500	23, 900
Chevelon Fork near Winslow	1, 010	22, 200	27, 300	72, 400	24, 500
Clear Creek near Winslow	607	28, 900	44, 600	149, 000	37, 600
Little Colorado River at Grand Falls	22, 100	189, 000	165, 000	466, 000	129, 000

LAKES AND RESERVOIRS

Laguna Salada, in T. 11 N., R. 25 E., Apache County, is the largest natural body of water in the region (pl. 10, *B*). The lake is fed by a spring that flows from extrusive igneous rocks. An analysis of the water from the lake shows 18,858 parts per million of dissolved mineral matter. (See s51, p. 90.) The lake has no surface outlet, and most of the loss of water from it apparently occurs by evaporation.

Concho Lake, in T. 12 N., R. 26 E., Apache County, is an artificial reservoir that collects a part of the water from Concho Springs. The water is used at the town of Concho.

Ortega Lake, in sec. 2, T. 11 N., R. 25 E., is also an artificial reservoir. It is used chiefly as a source of stock water, though there is some interest in plans to use the water in Windsor Valley, to the northwest, for irrigation.

Deep Lake (pl. 7, *A*), in sec. 25, T. 19 N., R. 29 E., Apache County, is a funnel-shaped depression in Tertiary sands and clays; it is about 100 feet deep on the north and west banks but is shallower on the south and east. Several similar but smaller depressions occur throughout the area covered by Tertiary sands between St. Johns and the Rio Puerco. Some of them, such as Squaw Lake, Hogan Lake, and Jacob's Well, are usually filled with water, but others are dry. The origin of these depressions is not known. They can hardly be sink holes, for there is no limestone and probably but little salt or gypsum in the rocks that immediately underlie them. They may have been excavated by the wind and may be sealed at the bottom by Chinle shales, or, as seems less plausible, they may be meteorite scars.

Hay Lake, in T. 16 N., R. 11 E., Coconino County, and Richard Lake, in T. 16 N., R. 17 E., Navajo County, are modified natural depressions which, by the aid of artificial dams and the puddling action of inwashed materials, have been made to hold water during part of the year. Hay Lake is in the outcrop area of lava flows, which are commonly porous. Richard Lake is in the outcrop belt of the Moenkopi sandstones but is underlain at no great depth by Kaibab limestone. Both Hay Lake and Richard Lake were dry in December 1933.

Dry Lake, in Navajo County, in T. 14 N., R. 19 E., is a large basin which conforms to a structural depression or syncline in the underlying rocks. It contains water only after heavy rains. In the foothill area north of the Mogollon Rim there are several small lakes and ponds that are used for stock water.

Small artificial reservoirs have been constructed by damming the lower sides of depressions at Lakeside, Springerville, St. Johns, Concho, and Babbitt's Tank, west of Sunshine.

Several dams have been constructed along the Little Colorado River and its tributaries to provide storage reservoirs for irrigation water. Lyman Dam, 10 miles south of St. Johns, is the largest project (pl. 11, *B*). Others are Zion Dam, 10 miles downstream from St. Johns; Silver Creek reservoir, just above the junction of Silver Creek and the Little Colorado; Silver Creek Dam, at Snowflake; and a dam on the Little Colorado near Joseph City. (See also statistics on reservoirs under "Agriculture and stock raising.")

In addition to the more pretentious structures mentioned above, there are throughout the area numerous small ponds, or "tanks," which have been formed by erection of low earthen dams across arroyos that carry flood waters. (See pl. 3.) The water so stored is often used for domestic purposes, as well as for cattle and sheep. Such reservoirs, if well constructed, are useful in controlling floods and hence lessen erosion. Furthermore, the existence of relatively closely spaced water holes leads to wider distribution of stock and tends to prevent the formation of new arroyos due to the wearing of cattle trails. Many more "tanks" and small reservoirs could profitably be constructed in the region. (See pls. 10, *A*; 11, *A*.)

RESOURCES AND INDUSTRIES

Agriculture and stock raising.—The Holbrook region is primarily a grazing country, and one of the principal problems of the region is to find watering places for the cattle and sheep that can be fed on the range.

Dry farming has proved of little applicability in this region, and it appears that the years of crop failure outnumber those of success. A traveler through the region is impressed with the number of abandoned ranches and houses, which give silent testimony to the vicissitudes of fortune in this arid country.

For many years certain tracts of land along the major drainage channels of the Holbrook region have been irrigated or attempts have been made to irrigate them. According to McClintock [5] the first dam

[5] McClintock, J. H., Mormon settlement in Arizona, p. 135, Phoenix, Ariz., 1921.

on the Little Colorado was constructed in 1873 by Sol Barth and his associates near the present site of St. Johns. In 1878 James Stinson had taken water out of Silver Creek for irrigation near the present town of Snowflake. The following quotation [6] gives some idea of the troubles endured in the early attempts to irrigate:

Every settlement along the Little Colorado River has known repeated troubles in maintaining its water supply. It would be vain recapitulation to tell just how many times each of the poor struggling communities had to rally back on the sands of the river bed to build up anew the structure of gravel and brush that must be depended upon, if bread were to be secured from the land. The Little Colorado is a treacherous stream at best, with a broad channel that wanders at will through the alluvial country that melts like sugar or salt at the touch of water.

There are instances that stand out in this struggle for water. The first joint dam of Allen's Camp and Obed cost the settlers $5,000. It is told that 960 days work was done on the dam and 500 days more work on the Allen ditch. This dam went down at the first flood, for it raised the water about 12 feet. Then in the spring of 1877 another dam was built, a mile and a half upstream, and this again washed away. In 1879 the St. Joseph settlers sought the third dam site at Leroux Wash, about 2½ miles west of the present Holbrook. In 1881 they spent much money and effort on a plan to make a high dam at the site of the first construction, but this again was taken downstream by the river. In 1882 a pile dam was built across the river, and it again was spoiled by the floods. This dam generally was in use until 1891 but had to be repaired almost every year. In the year named work was started upon what was hoped to be a permanent dam, at an estimated cost of $60,000. In 1894 Andrew Jenson wrote that at least $50,000 had been lost by the community upon its dams. Noting the fact that only 15 families constituted the population, he called St. Joseph the leading community in pain, determination, and unflinching courage in dealing with the elements around them.

The following table, compiled from the United States Census Bureau reports, shows the recent status of irrigation in the drainage basin of the Little Colorado.

Areas irrigated and number and capacity of irrigation reservoirs in the drainage basin of the Little Colorado River

[15th Census U. S.]

	Area irrigated (acres)		Reservoirs, 1930	
	1919	1929	Number	Capacity (acre-feet)
Little Colorado River direct	10,260	7,249	10	41,648
Nutrioso Creek	636	222	3	1,001
Concho Creek	244	823	2	1,197
Other tributaries	5,896	5,358	22	28,949
Total	17,036	13,652	37	72,795

According to the report of the Census Bureau the value of all crops sold in 1929, including fruit and vegetables, amounted to $176,883 in Apache County and $119,553 in Navajo County. In the same year the value of livestock and livestock products sold amounted to

[6] McClintock, J. H., op. cit., pp. 145–146.

$1,438,912 in Apache County and $739,875 in Navajo County. A large but unknown proportion of the livestock and livestock products, principally sheep and wool, came from the Navajo and Hopi Reservations, north of the Holbrook region.

Timber.—Timber is a valuable resource of the region. Parts of the Coconino, Sitgreaves, and Apache National Forests lie within its boundaries. Millions of feet of lumber is cut from these forests annually, and the mills and lumbering opearations furnish employment to hundreds of men. In addition the forests are used for grazing and furnish watershed protection, recreational opportunities, and refuges for wild game

Mineral resources.—The mineral resources of this region are meager. Several wells have been drilled in the area southwest of Holbrook in search of oil. Thus far the results have not been encouraging, though favorable structural features are present, and drillers have reported encouraging showings of oil and gas.

Deposits of low-grade coal occur in the Cretaceous strata west of Pinedale, Navajo County.[7]

Deposits of bleaching clay are worked east of Sanders and north of Chambers. The clays are interbedded with a thick series of unconsolidated to semiconsolidated buff to cream-colored quartz sands of Tertiary age. Minor amounts of sandstone, limestone, travertine, and clay or shale occur in places. Reconnaissance work indicates that over a wide area a thin bed of volcanic ash or tuff is present 50 to 75 feet above the base of the sands, and it is apparently this tuff from which the bleaching clay has been derived by alteration.

The clay is white, has a greasy feel, and contains little or no grit. Specks of manganese oxide are present throughout the deposits. Only one mine was in operation in 1933. This is about 3 miles east of Sanders, near the junction of secs. 8, 9, 16, and 17, T. 21 N., R. 29 E. The clay is 2 to 6 feet thick and is overlain by a greenish semiconsolidated shaly sandstone. The overburden consists of unconsolidated quartz sand and ranges from 1 foot to 20 or 30 feet in thickness. An area of half a square mile or more bears 5 feet or less of overburden.

In mining this deposit the overburden is stripped with scrapers, and the clay is removed by pick and shovel. It is then loaded into trucks by hand and hauled to the railroad at Sanders for shipment to Los Angeles for treatment. It is reported that the total production during 1933 was 192 carloads. Mining was formerly carried on northeast of Chambers and near Allentown. Other deposits of clay are reported, but they appear to be lenticular and spotted in occurrence.

The same volcanic tuff which on alteration yields deposits of bleaching clay finds a moderate use as building stone. The tuff is commonly from 1 to 5 feet thick, white or very light gray, and sufficiently hard

[7] Veatch, A. C., Coal deposits near Pinedale, Navajo County, Ariz.: U. S. Geol. Survey Bull. 431, pp. 239–242, map, 1911.

for ordinary uses. It is easily quarried and can be cut into dimension blocks. The only quarry in operation early in 1934 is about 4 miles east of Navajo, in sec. 15, T. 20 N., R. 27 E. Near Winslow and Holbrook the Moenkopi sandstones have been quarried and used for building stone. Several buildings in each of the towns are constructed of native stone.

At Penzance the Atchison, Topeka & Santa Fe Railway has a quarry from which stone of Moenkopi age is obtained for ballast and riprap work. Many deposits of gravel occur within the Holbrook region, and contractors usually have little difficulty in locating deposits of gravel near places where it is needed. The Shinarump conglomerate has been extensively worked in the vicinity of Holbrook and elsewhere.

The Chinle and Shinarump formations contain much highly colored petrified wood, which reaches a maximum development within the Petrified Forest National Monument. A local industry of considerable importance consists of cutting, polishing, and selling specimens of this wood. Points on the Santa Fe Railway in this region serve as trading and shipping centers for Indian-made products from the Navajo and Hopi Indian Reservations, farther north.

Natural features and recreational resources.—Other resources of the Holbrook region are its natural features, which attract tourists. The Petrified Forest National Monument is visited annually by about 225,000 people. The Painted Desert, which consists of badlands carved in the variegated Chinle beds, is another feature of great interest. The boundaries of the Petrified Forest National Monument have recently been extended to include a part of this desert (pls. 3 and 7, *A*).

Crater Mound, also known as Meteor Crater, about 20 miles west of Winslow, attracts many tourists. It is a cone-shaped crater, three-quarters of a mile in diameter and about 600 feet deep, the origin of which has caused much speculation among geologists.[8]

Springerville, with an altitude of nearly 7,000 feet, and the adjacent White Mountain country have become important summer resorts in recent years. The excellent fishing and hunting and the agreeable climate annually attract many citizens of Arizona and adjacent States.

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[8] Some of the more important papers on Crater Mound are as follows: Gilbert, G. K., The origin of hypothesis illustrated by the discussion of a topographic problem: Science, new ser., vol. 3, pp. 1–13, 1896. Barringer, D. M., and Tilghman, B. C., Coon Mountain and its crater: Acad. Nat. Sci. Philadelphia Proc., vol. 57, pp. 861–914, 1906; Meteor Crater of northern central Arizona, 24 pp., pls., Nat. Acad. Sci., Nov. 16, 1909; Exploration at Meteor Crater: Eng. and Min. Jour.-Press, vol. 121, no. 2, pp. 59 et seq., 1926. Darton, N. H., A reconnaissance of parts of northwestern New Mexico and northern Arizona: U. S. Geol. Survey Bull. 435, pp. 72–74, 1910; A resume of Arizona geology: Arizona Univ. Bull. 119, pp. 198–202, 1925. Merrill, G. P., A retrospective view of the origin of Meteor Crater, Ariz.: Astron. Soc. Pacific Pub., vol. 32, no. 189, pp. 259–264, 1920. Fairchild, H. L., Meteor Crater exploration: Science, new ser., vol. 69, pp. 485–487, 1929. Rogers, A. F., A unique occurrence of lechatlierite or silica glass: Am Jour. Sci., 5th ser., vol. 19, pp. 195–202, 1930. Longwell, C. R., Meteor Crater is not a limestone sink: Science, new ser., vol. 73, pp. 234–235, 1931. Jakosky, J. J., Geophysical methods locate meteorite: Eng. and Min. Jour., vol. 133, pp. 392–393, 1932.

RAILROADS AND ROADS

The main line of the Atchison, Topeka & Santa Fe Railway enters Arizona near Lupton, in the northeast corner of the Holbrook region, and roughly parallels the Rio Puerco to Holbrook. Thence it swings to the northwest, leaving the valley of the Little Colorado at Winslow, and continues westward.

The Apache Railroad, which extends southward from Holbrook to McNary, was built especially to serve the lumber industry in the national forests of southern Navajo and Apache Counties.

Winslow, with a population of 3,917 in 1930, is the largest town in the region. It is a division point on the railroad and a terminal for the Fred Harvey Indian detours. Holbrook, the seat of Navajo County, had a population of 1,115 in 1930 and is a shipping point for cattle, sheep, and other products. St. Johns, the seat of Apache County, had a population of 1,386 in 1930. It is on the Little Colorado River at a considerable distance from the railroad but can be conviently reached from Holbrook by motor transportation.

The main towns are connected by a system of excellent highways, many of which are paved. In addition, there are many country roads and trails that connect sawmills, ranches, and cattle camps (pl. 3). Many of the secondary roads, particularly those that cross outcrops of Kaibab limestone or of Tertiary lava, are rough and rocky. At time of heavy rains the roads that cross belts of shale may become so muddy that it is necessary to travel slowly or even to postpone journeys. The sun shines so many days, however, even during the rainy seasons, that it is generally possible to travel over graded dirt roads a few hours after a heavy rain.

ROCK FORMATIONS AND THEIR WATER-BEARING PROPERTIES

GENERAL RELATIONS

The rocks of the Holbrook region include unconsolidated and consolidated sedimentary strata and igneous rocks, chiefly of the extrusive type. The unconsolidated rocks are stream-terrace, alluvial-flat, lacustrine, and channel deposits of Quaternary and Tertiary age. age. The consolidated sedimentary rocks include limestone, sandstone, shale, and minor amounts of interbedded gypsum and coal. The sedimentary rocks exposed at the surface range from Permian to Recent in age, but the sequence is broken by disconformities and major unconformities. The igneous rocks of the Holbrook region cover wide areas. They consist of lava flows, cinder cones, ash beds, and intrusive dikes and plugs. The age relations of the igneous formations have never been studied in detail, though it is known that some are definitely Tertiary, some are perhaps older, and some are of Quaternary age.

The permeable rocks of the region are in general great natural reservoirs that store the rain and snow water that percolates into them and deliver it gradually to springs and wells. The impermeable rocks, on the other hand, serve as confining beds that tend to hold up the water in overlying water-bearing beds and to hold under artesian pressure the water in underlying water-bearing beds. Obviously it is necessary to know the stratigraphy of the region in order to understand the ground-water conditions, the thickness and texture of each formation, and its lithologic character as affecting the mineral character of its water.

The sequence, character, and water-bearing properties of the formations that occur within the Holbrook region are shown in the following table:

Generalized section of the geologic formations of the Holbrook region

Era	System	Series	Formation	Thickness in region (feet)	Physical character	Water-bearing capacity and kind of water
Cenozoic.	Quaternary.		Alluvium, chiefly valley fill and terrace gravel; lava flows.	0–150	Gravel, sand, and silt of fluviatile origin, sand dunes, alluvial fans, and thin deposits of terrace gravel. Lava flows.	Alluvial deposits yield much water, commonly rather highly mineralized. Many wells along all important streams produce water from these deposits.
	Quaternary and Tertiary.		High-level gravel, travertine deposits, lava flows, and intrusive igneous rocks.	(?)	Small deposits of gravel on benches and ridges, large deposits of travertine in certain localities, extensive basic lava flows and cinder cones, small dikes, plugs, and volcanic necks of intrusive igneous rocks.	Gravel yields some water in small areas; highly mineralized warm springs are associated with travertine deposits; lava flows yield large quantities of good water, particularly at lower contact where underlain by impervious sedimentary rocks. Cinder cones and intrusive rocks unfavorable for accumulation of water.
	Tertiary.		Sand and gravel.	0–200±	Fine-grained unconsolidated quartz sand, with lenses of gravel, conglomerate, and soft sandstone and thin beds of shale, limestone, volcanic ash, and clay.	Many small springs of good water emerge from base of sands where underlain by impervious rocks. A few wells produce water from the same horizon.
			—Unconformity—			
Mesozoic.	Cretaceous.	Upper Cretaceous.		(?)	Sandstones, coal, shales.	A good water horizon. Many springs and a few wells produce fresh water from sandstones. Only a small part of the Holbrook region is, however, underlain by these rocks.
			—Unconformity—			
	Jurassic.		Morrison formation.	(?)	Shales and sandstones. Extremely small outcrop in Holbrook region.	Not known to yield water in Holbrook region.
			—Unconformity—			
	Jurassic (?).		Wingate sandstone.	300±	Massive sandstones.	Unimportant as aquifer in Holbrook region. However, thick sandstone under proper conditions should yield water. One well at Lupton yields water from this formation.
	Triassic.	Upper Triassic.	Chinle formation.	400–700	Variegated shales, arkosic sandstones, and thin cherty limestone conglomerates; much volcanic ash (bentonite); fossil wood abundant.	Yields little water; usually salty or otherwise unfit for consumption. Used for stock water.
		Upper (?) Triassic.	Shinarump conglomerate.	20–60	Coarse sandstone and conglomerate, cross-bedded in part; petrified wood abundant.	Small seep springs, water good but in very small amounts. Small outcrop area and impervious character of overlying Chinle beds prevent accumulation of large supplies of water.
			—Unconformity—			

		Lower Triassic.	Moenkopi formation.	200–400	Sandy shales, sandstones, earthy limestones, conglomerate at base, gypsum stringers. Red, red-brown, and chocolate colors predominate.	Little water. Commonly yields nonpotable water of high mineral content, but near outcrop some fresh water.
			—Unconformity—			
Paleozoic.	Carboniferous.	Permian.	Kaibab limestone.	0–250	White to gray, more or less dolomitic limestone, in part cherty; lower part increasingly sandy and grades downward into sandstone without sharp change; fossiliferous in part; usually massive, marine origin.	Not water-bearing; crevices, joints, solution cavities, and complete dissection by streams permit water to flow from formation.
			Coconino sandstone.	450–865+	Massive fine-grained white or buff sandstone, cross-bedded.	Abundantly water-bearing; yields excellent water near outcrop belt but bears salt water down the dip. Chief artesian horizon in area, in localities where artesian conditions prevail.
			—Unconformity (?)—			
			Supai formation.	1,065–1,260	Red sandstone and shale, with beds of salt, gypsum, and limestone. No outcrops in Holbrook region.	Not known to yield fresh water in Holbrook region.
			—Unconformity—			
		Mississippian.	Redwall limestone.	600–700	Limestone and sandstone, with some shale and salt. No outcrops in Holbrook region.	Deep wells encountered only salty water.

SEDIMENTARY ROCKS

CAMBRIAN AND PRE-CAMBRIAN ROCKS

No pre-Cambrian rocks are exposed at the surface within the Holbrook region, but wells drilled in search of oil have penetrated strata believed to be older than Paleozoic. Darton [9] suggests that the sandstone and limestone below a depth of 3,685 feet in the Taylor-Fuller well, in the NW¼ sec. 21, T. 17 N., R. 20 E., possibly belong to the Apache group, of pre-Cambrian age, which crops out on Canyon Creek, 60 miles to the southwest.

CARBONIFEROUS SYSTEM

MISSISSIPPIAN SERIES

Redwall limestone.—The Redwall limestone, of Mississippian age, does not crop out within the Holbrook region and occurs only at considerable depth. The formation is about 650 feet thick in the Grand Canyon, its type locality, where it consists largely of massive limestone. It thickens toward the northwest but thins greatly toward the south and southeast and becomes much less massive.[10] The logs of the Adamana and Hopi wells, as correlated by Darton,[11] indicate that in the Holbrook region the Redwall is 600 to 700 feet thick and consists of interbedded limestone and sandstone, with subordinate shale and a little salt. Interpretation of the log of the Taylor-Fuller well (p. 93) is difficult, and the thickness of the Redwall, which must here contain a considerable amount of shale, is not known.

PERMIAN SERIES

Supai formation.—The Supai formation does not crop out in the Holbrook region except in the bottom of Crater Mound, but rocks found in deep wells have been correlated with it. In wells southwest of Holbrook the formation apparently ranges from about 1,000 to about 1,300 feet in thickness,[12] and consists largely of red shale and sandstone. Lenses and beds of limestone, salt, and gypsum occur throughout the section.

The contact between the Redwall limestone and the Supai formation represents a hiatus, as the Pennsylvanian strata that occur in the western part of the Grand Canyon region are not present in the Holbrook region. The Hermit shale, which overlies the Supai in the Grand Canyon, has not been recognized east of Lees Ferry.

So far as known, all water encountered in the Supai formation and older rocks in wells within the Holbrook region is too salty to be of

[9] Darton, N. H., Résumé of Arizona geology: Arizona Univ., Coll. Mines and Eng., Bull. 119, p. 203, 1925. (See also log of well 94, p. 93.)

[10] Darton, N. H., idem, pp. 63–64.

[11] Idem, p. 203. (See also logs of wells 110 and 113, p. 95.

[12] Idem, p. 203. (See logs of wells, pp. 93, 95.)

use. Even if fresh water were found it would probably be too deep in most places to be of practical value.

Coconino sandstone.—The Coconino sandstone is the oldest formation that crops out to any considerable extent in the Holbrook region, and it is the most valuable aquifer in the region. It covers a large area south and southwest of Holbrook and is extensively bared along the Mogollon River. It is also exposed in the canyons of Clear Creek and Chevelon Fork and in some of the tributaries of those streams. The Coconino underlies most of the plateau region of northern Arizona and probably underlies all of the Holbrook region. It is covered by younger rocks in eastern Apache County, and its eastward extent is unknown.

The formation appears to vary greatly in thickness. A well drilled at Winona, just west of the Holbrook region, penetrated a thickness of either 356 or 456 feet of Coconino, before it entered the red shales of the Supai formation.[13] The log of a well at Winslow, which obtained only salt water, indicates that the Coconino is at least 865 feet thick in that vicinity.[14] The Adamana well penetrated 600 feet of Coconino to the underlying Supai beds.[15]

The formation is usually white to buff but in places red or brownish. It is characterized by massive bedding and strong cross-bedding and forms prominent cliffs. (See pl. 4, *A*, *B*.) The typical Coconino is a uniformly fine-grained sandstone composed of small rounded quartz grains with siliceous cement. McKee [16] states that quartz composes from 88 to 95 percent of the formation. That the sandstone is not uniformly permeable to water is apparent from the well records, but it is not known whether the permeable strata occur at definite horizons within the formation.

The Coconino sandstone, so far as known, rests on the Supai formation within the Holbrook region and is overlain by the Kaibab limestone or by Moenkopi strata. (See pl. 4, *A*, *B*.) Both contacts are commonly well defined.

There are several localities in the Holbrook region in which wells produce water from the Coconino sandstone, but available records indicate that it is unsafe to predict that all wells which penetrate that formation will obtain fresh water. The chances of obtaining abundant supplies of good water are excellent in general, but down the dip, at variable distances from the outcrop, the water may be salty and unfit for use. Local structure determines in part the amount and artesian head of water in the sandstone.

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[13] Darton, N. H., a reconnaissance of parts of northwestern New Mexico and northern Arizona: Geol. Survey Bull. 435, p. 80, 1910.

[14] Idem, p. 204. (Also see log of well 43, p. 92.)

[15] Idem, p. 203. (Also see log of well 113, p. 95.)

[16] McKee, E. D., The Coconino sandstone, its history and origin: Carnegie Inst. Washington Pub. 440, pp. 77–115, 1933.

Wells drilled in the northward-dipping monoclinal area south of the Santa Fe Railway and south of the Colorado River usually obtain potable water in the Coconino. One deep well at Winslow yielded very salty water, but it is possible that this well was drilled too deep in an effort to obtain a larger supply and that beds containing fresh water were polluted with water from the lower beds.

Wells at the Tegakwitha Indian Mission and at Grubb's trading post at Houck produce fresh water from strata believed to be Coconino. Here the rocks dip toward the southwest. Only a few wells have been drilled in the area between Houck and the Little Colorado River, but it appears possible that the Coconino may yield salt water in some of them. Thus, a well in the Petrified Forest National Monument, which was drilled 228 feet into the Coconino sandstone to a total depth of 1,023 feet, obtained an abundant supply of salt water. The log of this well (108, p. 94) however, records salt water in both Chinle and Moenkopi beds, and there is no indication that proper shut-offs for the salt water were provided before the Coconino sandstone was reached.

Forty-two of the wells listed in the tables produce potable water from strata known or believed to be Coconino sandstone. Salt water has been reported from only two wells (43 and 108), and there is some doubt as to the source of salt water in both of these. Four wells in Coconino sandstone were dry. Two of these (25 and 65) were probably not drilled deep enough into the formation. One (20) is believed to have lost the water in a crevice, and one (252) flowed for a time but finally went dry.

Information on pumping tests and yields of wells is scanty. The well of J. W. McLaws, in sec. 10, T. 17 N., R. 20 E., which obtains its supply from the Coconino sandstone, is reported to have been pumped continuously for 48 hours at about 1,300 gallons a minute. This well was recently purchased by the city of Holbrook for a city water supply.

The water from the Coconino sandstone is in general exceeded in quality only by the spring waters from the base of lava flows or of Tertiary sands. Analyses of samples from 24 wells in the Coconino show an average of 588 parts per million of dissolved mineral matter and 320 parts per million of hardness. (See table of analyses.) The proportion of salt (sodium chloride) is very low as compared to that in well waters from any other geologic horizon in the area.

Available well data indicate great variation in the horizons at which water is found within the Coconino sandstone. R. F. Durfree, of Holbrook, who has drilled many wells in the Holbrook region, states that the upper parts of the formation are usually non-water-bearing and that water is commonly found at two horizons in the lower part of the sandstone, about 50 feet apart. The following table shows the relations between the top of the Coconino sandstone and the depth at which water was obtained in several wells.

Position of water-bearing beds with respect to top of Coconino sandstone

Name and location of well	Depth from surface to top of the Coconino sandstone (feet)	Depth from surface to water-bearing bed within Coconino sandstone (feet)
Shaft at Crater Mound, sec. 13, T. 19 N., R. 12½ E	250	650
Adamana Oil & Land Co. well, sec. 4, T. 14 N., R. 20 E	60	480
Indian Service well 393, sec. 2, T. 21 N., R. 12½ E	10	375
Indian Service well 394, sec. 14, T. 22 N., R. 13 E	175	404
Indian Service well 432, sec. 12, T. 21 N., R. 13 E	200(?)	225
Indian Service well 552, 14 miles north of west from Leupp and 5 miles north of well 394. (Not shown on maps of this report)	75	490
Indian Service well 438, sec. 16, T. 21 N., R. 13 E	130	185
Clear Creek Cattle Co., Bixby No. 1, Moqui Ranch, sec. 12, T. 14 N., R. 11 E	288	385
Hunt School District, sec. 18, T. 14 N., R. 26 E	294	330
Tegakwitha Indian Mission, sec. 25, T. 22 N., R. 29 E	220	346
J. W. McLaws, sec. 10, T. 17 N., R. 20 E	10	10
Ray Durfee, sec. 10, T. 17 N., R. 20 E	5	5

Some of these variations in the horizon at which water occurs are doubtless due to the fact that water is drained from the upper beds of the Coconino sandstone where they are exposed along the canyons of Clear and Silver Creeks, Chevelon Fork, and other tributaries of the Little Colorado River.

Furthermore, as the Holbrook region is on the margin of a great basin, where the precipitation in the intake area is insufficient to keep the whole aquifer full of water, only the lower beds of the Coconino are saturated. It might be predicted that farther down the dip, toward the central part of the Black Mesa coal basin, the Coconino sandstone will be found to contain more water. On the other hand is the possibility that the water farther down the dip is salty.

The available data indicate that a large proportion of wells drilled into the Coconino sandstone will be successful, but the distribution of present wells is spotted, data on the rate of recharge are lacking, and there is not much information as to the effects of local structural conditions and variations in lithology.

Kaibab limestone.—The Kaibab limestone is exposed over a large area in the southwestern third of the Holbrook region, and it also underlies Moenkopi and younger rocks in the western and southern parts.

In the vicinity of the Grand Canyon the Kaibab limestone is about 600 feet thick. Near Heber and at other points in the southern part of the Holbrook region it is about 200 feet thick and thence thins rapidly toward the north and east. On Clear Creek, near Winslow, the limestone is very thin, and along the Little Colorado River in the vicinity of Holbrook it is absent and Moenkopi strata rest directly on the Coconino sandstone. The well in the Petrified Forest National Monument several miles east of Holbrook is reported to have penetrated 40 feet of limestone of Kaibab aspect immediately above the Coconino sandstone (well 108, p. 94). Few other data are available, but it seems likely that the formation disappears eastward as well as northward. Darton [17] discusses the regional relations in some detail.

The Kaibab is a white to gray massive or slabby limestone and is dolomitic and cherty in part. Thin shaly beds alternate with the limestone in places and tend to form steplike benches between the nearly vertical cliffs of limestone. (See pls. 4, *A*; 8, *B*.) Locally the limestone is sandy, particularly near the top and bottom of the section, and in places it is difficult to find the exact contact with the Coconino sandstone.

Though it characteristically contains abundant Permian fossils, most of the outcrops of Kaibab limestone within the Holbrook region are rather sparingly fossiliferous. The limestone rests everywhere on Coconino sandstone, apparently conformably, and it is overlain unconformably by red shale and sandstone of the Moenkopi formation.

The Kaibab limestone crops out over a large area which is high in altitude and which receives more precipitation than other parts of the Holbrook region. The outcrop areas are thus of great importance as collecting grounds for rain and snow water. However, the formation, so far as known, is not an aquifer, because water escapes from it along joint planes, crevices, and solution channels and percolates downward into the pervious Coconino sandstone. Although much of this water eventually enters the Coconino sandstone, a large proportion of it is doubtless lost in such streams as Clear Creek and Chevelon Fork, which cut through the entire Kaibab section and expose the Coconino sandstone.

TRIASSIC SYSTEM

Moenkopi formation.—The Moenkopi formation is extensively exposed along the valley of the Little Colorado River from the vicinity of St. Johns to the northwestern margin of the Holbrook region, and it occurs as numerous scattered outliers south of the main outcrop area. It doubtless underlies the volcanic rocks in the southeastern and western parts of the region. The Moenkopi is probably from 200 to 400 feet thick in most of the Holbrook region where the full section is preserved. It thins to the northwest and finally disappears.[18]

The Moenkopi formation consists of a series of red, red-brown, or chocolate-brown shales and sandstones. Mud cracks and ripple marks are characteristic of many of the beds. Conglomerates and cross-bedded sandstones occur locally. A massive red fine-grained sandstone occurs persistently near the base of the formation in most

[17] Darton, N. H., A résumé of Arizona geology: Arizona Univ., Coll. Mines and Eng., Bull. 119, pp. 93–99, 1925.

[18] Darton, N. H., op. cit. (Arizona Univ. Bull. 119), p. 110.

of the Holbrook region, and a bed of gypsum 2 to 3 feet thick occurs about 60 feet above the base in much of the region near Holbrook and Winslow. In general, the formation is extremely variable, however, and no two sections appear to be exactly alike.

The Moenkopi overlies the Kaibab limestone and Coconino sandstone unconformably (see pl. 4, *B*), and in places deep, narrow channels in the Kaibab are filled with red shaly or conglomeratic Moenkopi material. It is overlain unconformably by the Shinarump conglomerate.

In general the Moenkopi cannot be considered an important aquifer. A few wells obtain water from this formation, but the yield is commonly small, and the water is of very poor quality. A well drilled at Adamana (well 208) is believed to have entered Moenkopi strata between the depths of 105 and 305 feet, but it did not penetrate the entire section. When this well was drilled, about 1900, the hydrostatic pressure was sufficient to raise salt water some 19 feet above the surface. The well drilled in the Petrified Forest National Monument in 1933–34 also obtained salt water from Moenkopi beds (well 108; see also log on p. 94).

Analyses of waters from six wells that are believed to obtain water from the Moenkopi formation show an average content of 1,854 parts per million of dissolved mineral matter, much of which is salt (sodium chloride). The water from this group of wells is of poorer quality than that from any other group except those in recent alluvium. (See tables, pp. 64, 88–90.) Notwithstanding the poor quality and small amount of water yielded by the Moenkopi, the formation nevertheless bears an important relation to the ground-water supplies of the region. The impervious nature of the formation as a whole makes its contact with the Shinarump conglomerate a spring horizon and also causes it to act as a confining stratum for artesian water in the Coconino sandstone in the areas where the Kaibab limestone is missing or thin.

Shinarump conglomerate.—The Shinarump conglomerate crops out in a narrow belt along the north side of the Little Colorado River from the vicinity of St. Johns to the northwestern boundary of the Holbrook region and it probably underlies all of the northeastern part of the region. Small outcrops occur in a few places south of the Little Colorado River and in the northeast corner of the region (pl. 2). The outcrop belt of the Shinarump in the vicinity of St. Johns and the Petrified Forest National Monument, as shown on plate 2, differs materially from that mapped by Darton.[19] The changes are based in part on field observations by the writers, and in part on the paleontologic and stratigraphic evidence as presented by Camp.[20]

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[19] Darton, N. H., Geologic map of Arizona, Arizona Bur. Mines, 1924.

[20] Camp, C. L., A study of the phytosaurs, with description of new material from western North America: California Univ. Mem., vol. 10, pp. 1–14, map A, 1930.

The Shinarump is in few places more than 60 feet thick, and the average thickness within the Holbrook region is probably somewhat less than 50 feet. The formation varies in character from place to place, but coarse sand, beds and lenses of conglomerate, and petrified wood are nearly constant features. The color is predominantly gray. Ordinarily the rock is rather hard, and because of its position between two shaly formations, the Moenkopi and the Chinle, it characteristically forms cliffs and mesas. In some places, however, notably along the Little Colorado River southeast of Holbrook, the beds are poorly cemented and break down rapidly to sand and gravel when exposed to weathering.

If the Shinarump were overlain by porous rocks, or if it had a greater area of outcrop, it would undoubtedly be an important aquifer. Because of its position beneath the impervious shales of the Chinle formation, however, and its narrow belt of outcrop, there is little opportunity for it to receive or hold large quantities of fresh water. In some places, as at Tucker Springs, 5 miles north of Winslow (s1, p. 66), small springs and seeps issue from the base of Shinarump, but no wells are positively known to obtain water at this horizon.

Chinle formation.—The Chinle formation is exposed at the surface or underlies all the area north and east of the outcrop belt of the Shinarump conglomerate (pl. 2). Only the lower portions of the formation are exposed in the Holbrook region, where they probably range from 400 to 700 feet in thickness.

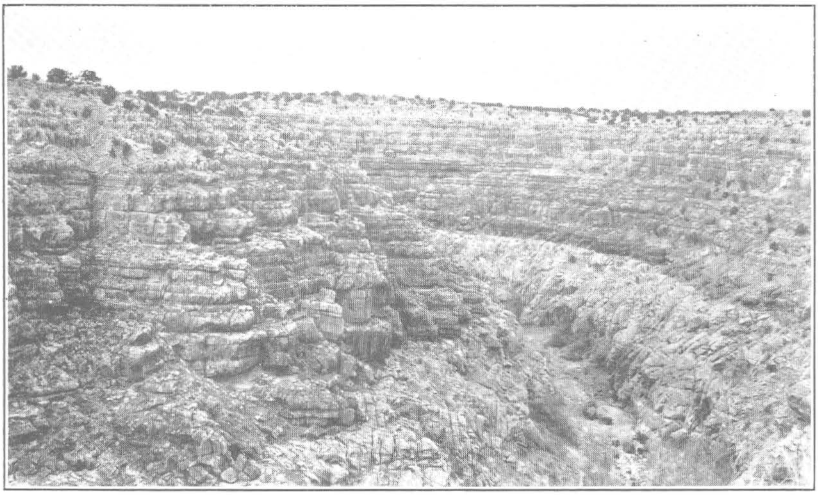
Gregory [21] recognized four subdivisions of the Chinle, but in the present work the formation was not studied in detail. Within the Holbrook region it consists of a series of variegated shales, sandstones, thin limestones, bentonite beds, and lenses of conglomerate (pl. 5, *A*). Petrified wood is abundant in this formation throughout northeastern Arizona. The Petrified Forest National Monument includes a remarkable concentration of petrified wood.

Gregory [22] describes the Chinle as follows:

> The Chinle is the most beautifully colored formation in the Navajo country. Where limestone conglomerate is prominent, the cliff faces are striated with bands of purple, pink, and gray; the friable marls and shales constitute a painted landscape with patches and bands of yellow, ash-gray, drab, lavender, rose, pink, slate, maroon, sienna, lilac, cream, and various shades of red and brown. Patches of blue, of white, and even of black are seen, and chocolate-colored shales predominate toward the base. * * *
>
> Erosion has carved the less resistant parts of the Chinle formation into badland forms—mounds and domes and short, low ridges, isolated or in groups, separated by trenchlike valleys of intricate pattern. Where sandstone beds are present the resulting erosion forms are mesas and buttes and towers, hats and inverted cups; where limestone is present flat-topped mesas or long lines of cliffs reached by a stairway of shale risers and limestone treads make up the landscape. The

[21] Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, pp. 43–44, 1917.

[22] Idem, p. 42.

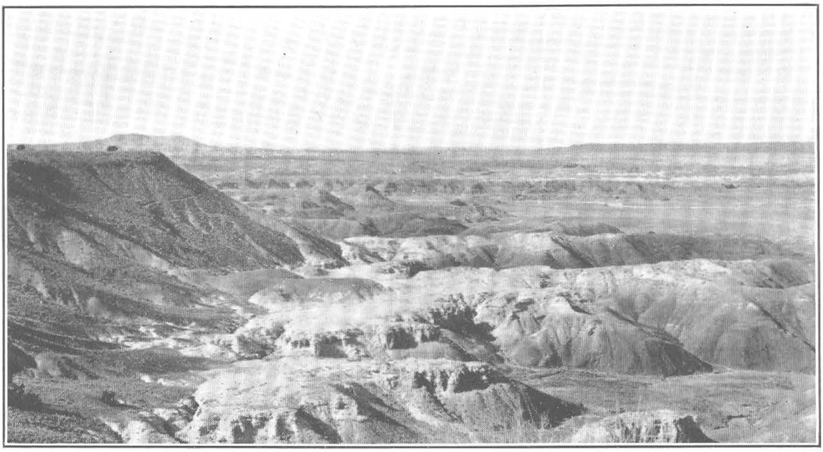


A. KAIBAB LIMESTONE OVERLYING COCONINO SANDSTONE.

The Coconino sandstone is light colored. Looking up Clear Creek Canyon at Clear Creek Cattle Co.'s pumping station. Photograph by E. B. Eckel.

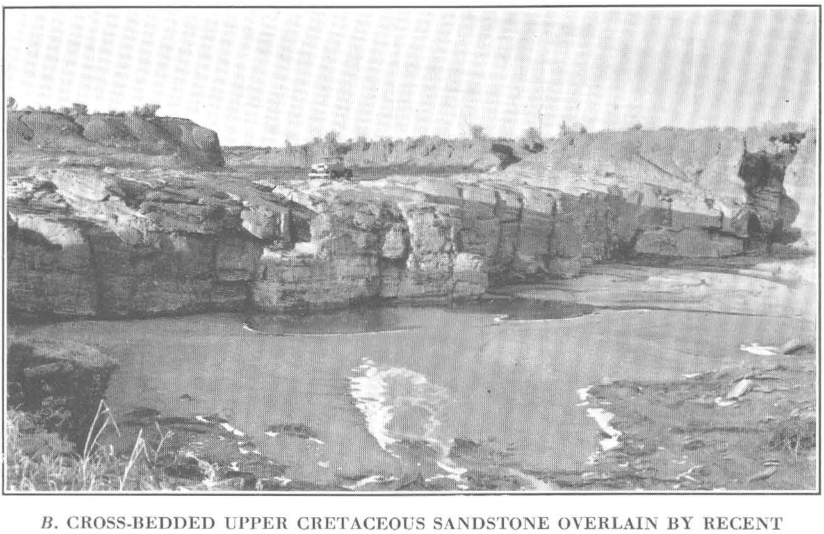
B. COCONINO SANDSTONE OVERLAIN DIRECTLY BY MOENKOPI FORMATION.

Looking northeast across Chevelon Canyon from bridge on old Santa Fe Trail Highway. Photograph by E. B. Eckel.



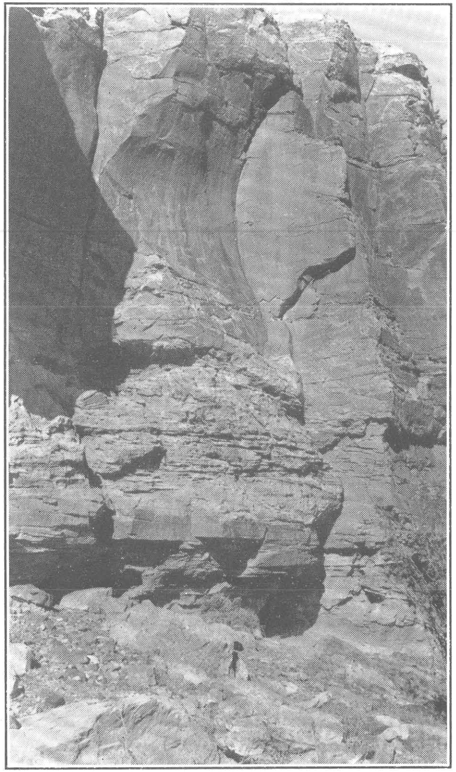
A. BADLANDS CARVED IN VARIEGATED SHALES OF THE CHINLE FORMATION.

Looking north across Painted Desert from point near Painted Desert Inn. Hill to left is capped by lava. Photograph by E. B. Eckel.



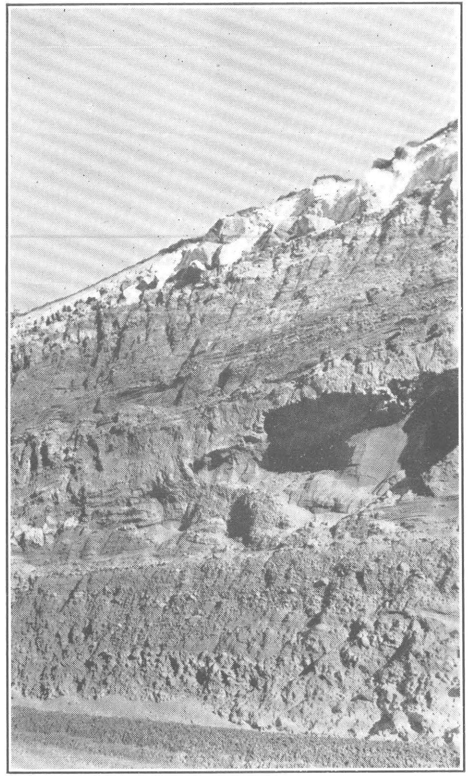
B. CROSS-BEDDED UPPER CRETACEOUS SANDSTONE OVERLAIN BY RECENT ALLUVIUM.

On Zuñi River at Rock Crossing Spring. The spring issues from the base of the sandstone, apparently at its contact with a shaly zone. Photograph by E. B. Eckel.



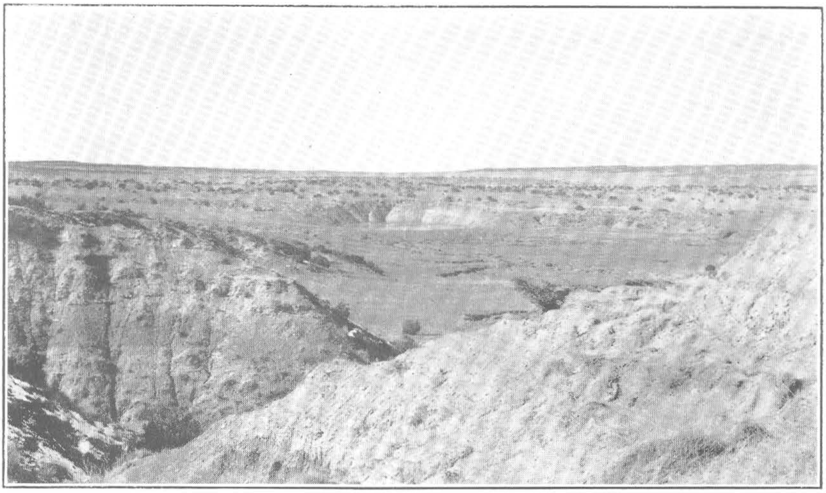
A. MASSIVE UPPER CRETACEOUS SANDSTONE, OVERLYING A ZONE OF SHALY SANDSTONE.

Cliff on Zuñi River, a quarter of a mile east of Cedro Spring. Note prehistoric inscriptions. Photograph by E. B. Eckel.



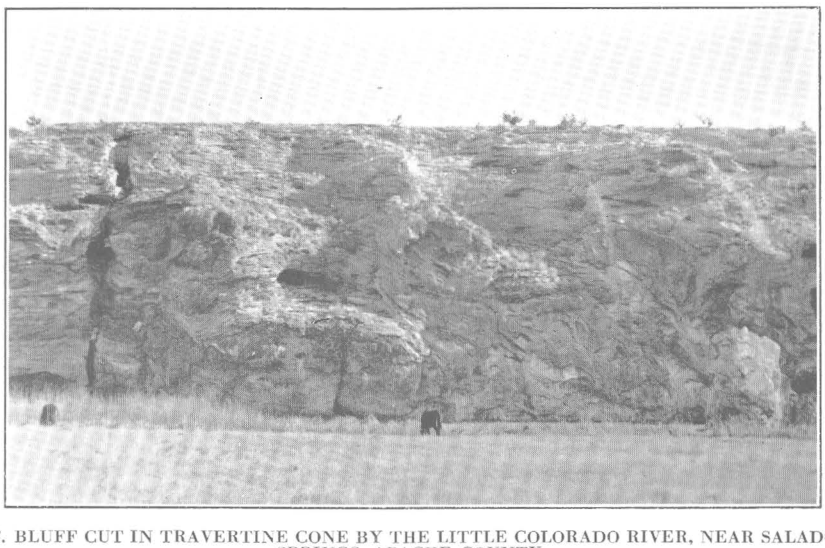
B. TERTIARY SAND AND GRAVEL CAPPED BY THIN LAVA FLOW.

In road cut 11.5 miles south of St. Johns. Photograph by M. A. Harrell.



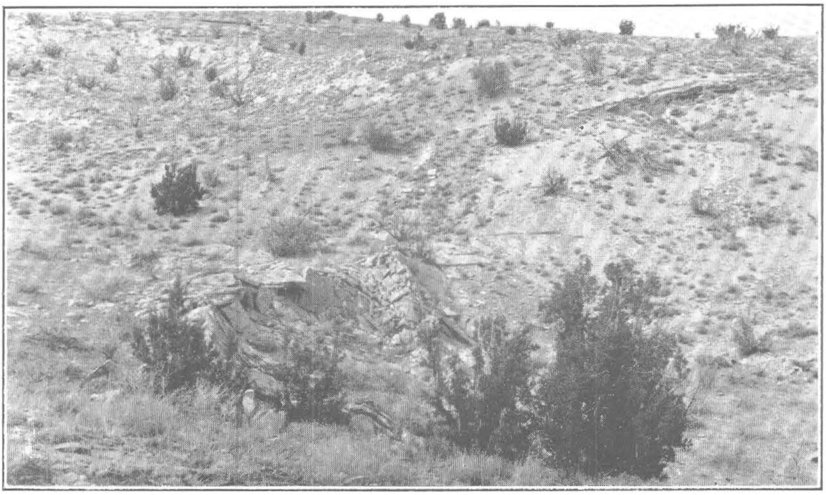
A. TERTIARY SANDS AT DEEP LAKE, APACHE COUNTY.

Shows nature of these unconsolidated sediments and typical topography that develops on them. The origin of Deep Lake and other similar depressions is unknown. Photograph by E. B. Eckel.



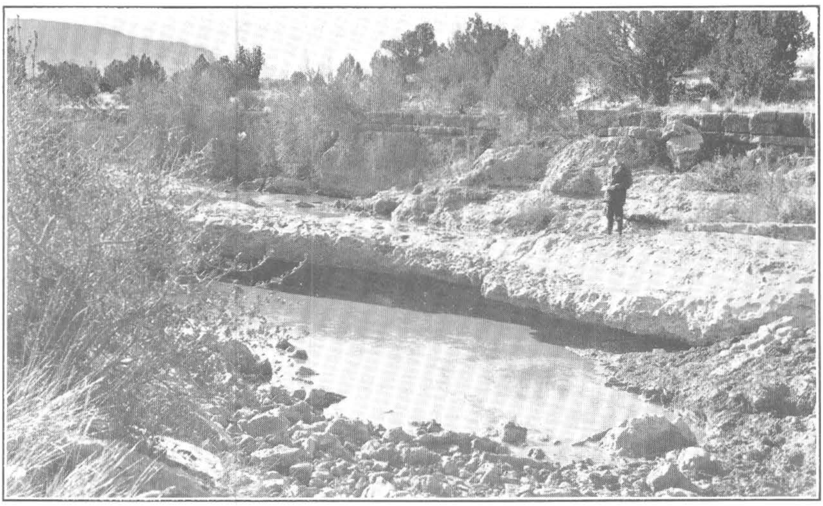
B. BLUFF CUT IN TRAVERTINE CONE BY THE LITTLE COLORADO RIVER, NEAR SALADO SPRINGS, APACHE COUNTY.

Shows typical structure of travertine. A probable former hot spring conduit appears at left. Photograph by M. A. Harrell.



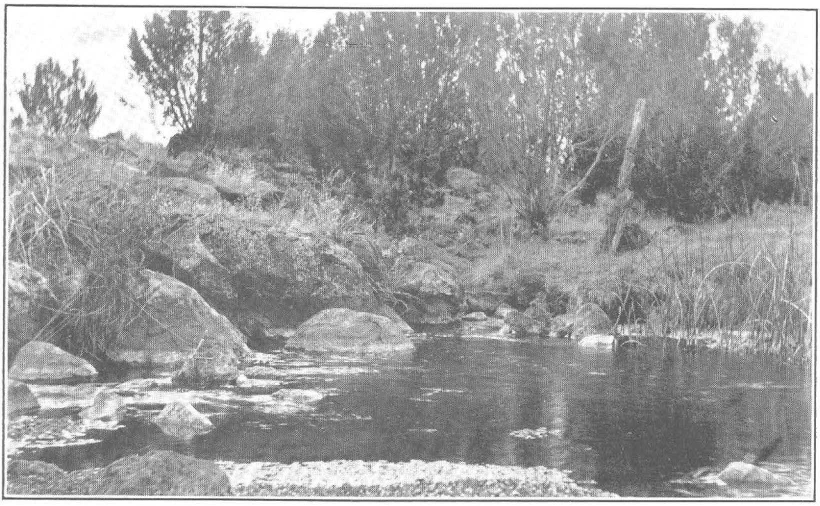
A. TEPEELIKE RIDGES FORMED BY COMPRESSION IN A SMALL SYNCLINAL AREA ON SOUTH SIDE OF THE HOLBROOK DOME.

Kaibab limestone, here very thin, is exposed at the surface and underlain by Coconino sandstone. Photograph by E. B. Eckel.



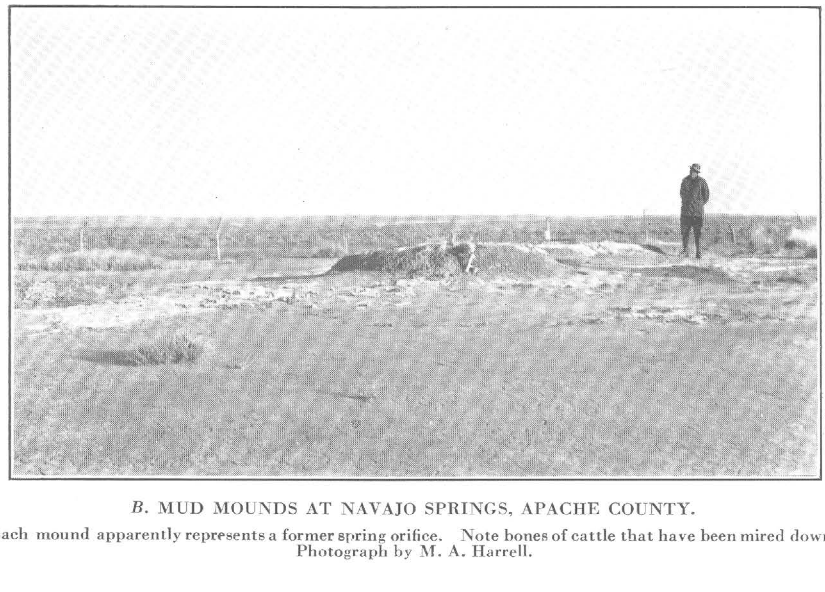
B. WATER HOLES IN KAIBAB LIMESTONE IN BED OF JACKS CANYON, COCONINO COUNTY.

Looking upstream near crossing of Winslow-Pine highway. Such water holes are of temporary character but are nevertheless important as sources of stock water. Photograph by E. B. Eckel.



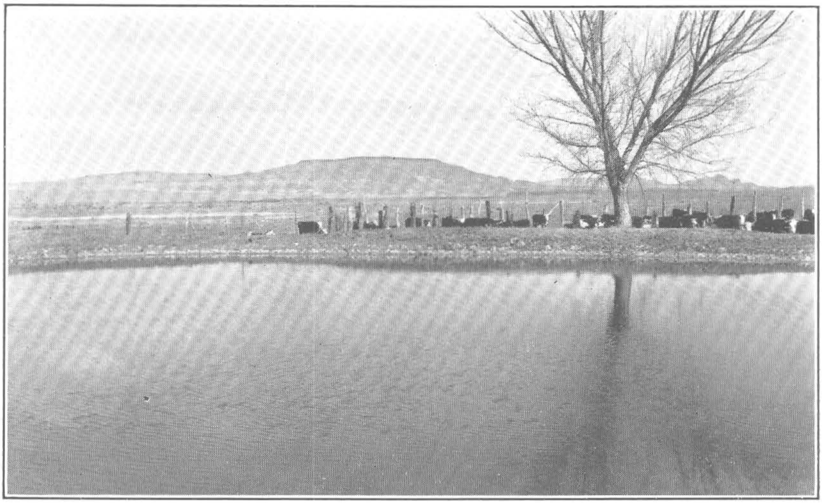
A. SILVER CREEK SPRING, NAVAJO COUNTY.

The largest spring in the Holbrook region, with a total flow of several second-feet. Water issues at the contact of lava and underlying sedimentary beds. Photograph by M. A. Harrell.



B. MUD MOUNDS AT NAVAJO SPRINGS, APACHE COUNTY.

Each mound apparently represents a former spring orifice. Note bones of cattle that have been mired down. Photograph by M. A. Harrell.

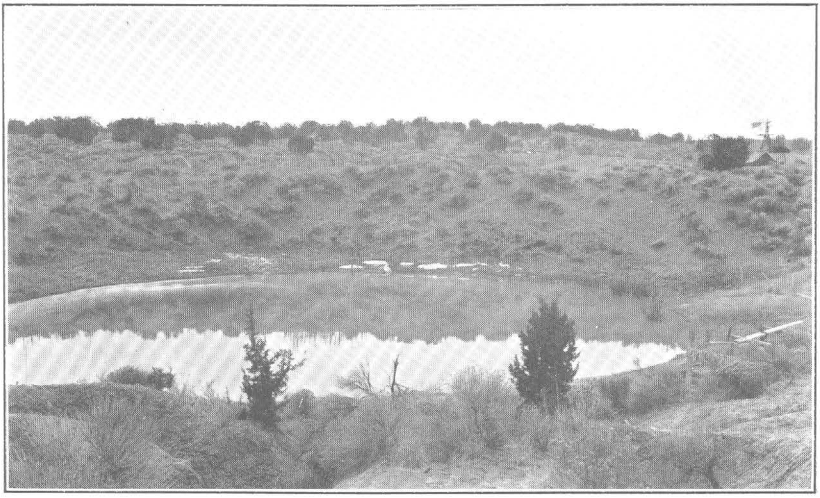


A. LANDSCAPE NORTH OF JOSEPH CITY, NAVAJO COUNTY.

Distant mesa is made up of Chinle shales, capped by lava flows. Marshall's tank, in foreground, is typical of the shallow artificial reservoirs that are used to conserve surface waters throughout the Holbrook region. Photograph by E. B. Eckel.

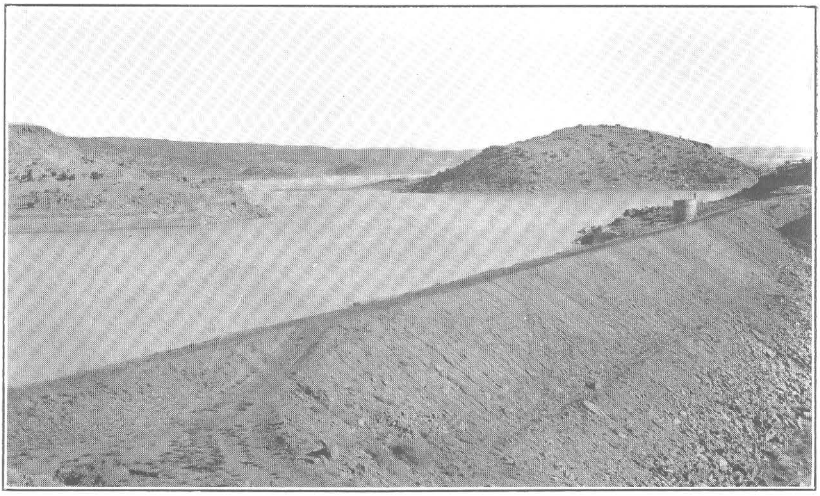
B. LAGUNA SALADA, APACHE COUNTY.

Looking southeast, with snow-capped Greens Peak in background. This lake, which has no known outlet, is fed by a spring. Photograph by M. A. Harrell.



A. GREEN LAKE AT LONG-H RANCH, APACHE COUNTY.

A typical water-filled sink in Tertiary sands. Photograph by E. B. Eckel.



B. LYMAN DAM ON THE LITTLE COLORADO RIVER SOUTH OF ST. JOHNS.

Other dams built for irrigation purposes in the Holbrook region are similar. Two small hills in center distance are travertine; other rocks are Chinle shale. Photograph by E. B. Eckel.

Chinle formation is a valley maker, in contrast to the overlying sandstones of the La Plata group, which form a red frame for the varicolored pictures developed in the shales.

The Chinle formation rests conformably on the Shinarump conglomerate and is in some places overlain conformably by the Wingate sandstone and in others unconformably by Cretaceous and Tertiary rocks.

Certain sandstone beds within the Chinle formation yield water to a few wells near the outcrop and to a few small springs near the base of the formation. Because of the shaly nature of most of the Chinle strata, the water is commonly highly mineralized and occurs only in small quantity. Five analyses of well waters from Chinle beds show an average content of dissolved mineral matter of 652 parts per million, with considerably more calcium and magnesium bicarbonate than salt.

JURASSIC SYSTEM

Wingate sandstone and Morrison formation.—The massive Wingate sandstone, which is probably of Jurassic age, occupies a small area near Lupton, in the northeast corner of the Holbrook region, and a somewhat larger area in the north-central part of the region, north of Holbrook. At Lupton the Wingate is overlain by the Morrison formation (pl. 2). No water supplies of importance are contributed by the Jurassic strata within the area covered by this report. The well of J. W. Bennett, at Lupton (well 130), is believed to derive water from the Wingate sandstone at a depth of 150 feet below the surface. It is barely possible that the water comes from alluvial material but it appears doubtful that the valley fill of the Rio Puerco can be as much as 150 feet thick.

CRETACEOUS SYSTEM

Upper Cretaceous series.—Strata of Lower Cretaceous age are not known to occur within the Holbrook region. The upper Cretaceous rocks, which have not been differentiated, crop out over relatively small areas along the southern and eastern boundaries of the region (pl. 2) and they probably underlie most of the southeastern part, where Tertiary igneous rocks appear at the surface. Records of wells drilled in Tps. 17 and 18 N., R. 29 E., indicate that "yellow sandstones" underlie the unconsolidated Tertiary sands at depths of 200 to 700 feet below the surface. It seems probable that these sandstones are of Upper Cretaceous age, although they may be Wingate.

In the eastern part of the Holbrook region the Upper Cretaceous rocks consist principally of massive cross-bedded buff to cream-colored sandstone, interbedded with thin shales and a little coal. (See pls. 5, *B*; 6, *A*.) The steplike bluffs along the Zuñi River are due to erosion of these beds. Veatch[23] has described an outlier of Cretaceous rocks west of Pinedale. The strata, which contain several low-grade coal beds near the base of the section, are made up chiefly of sandstone and shale. Veatch states that the strata are about 500 feet thick and dip slightly to the north.

The Cretaceous rocks rest unconformably on the eroded surfaces of older formations. East and south of St. Johns they lie on Chinle beds, in southern Navajo County they lie on Kaibab limestone, and elsewhere they are in contact with Moenkopi strata. They are overlain by Tertiary sands and extrusive igneous rocks.

Little is known of the water-bearing properties of the Cretaceous rocks and the few data at hand are somewhat conflicting. Several springs along the Zuñi River yield comparatively large quantities of good water from horizons in the Cretaceous sandstone. Pipe, Rock Crossing (pl. 5, *B*), and Pine Springs (s31, s32, and s34, p. 71) are typical. Several wells east of the State line, in New Mexico, produce good water from these rocks, but within the Holbrook region no well is positively known to obtain water from Cretaceous strata. Wells 218 and 224 yield good supplies of water from "yellow sandstone," which is probably of Cretaceous age. Water-bearing areas within this sandstone must be decidedly local in character, however, for in the same general area at least four dry holes are reported to have been drilled into "yellow sandstone" (wells 217, 223, 247, and 248).

Two analyses of water from wells believed to be in Cretaceous rocks indicate the water to be of exceptionally good quality, with an average of only 214 parts per million of dissolved mineral matter and a very low average hardness. The spring waters from horizons in the Cretaceous beds are by no means as good as the well waters, but they still rank among the more potable waters of the area.

TERTIARY SYSTEM

Sand and gravel.—The topography of large parts of Apache County is characterized by a monotonous succession of low, rolling sandy hills that have resulted from the erosion of deposits of horizontally bedded, unconsolidated sand and gravel. The deposits are in places about 200 feet thick and are made up in large part of light-colored, rather fine-grained quartz sand, but lenses of conglomerate or soft sandstone and thin beds of shale are common features. (See pls. 6, *B*; 7, *A*.) Thin beds of impure limestone, which contain cherty fragments, occur near the base of the sand deposits in places. A thin bed of white volcanic ash, or tuff, which is locally altered to a white clay, crops out at a number of places along the Rio Puerco and on Wide Ruin Wash. It appears to occur at a definite horizon about 50 feet above the base of the sand.

[23] Veatch, A. C., Coal deposits near Pinedale, Navajo County, Ariz.: U. S. Geol. Survey Bull. 431, pp. 239–242, 1909.

The sand deposits have not been studied in detail, and subdivision has not been attempted. They overlie the Cretaceous, Chinle, and older formations and are overlain in the southeastern part of the Holbrook area by lavas of probable Tertiary age. (See pl. 6, *B*.)

The outcrop area of Tertiary sands acts as a collecting basin for surface waters, but these unconsolidated deposits are so porous that much of the water that enters them sinks downward to their contact with the less permeable underlying formations. Several wells in the vicinity of the Rio Puerco obtain water at this horizon, but the yield of most of the wells is small. A great number of small springs and seeps occur at the same horizon in the area north of St. Johns and south of the Rio Puerco. Over most of the outcrop area precipitation is low and evaporation is high.

The water from the base of the Tertiary sands is of good quality. As shown in the table, the average of six analyses of samples from wells and springs shows only 270 parts per million of dissolved mineral matter, and very low hardness. Sodium carbonate and sodium sulphate appear to be the most abundant mineral constituents.

QUATERNARY AND TERTIARY SYSTEMS, UNDIVIDED

High-level gravel.—Deposits of gravel and conglomerate of Quaternary or Tertiary age are mapped by Darton [24] on several of the interstream divides in southern Navajo County between Showlow and Heber (pl. 2). They occur at altitudes of 6,500 to 7,000 feet, in an area of relatively high precipitation and sparse population, and were not examined by the writers.

Travertine deposits.—Numerous deposits of travertine, or calcareous tufa, occur along the Little Colorado River south of St. Johns and east of Hunt and cap several hills and ridges from 5 to 12 miles southeast of St. Johns (pl. 2). Most of these deposits are roughly cone-shaped or are made up of several coalesced cones. In places, as at Twin Buttes, near Hunt, and in the area southeast of St. Johns, they cap hills of sedimentary rocks, but elsewhere the travertine makes up the whole hill and even extends downward to considerable depth. Thus, the records of two wells (293 and 294) drilled at Lyman Dam, south of St. Johns, show that the tufa extends at least to depths of 90 and 160 feet, respectively, below the present stream level.

That the travertine deposits are the results of hot-spring activity is evident in the field. On some of the cones depressions of varying extent undoubtedly represent abandoned spring orifices. The thin, irregular beds of travertine commonly dip away from these centers, though in a few places the material within the depressions dips inward, as if minor subsidence had occurred while the deposits were still soft. (pl. 7, *B*). At the top of one of the Twin Buttes a narrow, irregular

[24] Darton, N. H., Geologic map of Arizona, Arizona Bur. Mines, 1924.

opening can be followed downward 100 feet or more beneath the surface. It has been used for many years as a ceremonial chamber by the Zuñi Indians.

Springs of warm, highly mineralized water now issue near the base of one of the Twin Buttes, and several similar springs, all of which are now depositing travertine, occur in the Little Colorado River Valley below Lyman Dam. (See data on Salado, Stinking, and Montoya Springs, s35, s36, s48, pp. 71–73.) The two wells drilled at Lyman Dam (293 and 294) were both artesian, though one was a failure, owing to loss of tools in the hole.

Field evidence indicates that as the spring waters deposited calcareous material from solution to build up the cones, existing channels became clogged and new outlets were formed repeatedly. The present warm springs probably represent the dying stages of hot-spring activity.

The travertine deposits probably began forming during Tertiary time, and deposition is still in progress. On Twin Buttes the travertine overlies basaltic lava that is believed to be of Tertiary age. No evidence was found to indicate whether or not all of the travertine is younger than all of the lava, but that some of the travertine was deposited long before the present topography took form is shown by the occurrence of residual caps of travertine on hills that are made up largely of sedimentary rocks.

The water from Stinking, Montoya, and Salado Springs and from the flowing well at Lyman Dam ranged in temperature from 62° to 74° F. when observed in midwinter. Analyses of four samples (springs s35, s36, and s48, and well 293) show that the water contains large quantities of dissolved mineral matter, mostly in the form of the bicarbonates, sulphate, and chlorides of calcium and sodium. Water from the Lyman Dam well and all the springs flows into the Little Colorado River but does not prevent use of the river water for irrigation. The water from well 293 contains less mineral matter than the spring waters, possibly on account of dilution by seepage water from the nearby Lyman Dam.

The warm temperature of the water may be due to contact with heated igneous rocks at depth. The source of the lime and other mineral constituents of the water is uncertain, but they were probably derived from older underlying limestone, such as the Redwall, or from soluble materials disseminated in sandstone, shale, or other rocks.

QUATERNARY SYSTEM

The sedimentary formations of Quaternary age consist of alluvial deposits in stream valleys and a few terrace-gravel and eolian deposits.

Cottonwood Creek, the Rio Puerco, Carrizo, Milky, and Leroux Washes, and the Little Colorado, Zuñi and Dead Rivers are the chief streams along which alluvial material occurs. The deposits are made up of poorly sorted sand, gravel, and silt and range from a few inches to 100 feet or more in thickness. The silt that makes up the valley fill in Carrizo Wash, a tributary of the Zuñi River north of St. Johns, is so fine that completion of wells in it has been found very difficult.

The alluvial gravel and sand in stream valleys commonly contain abundant supplies of easily accessible water, even when the surfaces of the stream beds are dry. Many wells throughout the Holbrook region obtain water from these materials. In addition to the sinking of more wells it might be suggested that the erection of subsurface diversion dams, securely sealed into bedrock at the bottom and sides of the valleys, would provide additional water in many places. It is probable that gravel-wall wells, such as are used by the Santa Fe Railway on the Rio Puerco, would be successful in obtaining water from the silt along Carrizo Wash, but they might prove too expensive to be an economical source of water for ranches.

The water from wells in stream valleys is commonly high in dissolved mineral constituents (see tables of analyses), and some waters cannot be used for domestic purposes, though all of them have been found satisfactory for cattle.

IGNEOUS ROCKS

QUATERNARY AND TERTIARY SYSTEMS, UNDIVIDED

The igneous rocks in the Holbrook region have not been studied in detail. Most of them were probably formed during Tertiary time, but some are perhaps older than Tertiary, and some are known to be of Quaternary age.[25]

Intrusive rocks.—Many isolated masses of intrusive igneous rock crop out in the north-central part of the Holbrook region, north of the Santa Fe Railway. Most of the rock is basic in composition and occurs largely as dikes or as volcanic necks and plugs. These probably represent in part the channels through which the extensive lava flows of the region were extruded. There are doubtless a number of similar intrusive masses beneath the lava flows in the southern part of the region. The intrusive igneous rocks have but little influence on the ground-water supplies of the region and are not shown on the map (pl. 2).

Extrusive rocks.—Basaltic lavas and cinder deposits cover much of the southeastern part of the Holbrook region, and lavas are also rather extensively developed along its western boundary (pl. 2). The rocks in the extreme northwest corner of the region are basalts of Quaternary age and have been described by Robinson.[26]

The lava flows, which are known locally as "malpaís", are in general dark and variable in character, though a porous, cellular texture is

[25] Darton, N. H., op. cit. (Arizona Univ., Bull. 119), pp. 165–166.

[26] Robinson, H. H., The San Franciscan volcanic field, Ariz.: U. S. Geol. Survey Prof. Paper 76, 1913.

a widespread feature. The beds and cones of unconsolidated reddish-brown to black cinders possibly mark original centers from which the lavas were erupted. They are abundant in places, particularly in the area between Springerville and Pinetop.

South of St. Johns, sand and gravel of Tertiary age are overlain by lava (pl. 6, *B*). The beds of volcanic ash that occur in the Tertiary sand deposits indicate that volcanic activity was in progress during part of the time when the sands were being laid down.

Most of the outcrops of volcanic rocks occur in areas of high precipitation, and they are therefore of great importance as catchment basins for surface water. The lavas and cinder beds are highly permeable, however, and water drains through them rapidly. Only a few wells have been drilled in the lava-covered areas, and with the exception of those that have gone through the lavas to the contact with underlying impervious sedimentary rocks, most of them have been failures. There are a few local areas where water is obtained within the lavas. Thus, many shallow dug wells in the village of Pinetop obtain water from a thin lava flow that overlies a thick bed of cinders. If the wells are dug too deep, however, the water may be lost in the cinder bed.

A well at Udall's Blood Tanks, approximately in sec. 33, T. 11 N., R. 27 E., is reported to have penetrated "malpaís" rock from the surface to a depth of 46 feet and cinders from 46 to 175 feet. The upper portion of the cinder bed was dry, but water was obtained in the lower portion. This well is near the northern margin of outcrop of the beds, and the well perhaps penetrated the entire thickness of "malpaís" and cinders. It is reported that a well about 2 miles farther west penetrated 400 feet of lava rock and encountered no water. (See also log, p. 55.)

The contact of the lavas with the underlying sedimentary rocks is an excellent horizon for water in most places. A few wells obtain abundant supplies of good water at this horizon and many large springs issue from it. Malpais, Concho, Silver Creek, Adair, and Pinetop Springs are important examples. The location of springs is probably governed in large part by irregularities in the surface of the underlying impervious strata.

As shown by the analyses given in the accompanying tables, the waters from the base of the lavas vary considerably in composition, but they are all fresh waters of good quality. The best water in the region comes from some of the springs in Navajo County. The spring waters in Apache County contain much more dissolved matter than those of Navajo County, possibly because in Apache County the lavas are largely underlain by Chinle and Moenkopi shales, from which the water may have dissolved considerable quantities of impurities, whereas in Navajo County the lavas are underlain in large part by Cretaceous sandstone or by the Coconino sandstone.

STRUCTURAL GEOLOGY

GENERAL FEATURES

The geologic structure of the Holbrook region is known only in a general way, though various structural features of the Colorado Plateau province have been discussed by several authors.[27]

The Holbrook region is bounded on the south and southwest by an area of great uplift that centers in the White Mountains. Northward from this uplift the strata dip into the great synclinal area known as the Black Mesa coal basin, which occupies the central parts of the Hopi and Navajo Indian Reservations, from 40 to more than 100 miles north of Holbrook. Because of the northward dip successively younger rocks are exposed at the surface as the central part of the basin is approached. Thus the entire succession from the Supai formation (Permian) to the Mesaverde formation (Upper Cretaceous) appears between the southern border of the region and Oraibi and other points in the Navajo country.

The southeastern part of the Holbrook region is largely mantled with extrusive igneous rocks, and the structural conditions and stratigraphic sequence of the underlying sedimentary formations are imperfectly known.

Gregory [28] has called attention to the occurrence of synclines, anticlines, monoclines, and domical upwarps in the Navajo country. Structural features of the same type occur in the Holbrook region, which may be considered a monocline modified by a few domical upwarps or local flexures and faults of small displacements.

FOLDS

The Holbrook dome, the largest local uplift within the Holbrook region, is an elongated anticlinal fold whose axis extends approximately N. 45° W. The fold is best developed at a point about 12 miles southwest of Holbrook, but there are indications that it extends from a point southeast of Snowflake at least as far northwestward as Hibbard or Canyon Diablo. The south limb of the anticline is much steeper than the north limb, and dips of 20° to 45° occur in places. The Coconino sandstone crops out over a wide area near the crest of the anticline.

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[27] Gilbert, G. K., U. S. Geog. and Geol. Surveys W. 100th Mer. Rept., vol. 3, pp. 17–187, 503–567, 1875. Dutton, C. E., Report on the geology of the High Plateaus of Utah, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1880; Tertiary history of the Grand Canyon region: U. S. Geol. Survey Mon. 2, 1882. Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, 1917. Butler, B. S., and others, Ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, 1920. Longwell, C. R., and others, Rock formations of the Colorado Plateau in southern Utah and northern Arizona: U. S. Geol. Survey Prof. Paper 132, pp. 1–23, 1923. Darton, N. H., and others, Geologic map of Arizona, prepared by the Arizona Bureau of Mines in cooperation with the Geological Survey, 1924; A résumé of Arizona geology; Arizona Univ., Coll. Mines and Eng., Bull. 119, 1925. Gregory, H. E., Colorado Plateau region; Guidebook-Excursions C–1 and C–2, 16th Internat. Geol. Congress, 1933.

[28] Gregory, H. E., Geology of the Navajo country: Geol. Survey Prof. Paper 93, pp. 109–116, 1917.

It seems probable that most of the folding occurred at the end of the Cretaceous period, during the Laramide revolution, but that part of it occurred in geologically recent time is suggested by the presence of open tension cracks in the sandstone along the crest of the dome and of tepeelike ridges due to compression in the syncline south of the dome. These features are more fully discussed under the heading "Faults."

Several deep wells have been drilled for oil in recent years on the Holbrook dome. The results have been somewhat discouraging, although showings of oil and gas have been reported. As abundant water is reported to occur in the Coconino and underlying formations on the flanks of the dome, it seems possible that the flushing effect of water has removed petroleum accumulations from their normal position on the Holbrook dome and that further prospecting for oil toward the center of the Black Mesa basin might prove more profitable.

The northeast corner of the Holbrook region is on the south flank of the Defiance uplift, which has been described by several writers.[29] Darton's map of the structural features of northern Arizona[30] gives contours on the base of the Kaibab limestone which show that the area between the Holbrook dome and the Defiance uplift is a saddle on the syncline between the two larger uplifts. The rocks dip away from the crest of the saddle toward the southeast and northwest in general, but there are local folds that interrupt this regional trend. The following data relating to the altitude of the top of the Moenkopi formation, in conjunction with Darton's map, indicate that the Blue Forest is near the crest of a local dome.

Altitude of top of Moenkopi formation at points in Holbrook region

Locality	Approximate location (sec., T. N., R. E.)			Altitude of top of Moenkopi above sea level (feet)
Well at headquarters, Petrified Forest National Monument	1,	16,	23	5,172
Billings Gap [a]	1,	17,	24	5,139
Blue Forest [a]	26,	18,	24	5,300
Point of Bluff [a]	36,	18,	23	5,135
Carrizo Butte [a]	19,	18,	23	5,015
Digger Wash [a]	12,	18,	22	4,950
Carrizo Wash [a]	22,	19,	23	4,960

[a] Camp, C. L., A study of the phytosaurs, with description of new material from western North America: California Univ. Mem., vol. 10, fig. 1, 1930.

[29] Newberry, J. S., Geological report, in Ives, J. C., Report upon the Colorado River of the West, explored in 1857 and 1858, pt. 3, 1861. Newberry, J. S., Geological report, in Report of the exploring expedition from Santa Fe, N. Mex., to the junction of the Grand and Green Rivers of the Great Colorado of the West, in 1859, under the command of Capt. J. N. Macomb, 1876. Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, 1917. Howell, E. E., U. S. Geog. and Geol. Surveys W. 100th Mer. Rept., vol. 3, pp. 227–310, 1875. Darton, N. H., A résumé of Arizona geology: Arizona Univ. Bull. 119, pp. 207–210, 1925.

[30] Darton, N. H., op. cit. (Arizona Univ. Bull. 119), pl. 52.

Between Zion Dam and Twin Buttes, a distance of about 5 miles, the Moenkopi shales and sandstones dip to the northwest at an angle greater than the fall of the Little Colorado River, although the normal dip in this area is eastward. In the immediate vicinity of Twin Buttes, T. 14 N., R. 26 E., the strata are locally much distorted. The occurrence of basaltic lava, travertine, and warm springs on the Twin Buttes suggests the presence of a plug of igneous rock beneath the area, the intrusion of which may have disturbed the sedimentary rocks.

Three miles east of St. Johns the Moenkopi beds appear to be truncated and overlain by the Chinle formation.[31] These relations seem to be evidence of a local uplift in the area, but its extent and possible magnitude are not known.

The attitude of the rocks along the Zuñi River north and northeast of St. Johns indicates the presence of a dome of unknown extent in this area. According to Darton's map [32] the regional dip is northeastward toward a structural basin that extends eastward into New Mexico. In secs. 2 and 20, T. 16 N., R. 29 E., however, the Cretaceous (?) strata dip 2° and 3° to the northwest and in sec. 29 of the same township they dip 12° to the southwest.

North of Springerville, near the electric-light plant, strata mapped as Chinle by Darton [33] dip as high as 60°. Several years ago a well was drilled on the supposed anticline. The following log of the well, which is believed to have been located in either sec. 8 or sec. 17, T. 9 N., R. 29 E., suggests that a buried volcanic plug may have caused the steep dips. The log was given from memory by Mr. George Childress.

Log of well drilled near Springerville electric-light plant

	Thickness (feet)	Depth (feet)
Red sandstone; water at 15 feet	15	15
Clay	10	25
Volcanic rock	660	685

At 125 feet the drill struck a crevice and the water was lost; some gas was reported at 400 feet.

Darton[34] notes the presence of a small dome east of Taylor, in Navajo County. The Coconino sandstone is brought to the surface and overlain by yellow sandy Kaibab limestone only a few feet thick.

Northwest of Leupp the Kaibab limestone has been brought to the surface along the Little Colorado River by local folding and subsequent erosion. Gregory [35] says of this area:

[31] Camp, C. L., op. cit., p. 1.
[32] Darton, N. H., op. cit. (Arizona Univ. Bull. 119), pl. 52.
[33] Darton, N. H., and others, Geologic map of Arizona, Arizona Bur. Mines, 1924.
[34] Darton, N. H., A résumé of Arizona geology: Arizona Univ. Bull. 119, p. 204, 1925.
[35] Gregory, H. E., Geology of the Navajo country; U. S. Geol. Survey Prof. Paper 93, p. 125, 1917.

> From a point near Winslow to Tolchico the valley [Little Colorado] is flat and broad, and the flood plain attains a width exceeding a mile. The form of the valley in this meandering stretch is doubtless due to the anticline bisected by the river at Wolf Crossing.

FAULTS

Faults are rare throughout the Holbrook region, and all the known faults have small displacement. The Holbrook dome is slightly modified by minor faulting, and similar relations may exist on other folds. Southwest of Holbrook, on and near the crest of the Holbrook dome, a great number of open fissures and crevices occur at the surface, in the Coconino sandstone. The cracks, which are nearly vertical, extend downward to depths of at least 100 feet, and some are locally reported to be much deeper. Individual fissures range from a few feet to at least 2 miles in length and from a fraction of an inch to about 10 feet in width at the surface. Little evidence of horizontal movement is apparent along any of the cracks. There are two distinct sets of fractures. The stronger and more persistent ones trend parallel to the axis of the dome, or about N. 46° W. The other set has an average trend of N. 48° E. The sandstone is thus broken into diamond-shaped blocks of varying size. A few blocks have dropped a distance of a few inches to about 2 feet, owing to minor block faulting, and a few are slightly tilted.

Only one fault with considerable displacement is known to occur on or near the Holbrook dome. This is the one mapped by Darton[36] in Tps. 14 and 15 N., R. 18 E. (See pl. 2.) The line of this fault, which trends about N. 30° E. and dips about 75° SE., is marked by a scarp 20 to 30 feet in height. Coconino sandstone occurs on the northwest side of the fault and abuts against Kaibab limestone on the downthrown southeast side. Definite markers within the Coconino sandstone are lacking, but the height of the scarp indicates that the displacement along the fault must be at least 30 feet.

This fault and the fissures described above appear to have been formed by tension along the crest of the Holbrook dome in relatively recent time. In a minor syncline on the southwestern flank of the dome the surface rocks show the effects of compression rather than tension, and the two lines of weakness are there represented by tepee-like ridges into which the rocks have been squeezed to the point of failure (pl. 8, *A*).

About 22 miles south of Holbrook there are several steep-sided depressions that are locally known as "The Sinks." Darton[37] describes them as follows:

> The Sinks are on the south slope of the large dome, about 10 miles northwest of Snowflake. There are 30 or 40 of them, ranging from a few yards to 100 yards

[36] Darton, N. H., and others, Geologic map of Arizona, Arizona Bur. Mines, 1924.
[37] Darton, N. H., A résumé of Arizona geology: Arizona Univ. Bull. 119, p. 204, 1925.

in diameter, in an area about a mile in length, and all near or on the steep dip to the south. Most of them expose sandstone of Coconino aspect * * * overlain by Kaibab limestone, here 20 or 30 feet thick. Undoubtedly this sandstone is underlain by a limestone member which has been removed in places by solution in underground waters passing into the valley of Dry Lake, to the southwest.

This latter valley is a syncline filled with Moenkopi formation, * * * which extends nearly to Chevelon Canyon. In the center of the basin, southwest of The Sinks, are two buttes capped by Shinarump conglomerate.

The zone in which the sinks occur trends N. 46° W., parallel to the trend of the Holbrook dome.

It seems possible that the sinks southeast of the Holbrook dome are the surface expressions of minor block faulting such as that which has occurred on the crest of the dome. Baker[38] has described and illustrated somewhat similar features in the Moab district, Utah, which he ascribes to graben faulting due to unequal settling of the surface rocks over salt beds as the salt was forced into adjacent anticlinal areas. The Supai beds in the Holbrook region contain an unknown but probably considerable quantity of salt, and the sinks may possibly be due to movement of salt at depth.

The only limestones known to occur below the Coconino sandstone are those of Mississippian age, which are separated from the Coconino by more than 1,000 feet of Supai red beds. It does not seem possible, therefore, that the sinks can have been formed by solution of underlying limestone.

RELATION OF STRUCTURE TO GROUND WATER, ESPECIALLY TO ARTESIAN CONDITIONS

The geologic structure of northeastern Arizona is one of the major factors that control the occurrence of ground water. The structure is known only in a general way, however, and many of the details that are necessary for correct interpretations of its relation to the ground water are lacking.

Artesian water is ground water that is under sufficient hydrostatic pressure to rise in a well above the zone of saturation, but artesian wells do not necessarily flow at the surface. Artesian conditions may occur in an inclined permeable bed that lies between two relatively impervious beds and is exposed at the surface at a considerably greater altitude than that of the water table at the well.

There are several areas in the Holbrook region in which artesian conditions exist.

In the western third of the region, west of Chevelon Fork, the Coconino sandstone is the only aquifer of importance. This part of the region is structurally a monocline, though a local fold near Leupp interrupts the regional northeastward dip of the rocks and brings the

[38] Baker, A. A., Geology and oil possibilities of the Moab district, Grand and San Juan Counties, Utah: U. S. Geol. Survey Bull. 841, pp. 74–76 and elsewhere, 1933.

Coconino sandstone relatively close to the surface. The only failures that were reported in a total of 21 wells drilled into the Coconino sandstone in this area are the 990-foot well at Winslow, which obtained salt water (see pp. 76 and 92), and three wells that were abandoned before they penetrated the Coconino far enough to obtain water. A shaft at Crater Mound also obtained an abundant supply of fresh water. Most of the wells are artesian to some extent, though none overflow at the surface, and no records are available regarding the rise of the water in the wells when the aquifers were penetrated.

In an extensive area south of the Little Colorado River, between Silver Creek and Chevelon Fork, fresh water has been found in the Coconino sandstone in every well drilled to that formation. Several wells have been drilled in prospecting for oil and gas on the Holbrook dome, and all are reported to have obtained good supplies of water.

Adjacent to and south of the Little Colorado River, between Holbrook and Joseph City, flowing wells have been obtained in the Coconino sandstone. The yield of some of these wells, which are all on the north flank of the Holbrook dome, has been found sufficient for irrigation. It is noteworthy that the head of water on both the flowing wells and the numerous nonflowing wells in the area is not great, though all the wells are artesian.

The Coconino sandstone occurs at the surface over a large area along the Mogollon Rim, south and southwest of the Holbrook region. This area is topographically high and has greater precipitation than the valley of the Little Colorado River. It would thus seem to be a good collecting area for water, except for the existence of steep slopes, which readily drain surface waters away.

At Heber, near the southern boundary of the region, the Coconino occurs at an altitude of about 6,450 feet, but in the vicinity of Holbrook and Joseph City it occurs at altitudes of about 5,000 feet. The regional dip of the Coconino sandstone, disregarding the structure of the Holbrook dome, is therefore about 34 feet to the mile. As continuous beds of Coconino sandstone underlie the area, it would seem reasonable to expect that deep wells in the vicinity of Holbrook, Joseph City, and Winslow would flow. The rarity of flowing wells may be due to the absence of an effective confining stratum above the Coconino sandstone or to other factors. The underlying Supai formation consists largely of shale, which probably prevents the downward movement of the ground water, but the jointed and creviced condition of the overlying Kaibab limestone probably makes it less effective as a confining bed, thus preventing the development of sufficient artesian head to cause flowing wells. Furthermore, the Coconino sandstone is exposed in the canyons of Clear Creek, Chevelon Fork, and Silver Creek, and the waters that penetrate the upper parts of the Coconino sandstone or overlying formations are drained by these streams. It seems likely, therefore, that the outcrop area of the Coconino sandstone on the Holbrook dome is the main intake area for the water that is obtained in wells north of the dome.

Little is known of the structural relations in the general vicinity of the Petrified Forest, but the fact that a well drilled within the forest obtained salt water in supposed Coconino sandstone at a depth of 1,023 feet suggests that the structural saddle between the Holbrook dome and the Defiance uplift may have some effect on the ground-water conditions.

Two flowing wells at Hunt and others at St. Johns are believed to obtain water from the Coconino sandstone. Local structural conditions favorable for the accumulation of water are doubtless in part the cause of the artesian head. Furthermore, the fact that the Kaibab limestone is missing and the Coconino is directly overlain by the relatively impermeable Moenkopi beds is probably also an effective factor.

Two wells drilled in travertine near Lyman Dam, south of St. Johns, are artesian. One of these (well 293) is a flowing well; the other (well 294) was drilled to a depth of 160 feet, and the water in it is reported to have risen within 5 feet of the surface. The factors that govern the occurrence of ground water in these travertine areas are not known, but it is reasonable to assume that local structural conditions are of great significance.

Large areas in the eastern part of the Holbrook region are covered by deposits of Tertiary sand or by extrusive igneous rocks. The structural conditions of the underlying strata in these areas are unknown, but many wells obtain water at the contact of the Chinle or Cretaceous strata with the younger rocks. Irregularities in the old erosion surfaces on which the Tertiary rocks were deposited are probably more effective than structure in determining the quantities of water yielded to wells and the location of springs and seeps.

GROUND-WATER SUPPLIES

GENERAL CONDITIONS

Ground water is of the utmost importance in the Holbrook region, and a very large proportion of the water used in the region for water supply comes from springs and wells. The fact that in the entire region only Silver Creek and the headwater streams of the Little Colorado River are perennial renders adequate development and conservation of ground-water supplies especially necessary. Only a small part of the water that falls as rain or snow has an opportunity to penetrate into the underlying porous rocks. Steep slopes along many of the streams, particularly near their headwaters, and the scanty vegetation in most of the area, promote rapid run-off. The winter snows melt gradually, and probably much of the water from this source enters the ground and appreciably augments the ground-water supply, but most of the water that falls during the torrential downpours that characterize the summer either makes its way promptly to the Colorado River or else wets the soil to only a shallow depth. The many ponds and reservoirs that have been constructed to conserve a part of these surface waters are shown on the hydrologic map (pl. 3). Descriptions of most of the important springs are given on pages 65–74 and are followed by a table that contains all available data on the well-water supplies of the area.

QUALITY OF GROUND WATER

By E. W. Lohr

A total of 118 samples of water were collected in the Holbrook region for chemical analysis. Of these, 86 were obtained from wells, 31 from springs, and 1 from a lake. Two samples, one from a spring (s57) and one from a well (313), are from Alpine, Apache County, which is outside the limits of the Holbrook region.

The water samples were analyzed by E. W. Lohr and S. K. Love in the laboratory of the Geological Survey. Owing to inadequacy of funds, complete chemical analyses were not possible, but the results as given in the table on pages 88–90 represent accurate partial analyses. These partial analyses indicate the suitability of the waters for domestic, industrial, and agricultural uses so far as such uses are affected by the dissolved mineral matter. They do not show the sanitary condition of the waters.

The chemical constituents determined were iron, calcium, magnesium, carbonate, bicarbonate, sulphate, chloride, fluoride, and nitrate. Sodium and potassium together are calculated as sodium. Silica was not determined, and iron only when a quantity in excess of 0.1 part per million was noted to be present. The figure for total dissolved solids was obtained by a summation of the mineral constituents determined or calculated. Hardness was calculated when both calcium and magnesium were determined, otherwise it was determined.

Silica present in the waters will probably average less than 20 parts per million and will not affect the usefulness of the water except as it contributes to the formation of boiler scale.

Iron is dissolved from many rock materials and may be dissolved from water pipes in quantities so large as to be objectionable. Many ground waters contain 2 or 3 parts per million and some even 10 parts or more. Much smaller quantities are present in surface waters, owing to the oxidation of the iron to an insoluble compound on exposure to air. Excessive iron in water will cause stains on white porcelain or enameled ware and fixtures, and on clothes washed in the water.

The iron present in the waters analyzed will average probably less than 0.1 part per million and will not make the waters objectionable.

Calcium and magnesium are dissolved from practically all rocks but particularly from limestone, dolomite, and gypsum. Waters from limestone or gypsum may contain from 30 to 100 or more parts per million of calcium. Such waters may contain only a few parts of magnesium. As the proportion of magnesium in the rocks increases the magnesium in the water increases till the waters from reasonably pure dolomite contain equivalent quantities of calcium and magnesium. Much smaller quantities of calcium and magnesium are found in waters from rocks of other types.

The salts of calcium and magnesium make water hard and with silica and iron form practically all the scale found in steam boilers. They are the cause of much of the trouble encountered in the operation of steam boilers.

The calcium content of the waters examined from the Holbrook region ranges from several parts to more than 200 parts per million, and the magnesium content from 1 to more than 100 parts.

Sodium and potassium are found in all natural waters. In humid areas they make up only a small part of the dissolved mineral matter, but in arid or semiarid areas they may make up the greater part of the dissolved mineral matter. The water from many deep wells contains much common salt (sodium chloride). The quantities of sodium and potassium are likely to be about equal in waters that contain only a few parts per million of the two together. As the total quantity of the two increases the proportion of the potassium decreases, so that a water having 50 parts per million of the two may have only 5 parts or less of potassium. Moderate quantities of these constituents in water have little effect on its use, but more than 50 parts per million of the two may cause trouble in the operation of steam boilers. Sodium salts in quantities greater than 60 percent of the total dissolved mineral matter in waters used for irrigation may injure crops and soils [39] and may make the waters unsatisfactory for other uses.

Some of the waters analyzed contain large quantities of sodium salts, so that they are unfit for most uses. The quantities of sodium and potassium together ranged from several parts to more than 2,000 parts per million. About 40 percent of the samples contained less than 50 parts, and about 60 percent less than 100 parts. Sodium and potassium together in about 40 percent of the samples made up the greater part of the dissolved mineral matter.

Carbonate and bicarbonate (CO_3 and HCO_3) occur in waters largely through the action of carbon dioxide, which enables the water to dissolve carbonates of calcium and magnesium. Carbonate is not

[39] Scofield, C. S., Quality of irrigation waters: California Dept. Public Works, Div. Water Resources, Bull. 40, 1933.

present in appreciable quantities in many natural waters. The bicarbonate in waters that come from insoluble rocks may amount to less than 10 parts per million; many waters from limestone contain from 200 to 400 parts per million; and certain waters that contain sodium bicarbonate may carry 1,000 or more parts per million of bicarbonate. The bicarbonate as such has comparatively little effect, although a large quantity may make water unsatisfactory for drinking and other domestic uses.

Sulphate (SO_4) is dissolved in large quantities from gypsum and from deposits of sodium sulphate. It is also formed by the oxidation of sulphides of iron and is therefore present in considerable quantities in waters from mines and from many beds of shale. Many alkali waters contain more than 1,000 parts per million of sulphate. Sulphate in waters that contain much calcium and magnesium causes the formation of hard scale in steam boilers and may increase the cost of softening the water.

Chloride (Cl) is dissolved in small quantities from rock materials in most parts of the country. The chloride in waters has little effect on their use unless it is present in excessive quantities, as in brines.

Nitrate (NO_3) in water is considered a final oxidation product of nitrogenous organic material. The quantities usually present have no effect on the value of water for ordinary use.

Bicarbonate is present in larger quantities than the other acid constituents in the waters analyzed from the Holbrook region. The average quantities of sulphate and of chloride in the samples are about equal. Nitrate and fluoride are present in comparatively small quantities.

Although fluoride is present in small quantities it is important because of the relation between fluoride in drinking water and the dental defect known as mottled enamel.[40] Drinking-water supplies that will be used by young children should be selected from waters whose analyses indicate concentrations of less than 1 part per million of fluoride.

Hardness is caused almost entirely by the salts of calcium and magnesium and is expressed in parts per million of calcium carbonate equivalent to the calcium and magnesium present. A hardness of 50 parts or less is scarcely noticed, but a hardness of 100 parts or more is noticed by almost everyone. Many laundries and industrial establishments find it profitable to soften water, even if its hardness is less than 100 parts per million.

The hardness of the waters analyzed has a wide range, with an average around 310 parts. About 20 percent of the samples have

[40] 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.

hardness less than 100 parts, and about 66 percent have hardness between 100 and 500 parts.

The chemical analyses show considerable variation in mineral content of the samples. The water from Pinetop Springs, Navajo County (s16 in the table), contains only 80 parts of dissolved mineral matter and is very soft. It is utilized by a State fish hatchery and by the village of Pinetop. In contrast might be mentioned well 99, in T. 17 N., R. 22 E., which yields salty water that contains 6,197 parts per million of dissolved mineral matter and has a hardness of 633 parts per million. About half of the waters analyzed contain less than 500 parts of dissolved mineral matter, and about 10 percent contain more than 2,000 parts.

The average composition of the waters from the principal water-bearing horizons in the Holbrook region is shown in the following table. As only a few samples were collected from some of the geologic units the analyses are possibly not representative of the waters from those particular formations. Furthermore, contamination from the surface or from water-bearing beds at other horizons, if it occurred, would tend to make some of the results unreliable. The best information and samples obtainable were used, however, and it is believed that in general the samples are truly representative of waters from the geologic horizons to which they are ascribed.

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Average composition of waters from the principal water-yielding strata of the Holbrook region

[Parts per million]

Source	Number of analyses	Total dissolved solids	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulphate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Total hardness as $CaCO_3$	Designation in table of analyses of wells and springs used in averages
Wells in alluvium in Rio Puerco Valley	3	754	102	27	122	318	285	44	0.3	16	366	151, 179.
Wells in alluvium in Cottonwood Wash	3	1,406	26	--------	513	538	262	356	.7	2.1	103	32, 33, 42.
Wells in alluvium in Leroux Wash	2	1,926	6	--------	778	1,134	426	234	4.6	.20	21	52, 67.
Wells in alluvium in Little Colorado River Valley	4	1,735	102	36	504	314	214	723	.15	.75	404	3, 56, 58, 95.
Warm springs and flowing well in travertine deposits	4	2,164	264	79	403	624	598	511	1.4	.42	983	293, s35, s36, s48.
Springs within or at base of extrusive lavas, Navajo County	2	84	14	--------	6	94	2	1.5	.0	.35	69	s21, s28.
Springs within or at base of extrusive lavas, Apache County	9	179	23	23	24	170	14	9.2	.28	4.8	120	s39, s42, s43, s44, s51, s52, s53, s54, s57.
Wells and springs at contact of Tertiary sand and Chinle formation	6	270	25	7.8	77	202	20	35	.17	11	80	205, 214, 216, s21, s28, s33.
Springs within Cretaceous strata	6	639	98	39	96	297	230	45	.4	1.6	336	s25, s30, s31, s32, s34, s49.
Wells in Cretaceous (?) strata	2	214	18	--------	68	192	10	23	.2	2.1	54	218, 224.
Wells in Chinle formation	5	652	62	47	135	449	143	46	.5	14	299	145, 155, 156, 302, 307.
Spring at base of Shinarump conglomerate	1	328	44	7	56	90	151	16	.2	9.0	139	s1.
Wells within Moenkopi formation	6	2,847	136	47	863	261	448	1,226	.05	.12	531	8, 9, 12, 16, 99, 105.
Wells within Coconino sandstone	24	588	72	34	93	230	153	122	.01	.09	320	5, 10, 11, 14, 15, 17, 19, 21, 22, 59, 60, 62, 87, 88, 90, 91, 92, 106, 111, 114, 136, 138, 251, 254.

SPRINGS

GENERAL RELATIONS

Springs are an important source of water in the Holbrook region. They range from mere seeps to excellent springs that flow several second-feet. In general the waters are soft and of better quality than most of the well waters. Some of the springs are well developed, and their waters are utilized to the greatest possible extent, but others have not been developed properly, and most of the water is permitted to go to waste.

Some rocks, such as sandstone, permeable limestone, volcanic ash, vesicular basalt, and cinders, permit water to escape readily, whereas shales, clays, and dense limestones are relatively impermeable to ground water and hence act as barriers. Where the contact of a permeable stratum overlying an impermeable stratum is exposed at the surface, a spring is likely to result, provided other factors are favorable.

Springs occur at several geologic horizons, as summarized in the following table:

Relation of springs to geologic horizons in the Holbrook region

Geologic horizon	Character of springs
"Mound type" water emerges at or near top of mud mound built up by accumulation of wind-blown sand and silt.	See Navajo Springs, pp 69-70.
Contact of Quaternary alluvium with older formations.	Commonly temporary, with small yields of poor water.
Contact of Tertiary sand with Chinle formation	Numerous small springs and seeps; good water.
Contact of lava flows with underlying impermeable strata.	Many springs, some very large. Water of excellent quality.
Warm springs from travertine deposits	Several large springs north of St. Johns and east of Hunt. Water highly mineralized.
Within or at base of Cretaceous strata, at contact of permeable and impermeable beds.	Numerous small springs of good water.
Contact of Wingate sandstone with underlying Chinle formation.	No springs known within Holbrook region, but a good horizon farther north.
Within Chinle formation, at contact of permeable and impermeable beds.	Water likely to be very poor and yield small.
Contact of Shinerump conglomerate with underlying Moenkopi shale.	Few small springs and seeps of good water.
Within Coconino sandstone	Several springs near Joseph City yield fresh water from this horizon.

COCONINO COUNTY

The names and locations of many springs in Coconino County are shown on plate 3. All the springs are in the mountainous country at high altitudes, and most of them occur at the contact between vesicular lava flows and the underlying sedimentary rocks. These springs are maintained by precipitation in the mountains, and during the dry seasons their volume diminishes and many springs fail entirely. None of the water reaches main drainage channels. For the most part these springs are small and are utilized for domestic supplies or for stock. Some of them are not used at all. Because of their isolation and relative unimportance the springs of the Coconino County portions of the Holbrook region were not studied in detail. The location of most of the springs has been taken from United States Forest Service maps. Anderson Springs, in T. 18 N., R. 10 E., are typical of most of the springs in this area, except for the fact that they are depositing travertine at the present time. The calcareous material is possibly derived from the Kaibab limestone, which underlies the lava in this vicinity.

NAVAJO COUNTY

Brief descriptions of many springs that are known to occur in Navajo County are given below:

s1. Tucker Springs, in sec. 35, T. 20 N., R. 15 E., 5 miles north of Winslow, a small spring at the contact of the Shinarump conglomerate and the underlying Moenkopi formation, yields excellent water (see analysis s1, p. 89) but flows only part of the year. It is used for stock and domestic purposes. The spring has been developed by means of a short tunnel dug into a cliff of conglomerate, and the floor of the tunnel serves as a collecting basin.

s2. Several springs are known to occur in the SW¼ SW¼ sec. 28, T. 18 N., R. 19 E., and a fairly large spring is reported in the same section. Two flowing wells that obtain water from the Coconino sandstone also occur in this section. About 30 small springs of similar character occur in sec. 33 in the same township. The area is low in altitude and the Coconino sandstone crops out nearby. Water undoubtedly comes from the Coconino, as the nearby Moenkopi is thinned by erosion and does not bear water.

s3. Fourmile Spring, on Cottonwood Creek in sec. 33, T. 13 N., R. 21 E., occurs in the bed of the wash where bedrock has been exposed by erosion. The water comes from valley fill, flows along the surface for a short distance, and again sinks into the wash materials.

s4. Shumway Springs, in sec. 25, T. 12 N., R. 21 E., include several springs with a comparatively small flow of good water that issue from the contact of a shale and an overlying sandstone, which are probably both of Moenkopi age. The strata dip 2°–5° NE. The valley of Silver Creek is entrenched in Quaternary alluvium in this vicinity. The main ditch that carries water from Silver Lake Reservoir to Taylor and Snowflake follows the hill a few feet above the valley floor, but it is probable that the springs are fed by ground water rather than by seepage from the ditch.

s5. Walnut Spring, in the SW¼ sec. 27, T. 12 N., R. 22 E., is a large spring that flows about 1 second-foot. The water issues from lava, and there are indications that it is under some hydrostatic pressure. Doubtless the water is diverted by underlying shales or by an impermeable layer in the lava. An artificial lake below the spring acts as a reservoir. It is reported that the flow of Walnut Spring varies directly with the amount of water stored in the nearby Silver Creek Lake, but the spring is known to have existed before the Silver Creek Dam was built. During very dry seasons Walnut Spring diminishes and occasionally dries up completely. The temperature of the water is 59° F.

s6. Several springs on the property of E. K. Muder, in sec. 30, T. 12 N., R. 22 E., are very similar to those in the vicinity of Shumway, described above, but the flow is considerably greater. The water issues from a sandstone in the Moenkopi formation, is moderately hard, and has a temperature of 50° F. Chemical analysis s6 represents this water.

s7. Clay Spring, in sec. 11, T. 11 N., R. 19 E., issues in the bed of an arroyo from gravel beds that are overlain by late valley fill, chiefly clay and silt. The yield is 4 gallons a minute, and the water is used to some extent for cattle, although the spring is poorly developed and much water is wasted.

s8. Perkins Spring, in the SW¼ sec. 24, T. 11 N., R. 19 E., yields a small flow from gravel in an arroyo. It formerly supplied drinking water for several ranches, but it is now dry except in extremely wet seasons.

s9. A large spring in the NW¼ sec. 19, T. 11 N., R. 23 E., issues from the contact of a lava flow with the underlying sedimentary strata. It is not possible to determine accurately the formation that underlies the lava in the area of these big springs, but a 10- to 15-foot cellar excavation near this spring has exposed beneath the lava red shale or red clay, which possibly came from Moenkopi beds. The spring is similar in all respects to Silver Creek Spring.

s10. Silver Creek Spring, in the SW¼ sec. 28, T. 11 N., R. 23 E., is the largest spring in the entire Holbrook region and supplies most of the water in Silver Creek. Old-time residents of the region state that the spring has never gone dry, even during severe droughts. It issues from lava, probably from the contact of the igneous rock and underlying sedimentary strata (pl. 9, *A*). The flow is several second-feet, but it cannot be measured accurately, as the water is not confined to a single point of issue. Mr. Decker, secretary-treasurer of the Snowflake-Taylor Irrigation Co., states that the combined flow of all springs at the head of Silver Creek totals 11 second-feet. The waters of Silver Creek are retained in the Silver Creek Reservoir, above Shumway, which supplies water for irrigation near Taylor and Snowflake and for power development at Shumway. The temperature of the water on February 14, 1934, was 60° F. (See chemical analysis s10.)

s11. James Peterson Spring, in the SW¼ sec. 16, T. 10 N., R. 20 E., yields about 5 gallons of water a minute from the contact of massive brown even-grained sandstone and light-colored thin-bedded shale, both of Cretaceous age. The water is used for domestic supply, irrigation of a small orchard, and stock use. A thin film of calcium carbonate forms on the water in the spring house. (See chemical analysis s11.)

s12. At Linden, in the SE¼ sec. 5, T. 10 N., R. 21 E., a small spring issues under the dam of a small earthen reservoir. It flows the year around but appears to be entirely due to seepage from the reservoir.

s13. Adair Spring, in the SE¼ sec. 26, T. 9 N., R. 22 E., yields an excellent water supply for the village of Lakeside. The water appears to issue from vesicular lava but is believed to come from the contact of the lava and the underlying sedimentary rocks, which are perhaps Cretaceous shale, although the contact is invisible. This is one of the best springs of the entire region and has an estimated flow of 0.5 second-foot. The temperature of the water is 54° F.

s14. Paige Spring, in the NW¼ sec. 18, T. 9 N., R. 23 E., flows from lava, like Adair Spring. A. W. Yoder, superintendent of the Arizona State fish hatchery at Pinetop, reports that the average temperature of the water at Paige Spring has been 64° for the last 5 years, 10° or 11° warmer than all other springs in this region.

s15. Thompson Spring, near the south quarter corner of sec. 34, T. 9 N., R. 23 E., flows from vesicular lava. It is small and dries up during prolonged droughts. According to A. W. Yoder, the temperature is 53° F.

s16. Pinetop Springs, in the NW¼ sec. 3, T. 9 N., R. 23 E., form one of the largest spring groups in the Holbrook region and yield 400 gallons a minute from vesicular lava. The springs bubble up from several points in a depression in the lava. The water is used in part at the Arizona State fish hatchery and in part for domestic supply at Pinetop. (See chemical analysis s16.)

s17. Halleck Spring, in the NW¼ sec. 4, T. 8 N., R. 23 E., is a small spring that issues from lava and is similar to Pinetop Springs but has a smaller flow. It was not visited by the writers.

APACHE COUNTY

All types of springs that occur within Apache County are represented in the brief descriptions of typical springs presented below, but no attempt is made to list all the springs of the county. A glance at the map showing wells and springs (pl. 3) will serve to indicate the widespread occurrence of springs in this county.

s18. Querino Spring, in the SW¼ sec. 28, T. 22 N., R. 29 E., owned by J. M. Counts, is a small spring that flows from the contact of red sandstone and red shale which appear to be parts of the Moenkopi formation, though possibly Chinle. (See chemical analysis s18.)

s19. A small spring near a prehistoric ruin in sec. 31, T. 22 N., R. 30 E., yields 2 gallons a minute. The water comes from Chinle or

Shinarump beds. The spring is not developed and most of the water is wasted.

s20. Taylor Spring, in sec. 27, T. 21 N., R. 27 E., 0.4 mile north of U. S. Highway 66, appears to issue from the contact of Chinle sandstone and shale. The flow, about 6 gallons a minute, is sufficient to supply a large road construction camp with water. (See analysis s20.)

s21. Emigrant Springs, in sec. 36, T. 21 N., R. 28 E., comprise three springs, several hundred feet apart, that yield a few gallons a minute from a conglomeratic bed in Tertiary sand. The water is used by Indians for domestic supplies and for stock. (See chemical analysis s21.)

s22. Salt Seeps, on the line between secs. 26 and 27, T. 20 N., R. 27 E., lie in an oval depression in Tertiary sands that is filled with water which seeps into the depression from several points along the margin. Bedrock is not exposed, but Chinle strata are near the surface, and the water horizon is probably at the contact between the Chinle shales and the overlying Tertiary sands. A white precipitate of "alkali" is formed on the banks of the pond. The water is used for stock.

s23. Squaw Spring, in the SE¼ sec. 12, T. 20 N., R. 27 E., in a depression in Tertiary sands, is a small seep that yields about half a gallon a minute. There is no indication to show whether the underlying Chinle formation is close to the surface. The water is used for stock.

s24. A small spring in sec. 16, T. 20 N., R. 27 E., in the bed of the Rio Puerco, is typical of several small springs that rise in the bed of the river. Even during droughts it yields sufficient water for stock. The water comes from the sand and gravel of the river flood plain and appears at the surface where erosion has exposed the sand and gravel and the underlying impermeable beds.

s25. The Navajo Springs, in the SE¼ sec. 29, T. 20 N., R. 27 E., 3½ miles southeast of Navajo, are typical of the mound type of springs, which are described by Bryan [41] as follows:

> Mound and knoll springs occur in arid climates. The water emerges at or near the top of a mound which has been built up by the accumulation of wind-blown sand and dust in the belt of vegetation surrounding the spring. The height of the mound is limited by the height to which the water can rise, for any accumulation of sand that is not moist is easily removed because it cannot support the protective vegetation. When the water can rise no higher, the process which builds the mound tends to ceil it over. If the water then finds a new and lower outlet, the mound is drained and subjected to erosion, especially by wind. Mound springs are found in many arid countries in places where water emerges under pressure. Good examples occur in the Tularosa Basin in New Mexico.

The Navajo Springs are situated on an outcrop of red shale which is probably part of the Chinle formation. Tertiary sand, which covers

[41] Bryan, Kirk, Classification of springs: Jour. Geology, vol. 27, pp. 522–561, 1919.

large areas in this part of Apache County, is very thin or absent in the vicinity of the springs. The ground surface is nearly level but slopes gently toward the west. Many low mud mounds, 12 to 18 inches high, occur within an area of about 2 acres, and water, mixed with some silt, bubbles upward from the centers of several of them (pl. 9, *B*). One of the spring orifices has been probed to a depth of 18 feet. The deep and sticky mud that surrounds the springs necessitates fencing to prevent the miring down of cattle.

Some years ago a 12-foot well was dug in one of the mounds. It was timbered and according to B. W. Porter, of Navajo, yielded a 3-inch stream of water indefinitely to a gasoline pump. The well is flowing at present but is not in use. Though the Navajo Springs have been known for many years they are now used only by grazing cattle. It should be possible to develop considerably more water by digging more wells and allowing the dangerous mud holes around the springs to dry up.

The source of the water in the Navajo Springs is not known. It may come from the basal beds of the Chinle or from lower formations and rise along a fissure through confining strata that would permit it to rise under hydrostatic pressure. Another possible explanation is that minor unconformities may occur within the Chinle formation and that a depression filled with porous material has been intersected by the ground surface. Ordinarily the Chinle beds yield little water and usually that is unfit even for stock use. The water from the Navajo Springs, however, contains only 367 parts per million of dissolved mineral matter (analysis s25).

s26. The Cottonwood Seeps, in the SE¼ sec. 23, T. 19 N., R. 26 E., are several small springs that occur in a deep wash and issue from the contact of the Chinle formation with overlying Tertiary sands. The estimated flow is 3 to 5 gallons a minute. Similar seeps downstream flow into a tank for stock use.

s27. Black Knoll Spring, in sec. 34, T. 18 N., R. 25 E., is a small spring on the east side of Black Knoll which is reported to yield "sufficient water for 8 to 10 head of stock." The geologic map (pl. 2) shows a small mass of igneous rock at this locality, and possibly the water comes from the contact between Chinle beds and lava.

s28. Ninemile Spring, in the SW¼ sec. 2, T. 18 N., R. 26 E., was well developed at one time, and pipes conducted water to a tank for stock use, but in recent years the pipe has rusted away. The water occurs at the contact of Chinle shales with overlying Tertiary sands. The flow is estimated to be 7 to 10 gallons a minute. Chemical analysis s28 shows the water to be of good quality.

s29. Prospect Spring (also known as Walford Spring), in sec. 34, T. 17 N., R. 28 E., issues from an area covered by Tertiary sand and is equipped with a concrete storage tank. The water is of poor quality, and the yield is small.

s30. Cedro Spring, in the center of sec. 34, T. 17 N., R. 30 E., issues at the base of a cliff along the Zuñi River, at the contact of Cretaceous sandstone and Chinle shale. The spring apparently occurs at a local high point on the contact. The measured yield is 17 gallons a minute and the water flows through a concrete spring house into a trough and earthen reservoir. It supplies water to irrigate 1 or 2 acres of land. (See analysis s30.)

s31. Pipe Spring, at the common corner of secs. 25, 26, 35, and 36, T. 17 N., R. 30 E., is similar to Cedro Spring except that the water is believed to emerge from within the Cretaceous strata. The yield is 2 gallons a minute, and the water is piped to a concrete trough for stock use. (See chemical analysis s31.)

s32. Rock Crossing Spring, in the SW¼ sec. 21, T. 17 N., R. 31 E., occurs at the base of a high ledge of sandstone in the bed of the Zuñi River just below the road crossing. The river is dry above the sandstone ledge. The water is doubtless diverted by an impermeable layer of shale. Downstream, the Zuñi River carries a fairly large volume of water, which is fresh and clear. Chemical analysis s32 shows this water to be fairly high in dissolved mineral matter, chiefly sulphates.

s33. Seven Springs, in sec. 20, T. 16 N., R. 27 E., occur at the contact of Tertiary sands with Chinle shales. The water from each spring is collected through tiles into a wooden box, and the water from the boxes is conducted by iron pipes to a central concrete tank. The combined flow of all the springs is about 5 gallons a minute. These springs are better developed than the average, but local ranchmen state that the investment did not pay. This is possibly due to the fact that most of the surrounding country is badland which supports only a few cattle. (See chemical analysis s33.)

s34. Pine Spring, in sec. 18, T. 15 N., R. 31 E., is near the bottom of a deep canyon and issues at the base of a 100-foot bed of massive sandstone. This sandstone and the underlying shale are probably of Cretaceous age. The spring is small and is used for stock, but no effort has been made to develop a good water supply. (See chemical analysis s34.)

s35. Stinking Spring, in the SW¼ sec. 10, T. 14 N., R. 26 E., and Montoya Spring have been described above in connection with the discussion of travertine deposits. The temperature of the water of Stinking Spring was 62° F. on February 16, 1934. The yield is about 40 gallons a minute, and the water, which has no appreciable odor at present, issues from a travertine cone built by the ascending waters. The surface geology is relatively complex and has not been adequately mapped. A short distance east of the spring are outcrops of Shinarump conglomerate and Moenkopi sandstone. In places the rocks dip 12°–15° W. Chemical analysis s35 shows the water from this spring to contain much more dissolved mineral matter than the average spring in the region. It is high in chlorides, sulphates, and bicarbonates. The water is used to a moderate extent for irrigation.

s36. Montoya Spring, in sec. 14, T. 14 N., R. 26 E., issues at the contact of a thick, massive cross-bedded red sandstone with an underlying shale that forms the base of the river flats. The sandstone, which is probably of Moenkopi age, dips 5°–10° W. Water from the spring flows into a dirt tank. The flow is estimated to be 5 gallons a minute. Chemical analysis s36 shows this water to be very similar to that from Stinking Spring and from Salada Springs.

s37. Zion Dam Spring, in the NE¼ sec. 21, T. 14 N., R. 27 E., is on the north bank of Zuñi River, below the Zion Reservoir Dam. The water issues from the contact of a cross-bedded red sandstone and a red shale, which are both probably of Moenkopi age. There is a possibility that this water represents seepage from the reservoir, but this interpretation is doubtful and the spring is considered natural. The flow is small.

s38. Schuster Spring, in the SW¼ sec. 33, T. 13 N., R. 27 E., is the main source of water for the town of St. Johns and yields about 12 gallons a minute. The spring occurs at the contact of Tertiary lava and underlying sedimentary rocks, probably Chinle shales. The water is led directly into a pipe, through which it flows by gravity to St. Johns, 3 miles distant. The temperature of the water was 44° F. on December 9, 1933. (See chemical analysis s38.)

s39. McIntosh Spring, in the SW¼ sec. 20, T. 13 N., R. 29 E., yields water that is used by the town of St. Johns to supplement the supply from Schuster Spring. It yields 5 gallons a minute. Moenkopi beds crop out near the spring, and it is possible that the Shinarump conglomerate furnishes the water supply. The water is piped from a concrete spring house to St. Johns but is not ordinarily used during the winter on account of danger of freezing the exposed pipe. (See chemical analysis s39.)

s40. Several small springs in T. 13 N., R. 30 E., are approximately in secs. 22, 23, 32, 33, and 35. Their yield is small, and the water is used chiefly for sheep. The water is reported to be unpalatable and highly mineralized. The springs probably issue from the Chinle formation, but possibly from Tertiary travertine or from Cretaceous formations.

s41. The Leverton Ranch Spring, in sec. 14, T. 12 N., R. 24 E., was not seen, but its location suggests that it issues from the Shinarump conglomerate.

s50. Bunger Spring, in sec. 28, T. 12 N., R. 25 E., occurs at the contact of lava and the underlying sedimentary rocks, probably Chinle shales. This spring might be classed as a dug well, as some excavation has been made, but when visited on January 4, 1934, it was flowing at the surface and resembled a spring. Whether or not it was a spring when first discovered is not known. (See chemical analysis s50.)

s42. The Ortega Springs, in the SW¼ sec. 10, T. 12 N., R. 26 E., are a series of springs that emerge along a small valley. Water flows from beneath the cap of lava on the margins of the valley. The water is excellent (analysis s42).

s43. The Concho Springs, in sec. 19, T. 12 N., R. 26 E., issue from several points at the contact of lava and Chinle shales and form a flowing stream that feeds Concho Lake. The water is excellent (analysis s43).

s44. Malpais Spring, in sec. 26, T. 12 N., R. 26 E., as the name indicates, flows from beneath lava, or "malpais" rock, probably at its contact with the Chinle formation. The spring occurs at the foot of a bluff that forms the east wall of a small valley. The water is excellent and the flow comparatively large (analysis s44).

s45. The Monico Springs, in secs. 7 and 8, T. 12 N., R. 27 E., are four springs that occur at the contact of lava with the underlying Chinle formation. The water temperature was 57° F. on December 6, 1933. The combined yield of the springs is about 4 gallons a minute. Water from one spring is piped to the Monico Garcia ranch headquarters, where part of it is retained in a small metal tank. Most of the water, however, flows into a mud hole, which is used by cattle. The supply of water could be considerably increased by proper development.

s46. Swinburne Spring, in sec. 30, T. 12 N., R. 27 E., which occurs at the contact of lava and underlying sedimentary rocks, was not seen by the writers but is reported to have a comparatively large flow.

s47. Springs and seeps on the property of Henry Platt, in sec. 12, T. 12 N., R. 28 E., occur in a wide wash that has sandy banks. The Chinle formation is the bedrock. The seeps occur along the convex side of the stream channel, apparently at the contact of a sandstone and a shaly bed, but they may represent subsurface flow that is brought to the surface where the stream channel crosses a resistant and relatively impervious stratum. The combined flow of the springs is estimated to be 25 gallons a minute.

s48. The Salado Springs, in the NW¼ sec. 21, T. 12 N., R. 28 E., comprise several springs along the Little Colorado River that yield water from crevices in travertine. The present springs are depositing travertine. The combined flow of all the springs in this area into the Little Colorado River is between 5 and 10 second-feet, and the temperature on February 2, 1934, was 74° F. (See analysis s48.)

s49. Gallegos Spring, in the NW¼ sec. 16, T. 12 N., R. 31 E., is a small spring that is estimated to flow 3 to 5 gallons a minute. It occurs in a small wash in which Chinle shale overlain by Cretaceous conglomerate and sandstone is exposed. Water issues from the contact of these formations and from the conglomerate. The spring is not developed. (See chemical analysis s49.)

s51. Laguna Salada Spring, in sec. 20, T. 11 N., R. 25 E., issues beneath lava. Known Cretaceous formations crop out a short distance to the south, and it is probable that this spring occurs at the contact of the lava and the Cretaceous rocks. The spring water enters Laguna Salada, which has no known outlet, and the dissolved mineral matter is highly concentrated by evaporation. (See analysis s51.)

s52. The "24" Ranch Spring, in the SE¼ sec. 6, T. 10 N., R. 28 E., is an excellent spring that yields 31 gallons a minute (measured). Water issues from the contact of lava and a hidden impervious stratum, probably part of the Chinle shale. The water is retained in a small natural lake and is used principally for stock. (See analysis s52.)

s53. A spring on the property of W. E. Wiltbank, in sec. 8, T. 10 N., R. 28 E., is located in a large basin, known as a cienega, in which water may be obtained a few feet below the surface at any place. Lava caps the surface, and the water occurs at the contact of the lava with the underlying strata, probably Chinle shale. Springs break forth at several points where the lava has been fractured or where its base is exposed by erosion. (See chemical analysis s53.)

s54. Neilsen Spring, in sec. 2 or 3, T. 10 N., R. 28 E., is typical of a great number of springs at and near Richville along the Little Colorado River. The water issues from the contact of Tertiary lava and underlying red shales that are believed to be of Chinle age. (See chemical analysis s54.)

s55. A spring on the ranch of Bert Colter, in sec. 8, T. 9 N., R. 29 E., issues about 100 feet below the top of a large mesa that is capped with Tertiary lava. The water comes from a sandstone in sedimentary rock of probable Chinle age. The flow is about 5 gallons a minute, and the water is of good quality.

s56. Tanner Spring, in the NW¼ sec. 6, T. 25 N., R. 21 E., issues from the contact of Tertiary sands and Chinle shale and yields about 12 gallons a minute. Several small mud craters, similar to those near Navajo Springs, occur in the immediate vicinity. The spring water runs into a trough and thence into two small ponds. It is used by Indians for domestic purposes and stock.

WELLS

With the exception of a few shallow dug wells within some of the towns, available data on all known wells and well-water supplies in the Holbrook region are given in the following table and on plate 3. The distribution of wells is decidedly spotted, the greatest concentration being along the railroad and near the centers of population. Thus, although the number of wells only slightly exceeds the number of townships in the region, there are many large areas, covering several townships, where no wells or other permanent water supplies have been obtained. This condition is due in part to lack of necessity for water, in part to unfavorable geologic conditions, and in part merely to lack of efforts to obtain water. Grazing conditions in the badlands of the Painted Desert region, for example, are unfavorable at best, and there is no particular incentive for drilling deep and expensive water wells. Wells drilled in Chinle shale, in Tertiary sand, or in the thick lava flows are ordinarily not successful unless the whole formation is penetrated, and wells are naturally scarce in areas covered by these rocks. Available data indicate, however, that where these formations are thin, or where such aquifers as the Coconino sandstone or the Cretaceous sandstones are relatively close to the surface, more wells might be drilled to advantage.

Records of wells in the Holbrook region, Arizona

[Wells 393, 394, 432, 438, numbers assigned by Office of Indian Affairs. For wells marked with asterisk (*) chemical analysis of water is given in table on pp. 89–90. Method of lift in wells: E, engine; W, windmill. Use of water: D, domestic; I, irrigation; PS, public supply; Ry, railway; S, stock]

Coconino County

No.	Type	Depth (feet)	Diameter	Water level (feet below surface)	Method of lift	Use of water
1	Drilled	900	8¼ inches	870	E, W	S
2						
*3	Drilled	78-100	8¼ inches		E	D, PS
393	do	400	do			S
394	do	425	do			S
432	do	253	do			S
438	do	255	do			S
4					W	D, S
*5	Drilled	1,155	8¼ inches	650	E, W	S
*6	do	400?	do	(?)	W	D, S
7	do	200	do	(?)	W	S
*8	do	320	do	(?)	W	S
*9	do	300	do	30	W	S
*10	Shaft, boarded	713	5 by 10 feet	648	None	
*11	Drilled	470?	8¼ inches		E, W	S
*12	do	220	do		W	S
13	do	700	do		W	S
*14	do	475	do		W	S
*15	do	330	do		W	S
*16	do	240	do		W	S
*17	do	480	do		E, W	S
*18	Dug	12	4 feet		Bucket	D, S
*19	Drilled	900	8¼ inches		E	S
20	do	250	do		E	D, S
*21	do	520	do		W	S
*22	do	580	do		E, W	D, S
23	do	744	do	217	(?)	D, S
24	Dug	74	3 feet			
25	Drilled	470	8¼ inches			
26						
27	Drilled	477	8¼ inches	372		S
28						

See notes at end of table.

Records of wells in the Holbrook region, Arizona—Continued

Navajo County

No.	Type	Depth (feet)	Diameter	Water level (feet below surface)	Method of lift	Use of water
30, 31	Driven	27			W	S
*32	Drilled	38	8 inch (top); 6 inch (bottom)		W	D, S
*33	do	105	8¼ inches	95	W	D, S
34, 35	Driven	18				
36	do	35	3 inches			S
37	do	35			W	S
38	do	35				
39	do	37		12	W	S
40	do	37		37		S
*41	Drilled	280	8 inches	169	W	D, S
*42	Shaft, boarded	40		38	W	S
43	Drilled	990	12½ inches	70	E	
44						
45, 46						
47	Driven	37				
48	do	30				
49	do	35				
50	do	40			W	
51	do	45				
*52	Dug and driven	30	10 by 4 feet (for 10 feet), 8 inches (for 20 feet).	30		S
53	Driven	27				S
54	Drilled	307	8¼ inches			S
*56	Dug	12	3 feet			S
57	do	Shallow	do			S
*58	do	do	do			S
*59	Drilled	325	8¼ inches	320	Power pump	PS
*60	do	328	do	45		PS
61	do					
*62	do	60–100	8¼ inches			S
63	Driven	40				S
64	Dug	30				
65	Drilled	400	8¼ inches			
66	Driven	48				S
*67		Shallow		7		
68	Drilled	150	8¼ inches	60		D, S
69	do	35				S
70	Driven	40				S
71	Drilled	65	8¼ inches			S
72	Slush-bucketed	50	3 inches			S
73	Driven	45		7		S
74, 75	do	50				S
76	Driven	65				S
77	do	40				S
78	Dug	35	4 feet			S
*79	Drilled	50		38		D, S
80	Driven	55				S
81	do	60				S
82	do	55				S
83	do	35				S
84, 85		50				
86						
*87	Drilled	50–80	8¼ inches			I
*88	do					
89	do	45	8¼ inches			
*90	do	55	do			
*91	do	65	do	10		D, I, S
*92	do	250	do	215		D
93	do	214	do	189		
94	do	4,675				
*95	do	78	8¼ inches			PS
96	do	139	do	12½		Ry
97	do	136	16 inches	15		Ry
98	do	82–92				
*99	do	400		120		S
100	do	300				
101	do	100				S

See notes at end of table.

Records of wells in the Holbrook region, Arizona—Continued

Navajo County—Continued

No.	Type	Depth (feet)	Diameter	Water level (feet below surface)	Method of lift	Use of water
102	Drilled (cored)	476	8¼ inches			
103	Drilled	480	do	450		D, S
104	do	365	do			
*105	do	125	do		Hand pump	
*106	do	41	do		W	PS
107						
108	Drilled	1,023	8¼ inches	121		
109	do	±3,400				
110		±2,500				
*111	Drilled	400	8¼ inches	290	W, E	D, S
112	do	420	do		W	D, S
113	do	3,380				
*114	do	300	8¼ inches	80	E	PS
*115	do	110	do		W	S
*116	Dug	14	3 feet		Bucket	D
*117	do	14	do	12	do	D
*118	Drilled	57	8¼ inches		W	D
119	Dug	18	2 to 4 feet			D, S
120	do	Shallow				D, S
121 122						
123	Drilled	492				
124	Dug	15–40				D, S
125	do					
126	Drilled	345	8¼ inches			
127	do	90	do	32		

Apache County

No.	Type	Depth (feet)	Diameter	Water level (feet below surface)	Method of lift	Use of water
*130	Drilled	40 300		30		D, S
131	Dug	35			Bucket	D, S
*132	Drilled	78	8¼ inches	35	W, E	D, S
133	do	130			W	D, S
134	do	115	16 inches			Ry
135	do	96	do	20		Ry
135	do	200	16 inches (top) 12 inches (bottom)	17		Ry
135	do	109	16 inches			Ry
135	do	110	do			Ry
135	do	210	20 inches (top) 12 inches (middle) 10 inches (bottom)	32		Ry
135	do	210	20 inches (top) 12 inches (middle) 10 inches (bottom)	32		Ry
*136	do	360	8¼ inches	340		
137	Dug	17				
*138	Drilled	312	8¼ inches	200		D
139	do	70	do		W	
140						
141	Drilled	70				
142	do	120 180				
143	do	135	8¼ inches			
143a	do	303				
143b	do	605				
*144	do	85	10 inches	38		
*145	do	180	8¼ inches			
146	Driven	55	2 inches			
147	Dug	35		24		
148	do	12				
149	Driven	20	4 inches			S
150	Dug and cribbed	28				S
*151	Dug and driven	53				
152	Driven	50				
153	Dug and driven	90				
154	Drilled	110 130 210				
155	do	210	8¼ inches	135	W	D, S
*156	do	110	do	105	W	D, S

See notes at end of table.

Records of wells in the Holbrook region, Arizona—Continued

Apache County—Continued

No.	Type	Depth (feet)	Diameter	Water level (feet below surface)	Method of lift	Use of water
157	Drilled	110				
158	Dug and blasted	44				
159	Dug	38				
160	Drilled	135	8¼ inches			S
161	Dug	10				
	do	20				
	Dug and driven	24				
162	Drilled	178				
163	Driven					
164	do	26				
	do	38				
165	Dug and driven	40				
	Drilled	80				
166	Dug and driven	40				
167	Drilled	110				
168	Dug and driven	39				
169	Driven	32				
170						
171	Dug	14				
*172	do	8		5	Bucket	
173	Drilled	170				
174	do					
175	Driven	50				
176	do	50				
177	do	50				
178	Drilled and dug					
*179		35				
		70				
*180	Drilled	142		110	W	
181	Driven	22	4 inches			
182						
183	Driven	25				
184	do	25				
185	do	25			W	
186	do	45				S
187						
188	Driven	50				
189	Drilled	136				S
190	do	946				S
191, 192	Driven	27				S
193	Drilled	100	12 inches			
	do	80	10 inches			Ry
	do	98	12½ inches			
194	do	45				S
195		43				D, S
196	Drilled	82				S
197	do	60	10 inches			S
198	Driven	50				S
199	Drilled	50				S
200	Driven	50			E	
201	Drilled	112				S
202	do	123				S
203	do	270				
204	do	140				
*205	do	100				D, S
206	Driven	37				
207	do	37				
208	Drilled	305				
209	do	91	16 inches			Ry
	do	80	do			Ry
	Dug	29	28 feet			Ry
	do	40	do			Ry
210	Driven	50				
211	do	50				
212	do	30				
213	do	30				
*213a	Dug	18			W	S
*214	Drilled	110				S
215	Dug	50				S
*216	Drilled	185				S
217	do	600–700				
*218	do	500–552				
219	do	72				
220						
221	Dug	110?				
*222	do	16			W, E	

See notes at end of table.

Records of wells in the Holbrook region, Arizona—Continued

Apache County—Continued

No.	Type	Depth (feet)	Diameter	Water level (feet below surface)	Method of lift	Use of water
223	Drilled	325				
*224	do	300				D, S
225	Dug	12			W	
226	do	20			W	
227	do	30	20 feet		W	D, S
228	Drilled	50			W	D, S
229	do	50			W	D, S
*230	Dug	30	15 feet		W	D, S
231	Drilled	447				S
232	Dug	20				
233	Dug	25	20 feet			
*234	do	10			W	
235	Drilled	600				
*236	Dug					D, S
237						
238						
239						
240, 241	Drilled	300				S
242	Dug	Shallow				
*243	do	Shallow			W	
244						
*245	Dug	35				
246						
247	Drilled	410?				
248	do	150				
249, 250						
*251	Drilled	175	8¼ inches			D, S
252	do	266	do			D, S
253	Dug	Shallow				S
*254	Drilled	330	8¼ inches			D, S
255						
256	Drilled	70	8¼ inches			
257	Dug	27	3 feet			S
258						
259	Drilled	350	8¼ inches			
260	do	300	do			
261	do	156	do	110		
262	Dug					
263						
264						
265						
266	Drilled	125	8¼ inches		W	S
*267	do	190	do	125	Bailer	
268	do	160	do	60	W	D, S
269						
270						
*271	Drilled	170	8¼ inches	122	E, W	D
*272	do	+150	do	122		
273	do	+225	do			
275	do	100	do			
276	Dug	80	4 feet	4		
277	Drilled	365		165	W	S
278						
279	Drilled	328				
*280	do	350	8¼ inches			
	do	90	3 feet	57	W	D, S
281	Dug	40–70				
282						
283	Drilled	225		30		
284	Dug	10		10	W	
285	do	35				
286, 287						
288	Drilled	167			W	
289	do	340				
290	Dug					
291	Drilled	200	8¼ inches	60	W	
292	do	175	do			
*293	do	90	do			I
294	do	160	do			
295	Dug	30	3 feet	2	W	
*296	do					
297	Drilled	225				
*298	do	155	8¼ inches	90		
299	do	84	do	40		

See notes at end of table.

Records of wells in the Holbrook region, Arizona—Continued

Apache County—Continued

No.	Type	Depth (feet)	Diameter	Water level (feet below surface)	Method of lift	Use of water
*300					W	
*301	Dug	15	3 feet			
*302	do	18 18 40				
303	Drilled	685				
304	do	(?)	6 inches			
305	do	125	8¼ inches			
*306	Dug	35	3 feet			Hotel
*307	do	35	do			D, S
*308	Drilled	180	8¼ inches	126	W	S
*309	Dug	33	4 feet		W	S
*310	do	15	3 feet	7	W	D, S
*311	Drilled	125	8¼ inches		Power pump	D, S
312	Dug	17	3 feet	9	W	S
*313	do	17	do		Hand pump	D

1. Babbitt Bros., Flagstaff, sec. 25, T. 22 N., R. 11 E., in valley. Water from sandstone in Coconino (?). Not visited.

2. Sec. 19, T. 22 N., R. 12 E. No data.

*3. Office of Indian Affairs, 4 wells at Leupp Navajo Indian Agency, sec. 22, T. 22 N., R. 13 E., in valley flat of Little Colorado River. Supply town of 500 during school year.

*393. U. S. Indian Service, sec. 2, T. 21 N., R. 12½ E. Water from sandstone in Coconino at 375 feet. Pumps 10 gallons a minute. See log, page 91.

*394. U. S. Indian Service, sec. 14, T. 22 N., R. 13 E. Water from sandstone in Coconino at 404 feet. Pumps 10 gallons a minute. See log, page 91.

*432. U. S. Indian Service, sec. 12, T. 21 N., R. 13 E. Water from sandstone in Coconino at 225 feet. Pumps 10 gallons a minute. See log, page 91.

*438. U. S. Indian Service, sec. 16, T. 21 N., R. 13 E. Water from sandstone in Coconino at 185 feet. Pumps 10 gallons a minute. See log, page 91.

4. Sec. 25, T. 21 N., R. 13 E. No data.

*5. Babbitt Bros., Sunshine Well, sec. 30, T. 20 N., R. 12½ E., on upland, altitude 5,341 feet. Water from sandstone in Coconino. Drilled as oil prospect.

*6. Babbitt Bros., Dennison headquarters ranch, sec. 35, T. 20 N., R. 13 E., in small wash on upland, altitude about 5,000 feet. Water from sandstone in Coconino (?). Data meager.

7. Babbitt Bros., Red Gap Well, sec. 7, T. 20 N., R. 14 E., on upland. Water from Moenkopi (?). Drilled in 1924–25.

*8. Clear Creek Cattle Co., Winslow, Ariz., "Proonville Well," sec. 25, T. 20 N., R. 14 E., in Little Colorado Valley, not close to river. Water from Moenkopi.

*9. Clear Creek Cattle Co., Tucker Flat Well, sec. 33, T. 20 N., R. 15 E., on big flat. Water from sandstone in Moenkopi. Salty water.

*10. Meteor Crater Mining and Exploration Co., Phoenix, shaft on south side of Crater Mound, near crest, sec. 13, T. 19 N., R. 12½ E. Water from sandstone in Coconino. Developed as mining project; now practically abandoned.

*11. Babbitt Bros., Klunch Well, sec. 7, T. 19 N., R. 13 E., on upland. Water from sandstone in Coconino.

*12. Clear Creek Cattle Co., well 1, sec. 21, T. 19 N., R. 14 E., on big flat. Water from sandstone and sandy shale in Moenkopi. Quality fair.

13. Campbell-Francis Sheep Co. (now Clear Creek Cattle Co.), NW¼ sec. 13, T. 18 N., R. 12 E., on Kaibab limestone upland near Canyon Diablo. Water from sandstone in Coconino. Oil prospect, drilled by B. A. Gillespie Petroleum Co.

*14. Clear Creek Cattle Co., well 7, sec. 13, T. 18 N., R. 13 E., on plateau. Water from sandstone in Coconino.

*15. Clear Creek Cattle Co., well 4, sec. 13, T. 18 N., R. 14 E., on cuesta, 7.7 miles southwest of Winslow. Water from sandstone in Coconino. Quality good.

*16. Clear Creek Cattle Co., well 8, sec. 5, T. 18 N., R. 15 E., on Pine-Winslow highway 3.7 miles southwest of Santa Fe Railway. Water from sandstone in Moenkopi.

*17. Clear Creek Cattle Co., well 5, Tin ranch, sec. 23, T. 17 N., R. 14 E., on cuesta. Water from sandstone in Coconino.

*18. U. S. Forest Service, Chaves Pass Well, NW¼ sec. 13, T. 16 N., R. 11 E., in foothills of high area. Water from gravel at contact of Moenkopi shale and lava. Quality good.

*19. Babbitt Bros., sec. 4, T. 16 N., R. 12 E., on upland. Quality good.

20. Tremaine Cattle Co., Cow Trap Well, SE¼ sec. 29, T. 16 N., R. 12 E., in canyon cut in Kaibab limestone. Water from sandstone in Coconino (?). Water lost; thought crevice was struck.

*21. Clear Creek Cattle Co., Hot Cake Well 6, sec. 3, T. 16 N., R. 14 W., on upland near Clear Creek Canyon. Water from sandstone in Coconino.

*22. Wyrick Cattle Co., Winslow, sec. 17, T. 16 N., R. 15 E., on upland, only well between Clear and Chevelon Creeks. Water from sandstone in Coconino.

23. W. F. Bawcom, Hay Lake Well, sec. 5, T. 15 N., R. 11 E., on upland. Water from sandstone in Coconino or Supai (?).

24. —— Bennett, Red Hill ranch, sec. 24, T. 15 N., R. 12 E., on upland. Well cuttings were sandy limestone of Moenkopi and Kaibab, but well was dry hole.

25. W. E. Sorensen, Winslow, SW¼ sec. 20, T. 15 N., R. 15 E., on upland. Well stopped in Coconino sandstone, not drilled deep enough to obtain water in Coconino but should find water at greater depth.

26. Clint's well, SW¼ sec. 34, T. 14 N., R. 10 E. Not visited and no data obtained.

27. Clear Creek Cattle Co., Bixby well 1, Moqui ranch, sec. 12, T. 14 N., R. 11 E. Water from sandstone in Coconino. See log, page 92. Pumps 15 gallons a minute.

28. Well near Long Valley, SE¼ sec. 7, T. 13, N., R. 10 E. Not visited and no data obtained.

30 and 31. Sec. 15, T. 21 N., R. 23 E., in Leroux Wash. Two points to each well. Water from sand and gravel in valley fill. Yield 7 gallons a minute.

*32. A. B. Randall, Joseph City, SE¼SW¼ sec. 1, T. 20 N., R. 19 E., in Cottonwood Wash. Water from sand and gravel in valley fill. Drilled to 50 feet, but well yielded no water at that depth.

*33. A. C. Marshall, Joseph City, NW¼ sec. 32, T. 20 N., R. 19 E., in Cottonwood Wash. Water from sand and gravel in valley fill. Yields 15 gallons a minute.

34. —— Murphy, Turkey Track ranch, sec. 31, T. 20 N., R. 19 E., in Cottonwood Wash. No data.

35. —— Murphy, Turkey Track ranch, sec. 2, T. 20 N., R. 20 E., in Cottonwood Wash. Water from sand and gravel in valley fill.

36. Sec. 25, T. 20 N., R. 21 E., in Leroux Wash. Two points. Water from sand and gravel in valley fill. Some poor water at 10 feet. Yields 5 to 7 gallons a minute.

37. Sec. 9, T. 20 N., R. 22 E., in Leroux Wash. Two wells, two points each. Water from sand and gravel in valley fill. Yields 21 gallons a minute. Permanent supply of good quality.

38. Sec. 26, T. 20 N., R. 22 E., in valley. Two points. Water from sand and gravel in valley fill. Data meager.

39 and 40. Sec. 28, T. 20 N., R. 22 E., in Digger Creek. Two points to each well. Water from sand and gravel in valley fill. Yield 7 gallons a minute.

*41. R. R. Simon, Winslow. T. 19 N., R. 13 E., on upland. Water from sandstone in Moenkopi (?). Good supply.

*42. Wyrick Cattle Co., Double wells, sec. 15 or 16, T. 19 N., R. 18 E., in Cottonwood Wash. Water from alluvium in valley fill. Adequate for stock.

43. Atchison, Topeka & Santa Fe Ry., deep well at Winslow, sec. 30, T. 19 N., R. 16 E., in Little Colorado River Valley. Water from sandstone in Coconino. Yields 687 gallons a minute. Too salty for use. See log, page 92.

44. Sec. 23, T. 19 N., R. 17 E., along Cottonwood Wash. No data available. Water probably from valley fill.

45 and 46. T. 19 N., R. 18 E., along Cottonwood Wash. No data available. Water probably from valley fill.

47. "Dan Divelbess' old outfit," now owned by Julius Wetzler, Holbrook. Sec. 36, T. 19 N., R. 20 E., in Leroux Wash. Two points. Water from sand and gravel in valley fill. Yields 5 to 7 gallons a minute.

48. Howard homestead, sec. 30, T. 19 N., R. 21 E., in Leroux Wash. Two points. Water from sand and gravel in valley fill. Yields 8 to 10 gallons a minute.

49. Matt Clark, sec. 20, T. 19 N., R. 21 E., in Leroux Wash. Two points. Water from sand and gravel in valley fill. Yields 8 gallons a minute.

50. Sec. 16, T. 19 N., R. 21 E., in Leroux Wash. Two points. Water from sand and gravel in valley fill. Yields 7 to 8 gallons a minute.

51. Abandoned well in sec. 22, T. 19 N., R. 21 E., in Leroux Wash. Two points. Water from sand and gravel in valley fill. Considerable amount, but salty.

*52. Ralph Windsor, Holbrook. Sec. 10, T. 19 N., R. 21 E., in Leroux Wash. Water from sand and gravel in valley fill.

53. George Hennessey, Holbrook. Sec. 2, T. 19 N., R. 21 E., in Leroux Wash. Two points. Water from sand and gravel in valley fill. Yields 15 to 20 gallons a minute.

54. George Hennessey, SE¼ sec. 2, T. 19 N., R. 21 E. Struck salty water at 19 feet, some water at 67 feet, and more water at 307 feet, in Chinle formation.

*56. Wyrick Cattle Co., SW¼ sec. 6, T. 18 N., R. 17 E., in Little Colorado River Valley. Water from sand and gravel in valley fill.

57. Wyrick Cattle Co., sec. 4, T. 18 N., R. 17 E., in Little Colorado River Valley. Water from sand and silt in valley fill.

*58. Wyrick Cattle Co., Manila Well, sec. 8, T. 18 N., R. 18 E., in Little Colorado River Valley. Water from sand and silt in valley fill.

*59. J. E. Richards, Joseph City, SW¼ sec. 16, T. 18 N., R. 19 E., in valley. Water at 320 feet from sandstone in Coconino. Water also at 45 feet. Part of Joseph City public supply.

*60. Akins Smith, Joseph City, SE¼ sec. 16, T. 18 N., R. 19 E., in Little Colorado River Valley. Water from sandstone in Coconino. Part of Joseph City public supply. Water at 45 feet cased off (?).

61. Leo Frost, SE¼ sec. 34, T. 18 N., R. 19 E., in Little Colorado River Valley. Water from sandstone in Coconino.

*62. Aztec Land & Cattle Co., Albuquerque, N. Mex., 7 wells, 6 flowing, NW¼ sec. 35, T. 18 N., R. 19 E., in Little Colorado River Valley. Water from sandstone in Coconino. Wells permitted to flow openly.

63. Larson homestead, sec. 12, T. 18 N., R. 20 E., in Leroux Wash. Two points. Water from quicksand and gravel in valley fill. Yields 5 to 7 gallons a minute.

64 and 65. Henry Scorse homestead, sec. 14, T. 18 N., R. 20 E., two wells in and near Leroux Wash. Shallow well receives water from perforated pipe laid in trench dug across Leroux Wash; not enough water for irrigation. Water in deep well from sandstone in Coconino; tools lost in hole and abandoned.

66. Sec. 26, T. 18 N., R. 20 E., in Leroux Wash. Two points. Water from silt and sand in valley fill. Yields 5 gallons a minute. Quality poor.

*67. Ralph Windsor, Holbrook, sec. 6, T. 18 N., R. 21 E., in Leroux Wash. Two points. Water from sand and quicksand in valley fill.

68. Mrs. D. J. Thomas, SE¼ sec. 30, T. 18 N., R. 21 E., on hill. Water from Shinarump or Moenkopi (?).

69. Dick place, sec. 34, T. 18 N., R. 21 E., in Rio Puerco Valley. Water from sand and gravel in valley fill. Yields 10 gallons a minute.

70. Cassidy homestead, sec. 26, T. 18 N., R. 21 E., in Rio Puerco Valley. Water from sand and gravel in valley fill. Quantity small.

71. Sec. 7, T. 18 N., R. 22 E., on mesa. Water from gravel in Shinarump (?), very salty.

72. Jones Grigsby, sec. 12, T. 18 N., R. 22 E., in Rio Puerco Valley. Water from coarse gravel in valley fill. Yields 15 gallons a minute.

73. Old No. 3 well, NW¼NW¼ sec. 14, T. 18 N., R. 22 E., in Rio Puerco Valley. Two points. Water from sand and gravel in valley fill. Yields 15 gallons a minute.

74 and 75. Sec. 16, T. 18 N., R. 22 E., in Rio Puerco Valley. Two wells close together. Two points each. Water from silt and sand in valley fill. Yield 7 gallons a minute each.

76. Old Rafter D headquarters, NE¼ sec. 20, T. 18 N., R. 22 E., in Rio Puerco Valley. Two points. Water from sand and gravel in valley fill. Slightly salty. Yields 5 gallons a minute.

77. Sec. 29, T. 18 N., R. 22 E., in Rio Puerco Valley. Two points. Water from sand and gravel in valley fill. Yields 10 gallons a minute.

78. Tom Ortega, near east line of sec. 35, T. 18 N., R. 22 E., in valley of tributary of Rio Puerco. Water from sand and gravel in valley fill. Yields 10 gallons a minute.

*79. Jones Grigsby homestead, Goodwater filling station, SE¼NW¼ sec. 6 T. 18 N., R. 23 E., in Little Carrizo Wash. Water from coarse gravel in alluvial material at depth of 38 to 50 feet. Quality good.

80. Emmett Wallace, SE¼ sec. 8, T. 18 N., R. 23 E., in Rio Puerco Valley. Two points. Water from sand and gravel in valley fill. Yields 8 gallons a minute.

81. Jim Donohoe, old ranch, sec. 10, T. 18 N., R. 23 E., in Rio Puerco Valley. Two wells; one may be in sec. 3. Two points each. Water from sand and gravel in valley fill. Yield 7 gallons a minute each.

82. George Jensen, SE¼ sec. 14, T. 18 N., R. 23 E., in Rio Puerco Valley. Two wells, two points each. Water from sand and gravel in valley fill. Yield 7 gallons a minute each.

83. Old Ramsey ranch, NE¼NE¼ sec. 14, T. 18 N., R. 23 E., in Rio Puerco Valley. Water from coarse sand and gravel in valley fill at depths of 5 and 35 feet. Well flowed at 35 feet. Yields 10 gallons a minute.

84 and 85. Sec. 17, T. 18 N., R. 23 E., two wells close together, in valley. Water from sand and gravel in valley fill, slightly salty. Yield 10 gallons a minute each.

86. Sec. 31, T. 18 N., R. 23 E., well on bank of arroyo with tile collecting pipe across arroyo. Water from sand and gravel in valley fill.

*87. Joseph City Irrigation Co., NW¼ sec. 6, T. 17 N., R. 20 E., three wells in Little Colorado River Valley. Water from sandstone in Coconino.

*88. Walter McLaws, sec. 8, T. 17 N., R. 20 E., several wells in Little Colorado River Valley. Water from sandstone in Coconino. Big flow.

89. Ray F. Durfee, sec. 10, T. 17 N., R. 20 E., in Little Colorado River Valley. Water from sandstone in Coconino at depths of 6, 30, and 42 feet. Flow fills 2-inch pipe.

*90. Ortega heirs, sec. 10, T. 17 N., R. 20 E., in Little Colorado River Valley. Water from sandstone in Coconino. Big flow, wasted.

*91. J. W. McLaws, sec. 10, T. 17 N., R. 20 E., in Little Colorado River Valley. Water from sandstone in Coconino. Pumps 8-inch stream, no draw-down. City of Holbrook has bought this well for city use.

*92. T. E. Taylor, NE¼ sec. 12, T. 17 N., R. 20 E., on hillside. Water from sandstone in Coconino. Good well.

93. Dr. Switzer, Winslow. Sec. 13, T. 17 N., R. 20 E., on hill. Water from sandstone in Coconino at 189 to 214 feet.

94. Great Basin Oil Co., Taylor-Fuller No. 1, NW¼NW¼ sec. 21, T. 17 N., R. 20 E., on upland. Test made for oil. See log, page 93.

*95. Holbrook Light & Power Co., SW¼ sec. 6, T. 17 N., R. 21 E., in Little Colorado River Valley. Bad water from sand and gravel in valley fill. Present supply of Holbrook.

96. Atchison, Topeka & Santa Fe Ry., well 3, sec. 6, T. 17 N., R. 21 E., in Little Colorado River Valley. Water from sand and gravel in valley fill. Yields 430 gallons a minute. Struck sandstone at 137 to 139 feet. See log, page 94.

97. Atchison, Topeka & Santa Fe Ry., well 1, sec. 6, T. 17 N., R. 21 E., in Little Colorado River Valley. Water from sand and gravel in valley fill. Yields 400 gallons a minute. Sandstone at 134 to 136 feet. See log, page 94.

98. Woods Well, east of American Telephone & Telegraph Building, on hill south of Holbrook, in sec. 7, T. 17 N., R. 21 E. Water from sandstone in Coconino, which is near the surface in this locality.

*99. —— Eubanks, sec. 25 or 27, T. 17 N., R. 22 E., on low, broad flat. Water from sandstone and sandy shale in Moenkopi, salty. Yields 20 to 25 gallons a minute.

100. Sec. 36, T. 17 N., R. 22 E. Not visited. Yields very little salty water.

101. Sec. 6, T. 17 N., R. 23 E. Not visited. Water from gravel. Yields 5 gallons a minute.

102. Cedar Ridge Land & Development Co., Black Canyon lease, sec. 20, T. 16 N., R. 17 E., on Kaibab upland. Dry hole. See Arizona Univ. Bull. 119, p. 204.

103. Carlos Castillo, sec. 28, T. 16 N., R. 20 E., on upland. Water from sandstone in Coconino, also poor water at 22 feet.

104. Apache Railroad, sec. 16, T. 16 N., R. 21 E., on upland. Water from sandstone in Coconino, top at 325 feet. No draw-down when pumped. Well not in use.

*105. Well at foot of Woodruff Butte, sec. 8 (?), T. 16 N., R. 22 E. Brackish water from sandstone in Moenkopi (?). Well not in use.

*106. Woodruff Domestic Water Co., sec. 20, T. 16 N., R. 22 E., in Little Colorado River Valley. Water from sandstone in Coconino. Town of Woodruff supply.

107. Padilla ranch, sec. 21, T. 17 N., R. 23 E. No data.

108. National Park Service, Petrified Forest, sec. 1, T. 16 N., R. 23 E., in valley. Salt water at 609 feet. Camp use; unfit for drinking. See log, page 94.

109. Holbrook Oil Co. test well, NE¼ sec. 23, T. 15 N., R. 18 E., on upland. Drilled in 1922 to about 2,400 feet; later deepened to about 3,400 feet.

110. Hopi Oil Co., sec. 21, T. 15 N., R. 19 E., on upland. See log, page 95.

*111. J. M. Flake, NE¼ sec. 17, T. 15 N., R. 21 E., on upland. Water from sandstone in Coconino.

112. Fred Baca, sec. 7, T. 14 N., R. 19 E., on big flat at edge of Dry Lake. Water from sandstone in Coconino.

113. Adamana Oil & Land Co., sec. 4, T. 14 N., R. 20 E., on upland. Drilled for oil in 1920–24. See log, page 95.

*114. City utility, Snowflake, NE¼ sec. 26, T. 13 N., R. 21 E., in Silver Creek Valley. Water from sandstone in Coconino. Town of Snowflake supply.

*115. N. Porter, Phoenix, sec. 10, T. 13 N., R. 22 E., on upland. Water from sandstone in Moenkopi. Can be pumped dry.

*116. Open well in Heber, SW¼ sec. 13, T. 12 N., R. 16 E., in Black Canyon. Water from gravel in valley fill.

*117. Well at Aripine post office, sec. 28, T. 12 N., R. 18 E., in valley in foothills. Water from gravel in valley fill.

*118. J. H. Allen, Taylor, sec. 2, T. 12 N., R. 21 E., in Silver Creek Valley. Water from sandstone in Moenkopi (?).

119. Several wells at Clay Springs, sec. 11, T. 11 N., R. 19 E., in valley. Water from gravel and Recent sand, at contact of sand and underlying shale.

120. Peterson ranch, N½ sec. 4, T. 10 N., R. 20 E., in wash. Several shallow wells. Water from gravel in valley fill.

121 and 122. Standard Lumber Co., Standard, NE¼ sec. 17, T. 10 N., R. 20 E. Trench dug to shale below gravel feeds into box sunk to collect water. Enough water to operate large sawmill.

123. Standard Lumber Co., Standard, sec. 17, T. 10 N., R. 20 E., on upland. "Malpais" to 90 feet, then clay to 492 feet. Flows 5 gallons a minute.

124. Several wells at or near Showlow, sec. 20, T. 10 N., R. 22 E., in Showlow Creek Valley. Water from gravel in valley fill. Some wells went 50 feet into shale, with no water.

125. Three wells in Pinetop, sec. 5, T. 8 N., R. 23 E., on upland. Dug in lava boulders, gravel, and sand. As Pinetop is underlain by cinders at a depth of about 20 feet, it is necessary that wells be shallow, or water will penetrate cinder beds and escape. Public supply of Pinetop comes chiefly from Pinetop Springs, through ditches.

126. U. S. Forest Service, SW¼ sec. 29, T. 11 N., R.20 E., on upland. Dry hole. See log, page 96.

127. U. S. Forest Service, SE¼ sec. 32, T. 11 N., R. 20 E., on upland. Water from sandstone at 46 feet. See log, page 96.

*130. J. W. Bennett, sec. 33, T. 23 N., R. 31 E., in canyon in Rio Puerco Valley. Two wells. West well, water from quicksand in Wingate (?); yields 10 gallons a minute. East well, water from sandstone in Wingate (?); yields 2,000 gallons a day.

131. Indians, NE¼ sec. 3, T. 22 N., R. 26 E., in valley. Water from gravel in valley fill. Small yield.

*132. Mary Lynch, sec. 4, T. 22 N., R. 26 E. Water from sand and gravel at contact with Chinle shale. Engine pumps 3¾-inch stream with no draw-down.

133. Chee Dodge, sec. 8, T. 22 N., R. 26 E., in valley. Water from sand and gravel at Chinle contact.

134. Atchison, Topeka & Santa Fe Ry., Houck, sec. 26, T. 22 N., R. 29 E., in Rio Puerco Valley. Completed in 1926. Drilled in old well, which was 35 feet deep, to depth of 115 feet. Yields 188 gallons a minute for 24 hours. See log, page 97.

135. Atchison, Topeka & Santa Fe Ry., sec. 25, T. 22 N., R. 29 E., in Rio Puerco Valley. See logs, pages 97–98.

*136. Tegakwitha Indian Mission, SW¼NE¼ sec. 25, T. 22 N., R. 29 E., on hill. Water from sandstone in Coconino. Good well. See log, page 98.

137. Sec. 36, T. 22 N., R. 29 E. Data meager.

*138. Jos. A. Grubbs, Houck, SW¼ sec. 19, T. 22 N., R. 30 E., on upland. Water from sandstone in Coconino.

139. Presbyterian Mission, SW¼ sec. 27, T. 22 N., R. 30 E., in Rio Puerco Valley. Water at 43 feet in Shinarump (?) or valley fill.

140. SE¼ sec. 35, T. 21 N., R. 26 E. No data.

141. Joe Mullen, store, sec. 10, T. 21 N., R. 27 E. Not visited.

142. Addy Montano homestead, sec. 24, T. 21 N., R. 27 E. Two wells. Water may come from contact of Tertiary sand and Chinle (?). Mineralized; unfit for domestic use.

143. Tom Ortega homestead, SE¼SE¼ sec. 24, T. 21 N., R. 27 E., on upland. Water from sand and gravel at Chinle-Tertiary contact. Yields 43 gallons a minute. Quality good.

143a. Atchison, Topeka & Santa Fe Ry., Chambers, sec. 25 (?), T. 21 N., R. 27 E., in valley. By December 1907 well had sanded up and was abandoned. See log, page 98.

143b. Atchison, Topeka & Santa Fe Ry., sec. 25 (?), T. 21 N., R. 27 E., in valley. Completed and abandoned in 1902. See log, page 99.

*144. Atchison, Topeka & Santa Fe Ry., well 3, Chambers, sec. 25 (?), T. 21 N., R. 27 E., in valley. Yields 500 gallons a minute. See log, page 99.

*145. R. W. Cassidy, Chambers store, SW¼ sec. 25, T. 21 N., R. 27 E., on hill. Water from shale in Chinle. Cloudy when pumped heavily.

146. McCarrell Well, sec. 26, T. 21 N., R. 27 E., in Chambers Wash. Water from sand in valley fill. Yields 5 gallons a minute.

147. NE¼ sec. 34, T. 21 N., R. 27 E., in valley. Water from sand and gravel in valley fill. Yields 5 gallons a minute.

148. SW¼ sec. 29, T. 21 N., R. 27 E. Water from Tertiary sand. Well now abandoned; yielded enough for small herd of sheep.

149. E. P. Howell, SE¼ sec. 34, T. 21 N., R. 27 E., in Rio Puerco Valley. Two points. Water from sand and gravel in valley fill. Yields 15 gallons a minute.

150. Well developed by —— Ray, SW¼ sec. 34, T. 21 N., R. 27 E., in Rio Puerco Valley. Water from sand and gravel in valley fill.

*151. G. S. Woods, NE¼ sec. 30, T. 21 N., R. 28 E., in Rio Puerco Valley. Water from sand and gravel in valley fill. Yields 275 gallons a minute.

152. G. S. Woods, NE¼NE¼ sec. 30, T. 21 N., R. 28 E., in Rio Puerco Valley. Two points. Water from sand and gravel in valley fill. Yields 10 gallons a minute.

153. Frank Davidson homestead, SW¼ sec. 20, T. 21 N., R. 28 E., in Rio Puerco Valley. Dug 40 feet, then driven (two points) to 90 feet. Water from quicksand in valley fill. Yields 5 gallons a minute.

154. SW¼SE¼ sec. 20, T. 21 N., R. 28 E. Three wells. Water from sand and gravel in valley fill. 110-foot well good when first drilled; 130-foot well yielded 21 gallons a minute, but sanded up within 2 years and was abandoned; 210-foot well drilled to bedrock but hole was lost.

155 and 156. Sanders, two wells, NE¼SE¼ sec. 14, T. 21 N., R. 28 E., on hillside. Water from sandy shale in Chinle. Data from S. Balcomb, Sanders.

157. Near west line sec. 13, T. 21 N., R. 28 E. Yields 12 gallons a minute.

158. Clifton Hill, SW¼ sec. 24, T. 21 N., R. 28 E. Dug 40 feet and blasted 4 feet. Water from Chinle. Yields 5 gallons a minute.

159. Clifton Hill, NW¼SW¼ sec. 24, T. 21 N., R. 28 E. Yields 10 gallons a minute.

160. Clifton Hill, NE¼NW¼ sec. 24, T. 21 N., R. 28 E. Water from Chinle, water in gravel at 60 feet cased off. Yields 5 gallons a minute.

161. Billie Burke, three wells, NE¼NE¼ sec. 4, T. 21 N., R. 29 E., in Rio Puerco Valley. 10-foot well, water from sand and gravel in valley fill; goes dry in dry seasons. 20-foot well, water from sand and gravel in valley fill; yields 4 gallons a minute but almost dry in dry seasons. 24-foot well, dug 20 feet and driven 4 feet; water from quicksand in valley fill; yields 5 gallons a minute and never goes dry.

162. Cedar Point trading post, sec. 7, T. 21 N., R. 29 E., on hill. Water from gravel in Moenkopi or Shinarump (?). Yields 60 to 70 gallons a minute from depth of 155 feet.

163. Several wells in Rio Puerco Valley flat, secs. 5 and 8, T. 21 N., R. 29 E. Not visited.

164. George Perkins, NE¼ sec. 8, T. 21 N., R. 29 E., in valley. Two wells. Water from sand and silt in valley fill. Quality good.

165. E. W. Grimes, SW¼ sec. 8, T. 21 N., R. 29 E., in valley. Two wells. 40-foot well, dug to 30 feet and driven to 40 feet; water from gravel and quicksand in valley fill. 80-foot well, water from Shinarump (?) clay at 80 feet; yields 60 gallons a minute.

166. J. W. Mow, center SE¼ sec. 8, T. 21 N., R. 29 E., in valley. Dug 30 feet and driven (two points) to 40 feet. Water from gravel and quicksand in valley fill. Yields 10 to 15 gallons a minute.

167. Sam Jones, center sec. 18, T. 21 N., R. 29 E., in valley. Data meager.

168. Burr W. Porter, of Navajo, Leonard Olsen homestead, SW¼ sec. 22, T. 21 N., R. 29 E. Dug 35 feet and driven (four points) 4 feet farther. Water from Tertiary sand and quicksand. Yields 10 gallons a minute.

169. Billie Burke, SW¼SE¼ sec. 22, T. 21 N., R. 29 E. Water from Tertiary sand. Yields 5 gallons a minute.

170. Sec. 19, T. 21 N., R. 30 E. Abandoned; no data obtained.

171. Jess Burkett, sec. 30, T. 21 N., R. 30 E., in valley. Water from reworked Tertiary sands in valley fill.

*172. Ed Bargeman, Sanders, NE¼ sec. 30, T. 21 N., R. 30 E., in valley. Water from reworked Tertiary sands. Pump capacity 100 gallons a minute. One of the best water supplies in the county.

173. Sec. 3, T. 20 N., R. 25 E. Water from Chinle. Yields 18 gallons a minute. Stock will use it in winter but water too salty for summer use.

174. Old Henning Well, sec. 36, T. 20 N., R. 25 E., in upland valley. Water from quicksand in valley fill. Yields 15 gallons a minute.

175. E. P. Howell, sec. 28, T. 20 N., R. 26 E., in valley. Two wells close together. Three points each. Water from sand and gravel in valley fill. Yield 10 gallons a minute.

176. Harry Jamison, sec. 27, T. 20 N., R. 26 E., in valley. Two points. Water from sand and gravel in valley fill. Yields 5 gallons a minute.

177. Harry Jamison, Vernon Barber homestead, sec. 26, T. 20 N., R. 26 E., in valley. Two points. Water from sand and gravel in valley fill. Yields 5 gallons a minute.

178. Burr W. Porter, SE¼ sec. 24, T. 20 N., R. 26 E. Drilled well to 87 feet, but necessary to dig open well, as quicksand filled drilled well.

*179. Burr W. Porter, NE¼ sec. 24, T. 20 N., R. 26 E., in Rio Puerco Valley. Water from sand and gravel. Yields 1 to 2 gallons a minute.

*180. Mrs. O. W. Marty, NW¼ sec. 24, T. 20 N., R. 26 E., on hill. Water from sandstone in Chinle (?).

181. McCarrell ranch, NW¼ sec. 4, T. 20 N., R. 27 E., in valley. Two points. Water from alluvium in valley fill. Yields 15 gallons a minute.

182. Cliff Smith, sec. 13, T. 20 N., R. 27 E. Water from contact of Tertiary sand and Chinle shale. No other data.

183. SW¼ sec. 17, T. 20 N., R. 27 E., in valley. Two points. Water from valley fill or Tertiary sand. Well now abandoned, not visited.

184. Burr W. Porter, Charles Day Well, SE¼ sec. 18, T. 20 N., R. 27 E., in valley. Two points. Water from sand and silt in valley fill. Yields 15 gallons a minute.

185. Sec. 18, T. 20 N., R. 27 E., in Rio Puerco Valley. Water from sand and silt in valley fill.

186. Sec. 26, T. 20 N., R. 27 E., on upland. Water from Tertiary sand. Yields 10 to 12 gallons a minute.

187. Wallis ranch, sec. 36, T. 20 N., R. 27 E., on upland. Abandoned. Considerable effort was made to reopen this well but failed.

188. Abandoned well near west line of sec. 30, T. 20 N., R. 28 E., in valley. Two points. Water from sand and silt in valley fill. Yields 10 gallons a minute.

189. Sec. 36, T. 20 N., R. 28 E., in Parker Wash. Water from sand and silt at contact of Tertiary sand and Chinle. Yields 8 to 10 gallons a minute. Quality good.

190. Zuñi-Arizona Oil Co., Zuñi Well, SE¼ sec. 6, T. 19 N., R. 24 E., near Carrizo Wash. Salt water at 940 feet; good water at 32 feet; well plugged back to 33 feet and made water well. Yields 15 gallons a minute. See log, p. 99.

191 and 192. Sec. 25, T. 19 N., R. 24 E., two wells in valley. Two points. Water from sand and gravel in valley fill. Yield 7 to 8 gallons a minute each.

193. Atchison, Topeka & Santa Fe Ry., Pinta, sec. 1, T. 19 N., R. 25 E., in valley. Water from sand and gravel in alluvium. Old well 2 (100-foot), completed in October 1901, yields 56 gallons a minute. Old well 3 (80-foot), abandoned. New wells 2 and 3 (98-foot), tested 7,000 and 4,000 gallons an hour, respectively. See logs, pages 99–100.

194. Harry Jamison, SW¼NW¼ sec. 12, T. 19 N., R. 25 E., in valley. Two wells. Water from sand and gravel in alluvium. Yield 5 gallons a minute.

195. Gifford Jamison home ranch, sec. 12, T. 19 N., R. 25 E., in valley. Two wells.

196. Sec. 23, T. 19 N., R. 25 E., in valley. Salty water.

197. Sweetwater, sec. 16, T. 19 N., R. 25 E., in valley. Two wells. Water from gravel in alluvium. Yield 7 gallons a minute each.

198. Sec. 28, T. 19 N., R. 25 E., in valley. Two points. Water from sand and gravel in alluvium. Yields 5 gallons a minute.

199. Jake Mabin, sec. 30, T. 19 N., R. 25 E., in valley. Water from sand and gravel in alluvium. Yields 13 gallons a minute.

200. Sec. 30, T. 19 N., R. 25 E., in valley. Two points. Water from sand and silt in alluvium. Yields 10 to 15 gallons a minute.

201. Gifford Jamison, sec. 1, T. 19 N., R. 26 E., on upland. Water from gravel and quicksand.

202. Harry Jamison, sec. 36, T. 19 N., R. 26 E., on upland. Water from sand and gravel at contact of Tertiary sand and Chinle shale. Yields 5 gallons a minute.

203. Sec. 17, T. 19 N., R. 27 E., on upland. Dry hole. Possibly drilled into Chinle. This is one well in which the Tertiary sand at the contact with the Chinle shale was not water-bearing. Sand all the way.

204. Sec. 29, T. 19 N., R. 27 E., on upland. Dry hole. Drilled to or below contact of Tertiary sand and Chinle shale.

*205. Little Silversmith, sec. 4, T. 19 N., R. 28 E., in valley. Water from contact of Tertiary sand and Chinle.

206. Dick Grigsby, NE¼SE¼ sec. 7, T. 18 N., R. 24 E., in valley. Water from sand and silt in alluvium. Yields 12 gallons a minute.

207. Dick Grigsby, NW¼SW¼ sec. 8, T. 18 N., R. 24 E., in valley. Water from sand and silt in valley fill.

208. Atchison, Topeka & Santa Fe Ry., deep well at Adamana, sec. 8, T. 18 N., R. 24 E., in Rio Puerco Valley. Salt water from sandstone in Moenkopi. Flowed 25 years; now plugged. See log, page 100.

209. Atchison, Topeka & Santa Fe Ry., sec. 8, T. 18 N., R. 24 E., in Rio Puerco Valley. Water from sand and silt in alluvium. Well 1 (91-foot), yields 70 gallons a minute. Well 3 (29-foot) completed in 1912. Well 4 (40-foot) completed in 1918. See logs, pages 100-101.

210. NE¼ sec. 8, T. 18 N., R. 24 E., in valley. Two points. Water from sand and gravel in valley fill. Yields 5 gallons a minute. Some salt water at 19 feet.

211. Sec. 11, T. 18 N., R. 24 E., in valley. Two wells, two points each. Water from sand and gravel in valley fill. Yield 5 gallons a minute each.

212. Sec. 16, T. 18 N., R 24 E., in valley. Two wells. Water from sand and gravel in valley fill. Yield 5 gallons a minute.

213. Joe Thomas, sec. 18, T. 18 N., R. 24 E., in valley. Two points. Water from sand and gravel in valley fill. Yields 5 gallons a minute.

*213a. J. C. Paulsell, sec. 34, T. 18 N., R. 24 E., in valley. Water from quicksand in alluvium. Yields 16 gallons a minute.

*214. Ninemile Well, NE¼ sec. 2, T. 18 N., R. 26 E., on upland. Water from sand at contact of Tertiary sand and Chinle. Yields 8 gallons a minute.

215. Harry Jamison, sec. 28, T. 18 N., R. 26 E., on upland. Water from sandy shales in Chinle. Yields 4 gallons a minute.

*216. Burr W. Porter, sec 6, T 18 N., R. 27 E., on upland. Water from contact of Tertiary sand and Chinle. Yields 8 gallons a minute.

217. Sec. 12, T. 18 N., R. 29 E. Dry hole. Data meager.

*218. Mrs. Tom Teal, G Lake ranch, NW¼ sec. 13, T. 18 N., R. 29 E., on upland. Water from yellow sandstone in Cretaceous (?) at 400 feet.

219. Dry hole ¼ mile west of G Lake well, sec. 14, T. 18 N., R. 29 E.

220. Dry hole, sec. 10, T. 17 N., R. 26 E.

221. SW¼ sec. 35, T. 17 N., R. 26 E. Big flow of salt water at 110 feet; solid rock at 12 feet (?).

*222. Loy Turbeville, NE¼ sec. 6, T. 17 N., R. 27 E., in valley. Water from sand and gravel of Recent sand in Milky Wash. Yields 10 gallons a minute.

223. Dry hole, sec. 3, T. 17 N., R. 29 E.

*224. Levi Udall and Rule Jarvis, Water-Witch ranch, S½ sec. 3, T. 17 N., R. 29 E., on upland. Water from yellow sandstone in Cretaceous (?). Yi elds 10 gallons a minute. Temperature 52° F.

225, 226. Hardscrabble ranch, SW¼ sec. 20, T. 17 N., R. 29 E. Two wells. Water from sand and gravel in valley fill.

227. Jacob Barth, SE¼ sec. 16, T. 17 N., R. 31 E., in valley. Water from sand and silt in valley fill.

228. Thompson ranch, sec. 26, T. 16 N., R. 24 E., in Milky Wash. Water from gravel in valley fill.

229. Donohue & Margesson ranch, sec. 16, T. 16 N., R. 25 E., in Milky Wash. Water from gravel in valley fill.

*230. Burt Potter, NW¼ sec. 12, T. 16 N., R. 25 E., in Milky Wash. Two wells. Water from gravel in wash materials. Yield 10 to 12 gallons a minute.

231. Sec. 33, T. 16 N., R. 26 E., in valley. Water from shale and sandstone in Chinle. Yield very small.

232. Old mail-stage well, sec. 7, T. 16 N., R. 28 E., on upland. Small yield. Abandoned.

233. NE¼ sec. 18, T. 16 N., R. 28 E., near old house. Small yield. Abandoned.

*234. Long H ranch, sec. 18, T. 16 N., R. 28 E. Water from Tertiary sand. Well caved in.

235. SE¼ sec. 28, T. 16 N., R. 28 E. Dry hole.

*236. Jacob Barth, G Bar ranch, E½ sec. 24, T. 16 N., R. 29 E., in valley. Shallow well near bank of Zuñi River. Water from Recent valley fill.

237. Sec. 17, T. 16 N., R. 30 E. No data.

238. Sec. 11, T. 16 N., R. 30 E. No data.

239. Sec. 34, T. 15 N., R. 24 E. No data.

240 and 241. Sec. 33, T. 15 N., R. 28 E., in valley. Water from sandstone in Chinle. Yield 5 gallons a minute. No water in lower 150 feet.

242. Babbitt Bros., Pine Springs Well, sec. 2, T. 15 N., R. 29 E., in Zuñi River Valley. Water from sand and silt in valley fill.

*243. Schnebley well, SW¼ sec. 9, T. 15 N., R. 29 E., in Zuñi River Valley. Water from sand and silt in valley fill. Yields 5 gallons a minute.

244. Sec. 17, T. 15 N., R. 29 E., in Zuñi River Valley. No data.

*245. Odell ranch, sec. 30, T. 15 N., R. 30 E., in valley. Water from sand and silt in valley fill. Yields 3 gallons a minute.

246. Well and spring, sec. 3, T. 15 N., R. 30 E. No data.

247. Buyobonita Flat, sec. 33, T. 15 N., R. 30 E., on upland. Dry hole.

248. Babbitt Bros., sec. 16, T. 15 N., R. 31 E. Dry hole.

249 and 250. Sec. 6, T. 14 N., R. 24 E. No data.

*251. Ned Mastas, Steel Bridge well, sec. 4, T. 14 N., R. 25 E., in Little Colorado River Valley. Water from sandstone in Coconino. Flowing well.

252. Garland well, sec. 10, T. 14 N., R. 25 E., in Little Colorado River Valley. Water from sandstone in Coconino. Flowing well, now dry.

253. Sec. 28, T. 14 N., R. 25 E., in valley. Water from sand and gravel in alluvium. Small yield.

*254. Hunt School District, sec. 18, T. 14 N., R. 26 E., in Little Colorado River Valley. Water from sandstone in Coconino. Flowing well. See log, page 101.

255. Sec. 34, T. 14 N., R. 26 E. No data.

256. Sec. 3, T. 14 N., R. 27 E., in valley. Dry hole.

257. Jake Mabin, SE¼ sec. 4, T. 14 N., R. 27 E., in Zuñi River Valley. Very salty water from alluvium in valley fill.

258. Sec. 30, T. 14 N., R. 29 E. No data.

259. No. 7 ranch, sec. 7 (?), T. 14 N., R. 29 E. Water from conglomerate in Shinarump (?).

260. NW¼ sec. 12, T. 14 N., R. 30 E., in Towaha Draw. Dry hole.

261. SW¼ sec. 31, T. 14 N., R. 30 E., in Carrizo Wash. Water from alluvium in valley fill.

262. Sec. 4, T. 13 N., R. 25 E., in Mail Station Arroyo. No data.

263. Sec. 16, T. 13 N., R. 24 E. No data.

264. Sec. 3, T. 13 N., R. 25 E. No data.

265. Sec. 20, T. 13 N., R. 25 E. No data.

266. Sec. 25, T. 13 N., R. 27 E., in valley.

*267. L. M. Farr, sec. 26, T. 13 N., R. 27 E., in valley. Water from Chinle or Moenkopi.

268. Arza Greer, sec. 34, T. 13 N., R. 27 E., in valley.

269. Sec. 19, T. 13 N., R. 28 E. No data.

270. Sec. 21, T. 13 N., R. 28 E. No data.

*271. Barth Hotel, NW¼ sec. 27, T. 13 N., R. 28 E., in Little Colorado River Valley. Water from Moenkopi (?). Yields ½ gallon a minute. Flowing well for years.

*272. Jacob Barth, NW¼ sec. 26, T. 13 N., R. 28 E., in Little Colorado River Valley. Water from Moenkopi (?). Yields 5 gallons a minute.

273. St. Johns High School, sec. 27, T. 13 N., R. 28 E., in Little Colorado River Valley. Water from sandstone in Coconino. Supply large. Used only for sanitary purposes.

275. Line between secs. 23 and 24, T. 13 N., R. 28 E., in Little Colorado River Valley. Small flow. 40 to 50 years old.

276. SE¼ sec. 24, T. 13 N., R. 28 E., in Little Colorado River Valley.

277. NE¼ sec. 10, T. 13 N., R. 29 E., near Carrizo Wash. Water from sandstone in Moenkopi (?).

278. Sec. 2, T. 13 N., R. 29 E. No data.

279. Leverton ranch, sec. 14, T. 12 N., R. 24 E., in valley. Water from sandstone in Coconino (?).

*280. C. R. Clark, SW¼SW¼ sec. 18, T. 12 N., R. 25 E., in valley. 350-foot well, water from sandstone in Coconino; no pump attached. 90-foot well, water from alluvium in valley fill or Chinle (?).

281. Concho, sec. 4, T. 12 N., R. 26 E., in valley. Water from alluvium.

282. Casper Nagle, sec. 27, T. 12 N., R. 26 E. Water from lava rock.

283. —— Duke, south line of sec. 7, T. 12 N., R. 28 E., on terrace. Water from shale. Good well.

284. Henry Platt, sec. 31, T. 12 N., R. 28 E., in valley. Water from Recent alluvium.

285. Henry Platt, sec. 20, T. 12 N., R. 29 E., in valley. Water from alluvium in valley fill.

286. Sec. 29, T. 12 N., R. 29 E. No data.

287. Sec. 31, T. 12 N., R. 29 E. No data.

288. Henry Platt, Platt ranch, sec. 7, T. 12 N., R. 30 E., in valley. Water from sandy clay.

289. Sec. 26, T. 12 N., R. 30 E., in valley. Dry hole. Clay and sandstone in Chinle at 300–340 feet; Tertiary sand at surface.

290. Gallegos ranch, sec. 8, T. 12 N., R. 31 E., on upland. Two wells. May be seep wells; they are below large reservoir.

291. Casper Nagle, sec. 17, T. 11 N., R. 26 E., in upland valley. Yields 3-inch stream with pumping.

292. —— Udall, Blood Tanks, sec. 33, T. 11 N., R. 27 E., on upland. Water from "malpais" cinders at contact with Chinle (?). (See p. 52.)

*293. Jacob Barth, reservoir well, NE¼ sec. 8, T. 11 N., R. 28 E., near Lyman Dam, in Little Colorado River Valley. Water from Quaternary or Tertiary travertine. Flows 1,000 gallons a minute.

294. Well above Lyman Dam, S½ sec. 9, T. 11 N., R. 28 E., in valley. Water from Quaternary or Tertiary travertine. Tools lost in hole and well lost. Reported that water rose within 5 feet of surface.

295. Henry Platt, sec. 5, T. 11 N., R. 29 E., in valley. Water from alluvium in valley fill, though reported in Chinle shale and sandstone. Yields 2 gallons a minute.

*296. Voight ranch, sec. 26, T. 11 N., R. 30 E., on upland. Two wells below dam. Water near surface and believed to represent seepage from reservoir.

297. Claude E. Phipps, sec. 21, T. 10 N., R. 25 E., on upland. Water from lava. No pump installed.

*298. School District, Vernon, sec. 22, T. 10 N., R. 25 E., on upland. Water from lava gravel, underlain by Cretaceous strata.

299. W. P. Brady, sec. 15, T. 10 N., R. 25 E., on upland.

*300. Mrs. Baca, sec. 12, T. 10 N., R. 29 E., in upland arroyo. Water from Chinle shale or valley fill.

*301. Bert Colter, sec. 24, T. 10 N., R. 29 E., on bank of Coyote Creek. Water from alluvium in valley fill.

*302. Roman Almandoz, sec. 5 T. 10 N., R. 30 E., on upland. Three wells, all connected. Water from Chinle.

303. Bert Colter, Bankers Petroleum Co., sec. 8, T. 9 N., R. 29 E., in Little Colorado River Valley. Water at 15 to 125 feet; water lost at 125 feet and hole dry to 685 feet. Test for oil. "Malpais" from 25 to 685 feet.

304. G. Becker, sec. 33, T. 9 N., R. 29 E., in Springerville. Well reported to have flowed, but hole was lost and no records are available.

305. Round Valley High School, sec. 33, T. 9 N., R. 29 E., in Springerville. Water from alluvium in valley fill (?); reported as seep from Chinle shale.

*306. Apache Tavern (—— Lynn, manager), sec. 33, T. 9 N., R. 29 E., in Springerville. Water from alluvium in valley fill.

*307. Price W. Nelson, sec. 35, T. 9 N., R. 29 E., in Springerville. Water from red sandstone in Chinle.

*308. G. Becker, NW¼ sec. 10, T. 9 N., R. 31 E., on upland. Water from Chinle (?).

*309. G. Becker, NW¼ sec. 20, T. 9 N., R. 31 E., on Coyote Creek. Water from valley fill.

*310. W. B. Eagar, sec. 4, T. 8 N., R. 29 E., in Eagar. Water from sand and gravel in valley fill.

*311. John C. Hall, sec. 4, T. 8 N., R. 29 E., in Eagar. Completed in 1933. Water from sandstone in Chinle (?).

312. G. Becker, SW¼ sec. 17, T. 8 N., R. 31 E., on upland.

*313. H. P. Burke, Alpine, NE¼ sec. 11, T. 5 N., R. 30 E., on upland. Water from sand and gravel below yellow clay. Temperature February 1, 1934, 47°F.

ANALYSES OF GROUND WATERS

The following table presents the results of chemical analyses of samples of ground water from the Holbrook region made in the laboratory of the Geological Survey.

Analyses of ground waters in the Holbrook region, Arizona

[Parts per million. Numbers in first column correspond to numbers of wells on plate 3 and in preceding tables and to numbers of springs (s1 to s57) described in text (pp. 65–74).]

Coconino County

[Analyses 3, 8, 9, 12, and 22 by E. W. Lohr; others by S. K. Love]

No.	Date of collection	Total dissolved solids (calculated)	Iron (Fe)	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)
3	Jan. 30, 1934	1,159	------	60	21	353	280	144	442	0.4	1.0	236
5	Nov. 20, 1933	616	------	108	50	25	226	295	26	0	1.2	475
6	do	488	------	78	43	33	232	157	63	0	.20	371
8	Feb. 26, 1934	2,281	------	87	46	723	262	176	1,120	0	0	406
9	do	3,446	------	97	55	1,152	260	219	1,795	0	0	468
10	Nov. 11, 1933	476	0.42	84	44	13	210	217	14	0	.30	390
11	Nov. 20, 1933	512	.97	94	44	16	224	226	21	0	.97	415
12	Nov. 11, 1933	1,022	.89	79	47	239	264	135	392	0	.40	390
14	Nov. 20, 1933	394	------	66	41	14	232	136	21	0	2.1	333
15	Nov. 21, 1933	345	------	67	37	3.5	246	105	11	0	.70	319
16	Nov. 20, 1933	1,860	------	218	63	339	198	632	510	0	.30	803
17	Nov. 21, 1933	386	------	78	36	7.7	254	123	16	0	.70	343
18	Nov. 9, 1933	358	------	80	31	13	316	41	37	.4	.10	327
19	Nov. 10, 1933	205	1.2	12	48	([a])	229	26	6	.2	.10	227
21	Nov. 21, 1933	357	------	74	35	4.2	262	104	10	0	.90	328
22	Jan. 29, 1934	475	.62	85	38	27	248	168	34	.3	.6	368

[a] Less than 10.

Analyses of ground waters in the Holbrook region, Arizona—Continued

Navajo County

[Analysis 41 by S. K. Love; others by E. W. Lohr]

No.	Date of collection	Total dissolved solids (calculated)	Iron (Fe)	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)
32	Jan. 24, 1934	1,341	0.21	[b] 15	------	513	476	216	395	1.2	5.3	[c] 64
33	do	1,820	.56	43	16	622	536	399	475	.4	1.0	173
41	Nov. 20, 1933	1,976	5.2	218	42	428	208	533	652	0	.50	717
42	Jan. 24, 1934	1,058	------	[b] 20	------	404	602	170	198	.6	0	[c] 72
52	Jan. 26, 1934	1,099	------	[b] 6	------	447	755	219	98	2.9	.40	[c] 20
55	Feb. 8, 1934	972	.33	[b] 12	------	387	616	186	121	1.0	1.5	[c] 32
56	Feb. 9, 1934	2,250	.70	124	40	680	378	209	1,010	0	.50	474
58	Dec. 26, 1933	2,264	.71	124	36	684	358	278	965	.2	1.0	458
59	Feb. 5, 1934	1,569	------	117	32	414	260	347	530	.8	0	424
60	do	1,599	.34	60	31	506	238	177	708	.2	0	277
62	Dec. 26, 1933	632	------	49	31	142	214	122	182	0	.10	250
67	Jan. 26, 1934	2,754	------	[b] 6	------	1,110	1,513	634	370	6.3	0	[c] 22
87	Dec. 26, 1933	459	------	45	26	86	192	114	93	0	.10	219
88	do	525	------	52	30	95	186	147	109	.2	.30	253
90	do	720	------	90	43	102	224	240	135	0	0	401
91	do	417	------	49	33	54	200	124	58	.2	.40	258
92	Jan. 15, 1934	1,314	------	100	52	313	230	224	512	0	0	463
95	Feb. 2, 1934	1,266	.88	100	48	300	238	225	475	0	.50	447
99	Dec. 4, 1933	6,197	.73	176	47	2,155	330	294	3,362	.1	------	633
105	Jan. 1, 1934	2,277	------	157	23	570	250	1,230	174	.2	0	487
106	do	584	------	84	33	76	242	193	79	0	.16	345
111	Feb. 14, 1934	626	------	71	31	118	252	120	162	.4	0	305
114	Jan. 1, 1934	336	------	64	26	42	276	75	9	.3	2.0	267
115	Jan. 2, 1934	641.	------	139	43	17	312	277	11	.2	.20	524
116	Dec. 29, 1933	129	------	34	12	([a])	140	[b] 4	1	.2	9.1	134
117	do	157	------	[b] 28	------	10	124	[b] 20	14	.1	2.5	[c] 123
118	Jan. 19, 1934	1,127	------	174	56	121	260	140	262	.2	246	665
s1	Jan. 27, 1934	328	------	44	7	56	90	151	16	.2	9.0	139
s6	Jan. 16, 1934	272	------	55	29	12	318	[b] 15	4	0	.80	256
s10	do	88	------	[b] 11	------	8	98	[b] 2	2	0	.40	[c] 69
s11	Jan. 17, 1934	302	------	100	11	([a])	326	[b] 12	8	.2	.40	295
s16	Jan. 19, 1934	80	------	[b] 16	------	4	90	[b] 2	1	0	.30	[c] 69

Apache County

[Analyses s30–s32, s34, s39, s48, s49, s52, s53, and s55 by S. K. Love; others by E. W. Lohr]

130	Jan. 11, 1934	634	------	38	15	192	530	111	16	0.4	0.40	156
132	Feb. 6, 1934	268	------	56	18	27	284	[b] 1	25	1.0	.10	214
136	Jan. 10, 1934	440	------	94	25	28	278	130	24	0	2.0	338
138	Jan. 11, 1934	466	------	92	22	41	244	151	32	0	7.8	320
144	Jan. 9, 1934	744	------	102	21	132	344	278	38	.2	3.4	341
145	do	923	------	[b] 8	------	400	952	36	46	1.4	2.3	[c] 18
151	Jan. 11, 1934	872	------	138	34	109	316	358	47	0	30	484
155	do	728	------	102	51	76	328	293	35	0	9.0	464
156	do	751	------	98	67	65	356	304	34	0	7.2	520
172	Jan. 10, 1934	195	------	47	5.6	16	140	[b] 17	17	0	23	140
179	Jan. 11, 1934	635	0.21	66	20	136	320	212	41	.6	1.4	247
180	do	804	.10	72	13	219	534	152	74	.3	11	233
205	Jan. 9, 1934	194	------	48	6.6	21	214	[b] 3	9	.2	.50	147
213a	Feb. 8, 1934	1,422	------	[b] 18	------	546	708	394	170	2.3	2.4	[c] 51
214	Jan. 9, 1934	249	------	[b] 20	------	61	164	[b] 10	35	.2	30	[c] 86
216	Jan. 11, 1934	289	1.0	[b] 20	------	88	198	[b] 24	38	0	21	[c] 66
218	Dec. 12, 1933	230	------	[b] 12	------	84	184	[b] 10	37	.4	1.7	[c] 34
222	Jan. 11, 1934	508	------	62	15	121	482	[b] 20	32	.6	20	216
224	Dec. 12, 1933	199	------	[b] 24	------	53	200	[b] 10	9	0	2.5	[c] 74
230	Jan. 11, 1934	910	------	[b] 7	------	382	824	102	42	1.4	9.0	[c] 22
234	Jan. 4, 1934	426	------	[b] 20	------	146	226	[b] 26	92	.2	38	[c] 56
236	Dec. 12, 1933	1,006	------	133	34	159	274	476	67	.1	2.2	472
243	do	610	------	83	18	95	144	300	38	0	5.2	281
245	Jan. 4, 1934	3,470	.37	103	23	1,183	480	499	1,425	.2	0	352
251	Jan. 6, 1934	322	------	49	19	42	160	75	58	.1	.10	200
254	Nov. 22, 1933	343	------	44	15	67	190	36	87	.1	0	172
267	Jan. 6, 1934	677	------	[b] 10	------	253	472	170	24	2.7	1.0	[c] 56
271	Dec. 22, 1933	1,718	------	246	69	280	736	468	290	2.7	0	898
272	Jan. 5, 1934	1,606	------	246	66	229	472	482	348	1.6	.75	886
280	Jan. 4, 1934	1,416	------	74	83	323	532	383	260	1.2	30	525
293	Dec. 6, 1933	1,261	------	186	49	198	500	368	212	1.6	.20	666
296	Dec. 20, 1933	468	------	125	29	16	524	[b] 14	3	.4	22	431

[a] Less than 10. [b] By turbidity. [c] Determined.

Analyses of ground waters in the Holbrook region, Arizona—Continued

Apache County—Continued

No.	Date of collection	Total dissolved solids (calculated)	Iron (Fe)	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)
298	Jan. 1, 1934	175		[b] 28		9	134	[b] 16	23	0.1	2.5	[c] 141
300	Dec. 21, 1933	872		44	61	177	400	365	18	2.3	8.1	360
301	do	2,032		187	103	338	384	953	175	1.2	86	890
302	do	427		[b] 36		77	320	[b] 45	58	1.2	1.5	[c] 228
306	Dec. 6, 1933	378		62	33	35	330	[b] 30	31	.4	24	290
307	Dec. 7, 1933	431		68	23	58	288	[b] 36	56	0	48	264
308	Dec. 22, 1933	206		[b] 28		26	192	12	13	.6	5.0	[c] 138
309	Dec. 5, 1933	258		46	13	36	248	[b] 12	13	.4	15	168
310	Dec. 6, 1933	441		60	42	43	368	[b] 24	26	.8	64	322
311	do	398		58	32	53	388	[b] 36	19	.7	8.2	276
313	Feb. 1, 1934	638		115	42	41	264	82	103	0	125	460
s18	Jan. 10, 1934	530		71	80	19	364	[b] 18	160	1.6	1.5	506
s20	Jan. 11, 1934	406		66	10	69	188	47	89	.2	32	206
s21	Jan. 9, 1934	190		[b] 8		75	198	[b] 8	6	.6	2.4	[c] 20
s25	Jan. 8, 1934	367		[b] 1		158	360	[b] 36	10	1.0	.20	[c] 5
s28	Jan. 9, 1934	272		44	9.1	48	210	[b] 10	37	0	20	147
s30	Dec. —, 1933	310		42	6.8	74	304	[b] 22	15	.4	.50	133
s31	Dec. 19, 1933	814		138	29	99	266	345	72	0	.10	464
s32	do	1,425		244	50	154	288	679	146	0	.30	815
s33	Jan. 4, 1934	425		[b] 8		167	230	63	84	0	7.7	[c] 15
s34	Dec. 19, 1933	601	13	126	28	41	294	245	14	.2	2.4	430
s35	Jan. 12, 1934	2,682	.52	280	99	550	628	678	765	1.0	0	1,106
s36	Jan. 5, 1934	2,452		265	96	484	624	642	655	1.6	1.0	1,056
s38	Dec. 22, 1933	276		[b] 26		72	236	[b] 36	6	1.2	12	[c] 96
s39	Dec. 9, 1933	329		28	19	68	230	39	26	1.4	34	148
s42	Jan. 4, 1934	135		[b] 14		27	148	[b] 5	2	0	.80	[c] 72
s43	do	91		[b] 14		8	98	[b] 2	3	.6	.86	[c] 72
s44	do	148		[b] 16		18	154	[b] 5	6	.4	1.5	[c] 102
s48	Dec. 6, 1933	2,259	1.0	324	72	379	746	703	412	1.6	.10	1,105
s49	Dec. 21, 1933	326		34	21	62	270	55	14	.8	6.0	171
s50	Jan. 4, 1934	885		93	99	86	350	160	250	.2	24	638
s51	do	18,858		421	1,427	3,597	583	11,512	1,640		0	6,903
s51a	do	201		42	17	10	182	[b] 26	15	.1	2.5	175
s52	Dec. 20, 1933	131		[b] 18		9	134	[b] 6	5	0	2.3	[c] 105
s53	do	137		[b] 20		12	135	[b] 10	6	0	1.2	[c] 102
s54	do	325		40	32	43	324	[b] 34	16	0	.70	231
s55	do	192		34	19	15	206	[b] 12	9	.6	1.2	163

[b] By turbidity. [c] Determined.

WELL LOGS

The numbers of the logs correspond to the well numbers given on plate 3 and in the well tables (pp. 75–88). The logs of wells 393, 394, 432, and 438 are given by courtesy of the Office of Indian Affairs and the numbers used are as assigned by that office.

393. *Well on Leupp Reservation, sec. 2, T. 21 N., R. 12½ E.*

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Moenkopi(?) formation:			Sandstone, white	56	103
Surface soil	3	3	Sandstone, buff	5	107
Red shale	1	4	Sandstone, white	32	139
Kaibab(?) limestone:			Sandstone, buff	61	200
Limestone, yellow	4	8	Sandstone	25	225
Sandstone, white	2	10	Sandstone, gray	25	250
Sandstone, yellow	13	23	Sandstone, buff	120	370
Sandstone, yellow, very hard	10	33	Shale, yellow, sandy	2	372
Coconino sandstone:			Sandstone, white, water-bearing	5	377
Sandstone, white	9	42			
Sandstone, pink	5	47	Sandstone, yellow	23	400

Depth to water 375 feet. Test run, 600 gallons an hour. Quality of water, good. Water-bearing formation, sandstone.

394. *Well on Leupp Reservation, sec. 14, T. 22 N., R. 13 E.*

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Kaibab limestone:			Sandstone, buff	30	210
Limestone, broken	25	25	Sandstone, white	5	215
Limestone, white	50	75	Sandstone, buff	115	330
Limestone, buff	40	115	Sandstone, white, very hard	60	390
Limestone, white	15	130	Sandstone, white, medium hard	5	395
Limestone, buff	20	150	Shale, yellow, sandy	2	397
Limestone, buff, exceedingly hard	25	175	Sandstone, white, water-bearing	7	404
Coconino sandstone:					
Sandstone, white	5	180	Sandstone, yellow	21	425

Depth to water 404 feet. Test run, 600 gallons an hour. Quality of water, good. Water-bearing formation, sandstone.

432. *Well on Leupp Reservation, sec. 12, T. 21 N., R. 13 E.*

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Surface soil and red shale	12	12	Coconino sandstone:		
Kaibab limestone:			Sandstone, buff	10	210
Limestone, red	8	20	Sandstone, gray	10	220
Shale, red	10	30	Shale, yellow, sandy	3	223
Shale, yellow	5	35	Sandstone, white, water-bearing	6	229
Sandstone, yellow	45	80	Sandstone, yellow	24	253
Limestone, buff	120	200			

Depth to water, 225 feet. Test run, 600 gallons an hour. Quality of water, good. Water-bearing formation, sandstone.

438. *Well on Leupp Reservation, sec. 16, T. 21 N., R. 13 E.*

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Moenkopi formation:			Sandstone, white, water-bearing, 3 gallons a minute	5	160
Shale, red	20	20	Sandstone, yellow	20	180
Kaibab limestone:			Sandstone, white; water-bearing	8	188
Limestone, yellow; full of crevices	18	38	Sandstone, yellow; water-bearing	15	203
Limestone, yellow	92	130	Sandstone, yellow	22	225
Coconino sandstone:					
Sandstone, white	20	150			
Shale, yellow, sandy	5	155			

Depth to water, 185 feet. Test run, 600 gallons an hour. Quality of water, good. Water-bearing formation, sandstone.

27. *Bixby No. 1, Moqui ranch, sec. 12, T. 14 N., R. 11 E.*

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Kaibab limestone:			Coconino sandstone:		
Limestone, broken	4	4	Sandstone, white	3	291
Limestone, buff, hard	29	33	Sandstone, hard, yellow	16	307
Limestone, pink, sandy	5	38	Sandstone, white	25	332
Limestone, white, sandy, in part very hard	25	63	Sandstone, gray	33	365
Limestone, red	8	71	Sandstone, buff	20	385
Limestone, buff	13	84	Sandstone, white; water-bearing stratum, water rose to 383 feet	8	393
Limestone, red	8	92	Sandstone, coarse, hard, white	45	448
Limestone, buff, sandy (small seep of water)	21	113	Sandstone, hard, gray	9	457
Limestone, gray, sandy	35	148	Sandstone, white; water-bearing stratum, water rose to 372 feet	4	461
Limestone, hard, white	30	178	Sandstone, buff	15	477
Limestone, buff, sandy	12	190			
Limestone, gray, sandy	52	242			
Limestone, buff	8	250			
Limestone, gray	18	268			
Limestone, yellow, sandy	20	288			

Diameter, 8¼ inches top to bottom. Water level 372 feet from surface. Pumps 15 gallons a minute, no lowering. Has 6 feet of 6⅝-inch casing cemented on top. 3-inch galvanized pump pipe hanging on clamps set on casing. Total length of water column, including cylinder, 424 feet 4 inches. 2¾-inch cylinder all brass ball and seat valves; 4 leathers on working valves; leather rings on standing valve. 1⅝-inch wood rods; ⅞-inch pins. Drilled July 1934. Log by courtesy of Wayne Thornburg, general manager, Clear Creek Cattle Co., 716 Security Building, Phoenix, Ariz.

43. *Atchison, Topeka & Santa Fe Railway well at Winslow, sec. 30, T. 19 N. R. 16 E.*

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Topsoil	5	5	Sandstone	19	233
Sandstone	2	7	Sandstone, white	473	706
Clay	3	10	Sandstone	17	723
Sandstone, red	50	60	Sandstone, white	100	823
Sandstone and shaly sandstone	40	100	Sandstone, very hard	2	825
Sandstone, gray	15	115	Sandstone, white	41	866
Limestone	7	122	Sandstone	8	874
Sandstone	7	129	Sandstone, white	94	968
Sandstone and "lime"	16	145	Sandstone, brown	22	990
Sandstone, alternating gray and white beds	69	214			

Drilled by Linscott Drilling Co., 1189 San Pablo Ave., Berkeley, Calif. Hole plugged and cemented at 900 feet. 12½-inch casing down to 150 feet. Obtained salt water at unrecorded depth. Log by courtesy of Arthur Saunders.

Darton [43] in 1910 recorded the drilling of a deep well at Winslow many years prior to that date. The well was reported to have gone to a depth of 1,700 feet, which would have penetrated Supai beds. No water was obtained. This well was drilled by the Atlantic & Pacific Railroad Co. It is probably not the same well as logged above.

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[43] Darton, N. H., A reconnaissance of parts of northwestern New Mexico and northern Arizona: Geol. Survey Bull. 435, p. 80, 1910.

94. *Taylor-Fuller No. 1 well of Great Basin Oil Co., Holbrook, NW¼NW¼ sec. 21, T. 17 N., R. 20 E.*

	Thickness (feet)	Depth (feet)
Coconino sandstone:		
Sandstone, many cracks, crevices, and caves; fresh water at 185 feet; heavy flow of fresh water at 205-210 feet	460	460
Supai formation:		
Brown shale	5	465
Brown sandy shale	50	515
Hard brown shale	35	550
Soft ochre sand	15	565
Brown sandy shale	35	600
Very hard brown sand	10	610
Sandy shale	25	635
Brown sandy shale	15	645
Brown lime	5	650
Sandy shale, fresh water at 660 feet	15	665
Brown lime	5	670
Red shale over hard lime, suitable for water shut-off	--------	--------
Red shale	30	700
Red shale	15	715
Red lime shell	8	723
White talc	2	725
Hard gray lime	3	728
Red shale	52	780
Red sandy shale	5	785
Rock salt and red shale	15	800
Red shale	20	820
Rock salt and red shale	10	830
Red shale	45	875
Shale and salt	85	960
Brown shale	10	970
Brown lime	4	974
Blue shale	3	977
Brown lime shell	8	985
Red shale	40	1,025
Brown shale	25	1,050
Shale and salt	175	1,225
Yellow-like shell	3	1,228
Yellow shale	22	1,250
Brown shale	55	1,305
Gray lime shells (decomposed)	10	1,315
Shale and salt	15	1,330
Brown shale	130	1,460
Hard gray lime	13	1,473
Brown shale	137	1,610
Shale and salt	10	1,620
Redwall limestone:		
Hard gray lime	10	1,630
Soft gray lime	30	1,660
Soft brown lime	20	1,680
Soft brown shale	173	1,853
Brown lime	5	1,858
Brown shale	42	1,900
Brown sandy shale	25	1,925
Brown sand (salt water, gas)	5	1,930
Brown sandy shale	55	1,985
Hard brown sandy shale with lime shells	200	2,185
Blue shale	3	2,188
Hard brown sandy shale, lime shells	5	2,193
Sandy brown lime	49	2,242
Soft red shale	18	2,260
Hard brown shale	14	2,274
Gray shale	3	2,277
Hard brown shale	46	2,323
Broken lime shells	107	2,430
Broken lime shells and shale	80	2,510
Brown shale and thin lime shells	40	2,550
Redwall limestone—Continued.		
Brown shale and thin lime shells	200	2,750
Brown lime	10	2,760
Brown shale	45	2,805
Gray sandy lime	5	2,810
Sandy shale	15	2,825
Brown sandy lime	15	2,840
Gray shale	15	2,855
Hard brown shale	40	2,895
Soft gray lime	20	2,915
Brown shale	13	2,928
Hard gray lime	12	2,940
Brown shale	15	2,955
Sandy blue shale	57	3,012
Hard gray lime	8	3,020
Brown shale	45	3,065
Gray lime	45	3,110
Sandy brown shale	8	3,118
Gray lime	22	3,140
Sandy brown shale	10	3,150
Hard sandy lime	115	3,265
Bluish gray shale	35	3,290
Hard sandy gray lime	25	3,315
Soft red shale	10	3,325
Hard sandy gray lime	65	3,390
Gray lime	40	3,430
Brown shale	10	3,440
Gray shale and lime shells	15	3,455
Sand; salt water filled hole to 750 feet	10	3,465
Gray lime	3	3,468
Gray lime	40	3,509
Sandy lime	6	3,515
Sandy pink shale	10	3,525
Gray lime	5	3,530
Gray lime, streaked pink shale	10	3,540
Water sand, hole full of water	2	3,542
Gray lime, streaks of brown shale	6	3,548
Lime, streaks of brown shale	7	3,555
Lime	3	3,558
Hard sandstones with streaks of sandy lime	32	3,590
Oil showing, strong odor	4	3,594
Hard sandstone, streaks of sandy lime	36	3,630
Crystallized lime	5	3,635
White lime, sandy lime	50	3,685
Pre-Cambrian:		
Arkosic sandstone; water sand, oil on tools at 3,860-3,862 feet	177	3,862
Arkosic sand	8	3,870
Lime with sand streaks	131	3,901
Lime, dull white under microscope	52	3,953
Water sand; flowing water and gas	7	3,960
Arkosic sandstone	50	4,010
Water sand	20	4,030
Brown sand	15	4,045
Arkosic sandstone	61	4,206
Red shale	34	4,240
Hard sandy lime and sandstone	34	4,274
Sandy gray lime	24	4,298
Sand with streaks of blue shale	6	4,304
Hard sandy red and gray lime	78	4,382
Hard gray sand streaked with hard shells	293	4,675

Altitude, 5,270 feet.

96. *Atchison, Topeka & Santa Fe Railway well 3 at Holbrook, sec. 6, T. 17 N., R. 21 E.*

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Old well		32	Sand and gravel	10	90
Yellow clay	18	50	Sand and gravel, water	10	100
Sandy clay	17	67	Gravel	37	137
Sand and fine clay	13	80	Sandstone	2	139

139 feet of stovepipe casing, perforated at water-bearing stratum. Tested 430 gallons a minute and no draw-down. Water level is 12½ feet below surface. Drilled April 26 to May 5, 1927.

97. *Atchison, Topeka & Santa Fe Railway well 1 at Holbrook, sec. 6, T. 17 N., R. 21 E.*

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Adobe sand and gravel	36	36	Sand	15	107
Sand, some clay	31	67	Sand and gravel (water)	3	110
Sandy clay	8	75	Gravel (water)	15	125
Quicksand	8	83	Gravel	9	134
Sand and gravel	9	92	Sandstone	2	136

136 feet of 16-inch casing, perforated at the water-bearing strata. Well tested 400 gallons a minute. Water stands 15 feet below the surface; draw-down, 6 feet while testing. Drilled March 1–10, 1927.

108. *Petrified Forest National Monument well, sec. 1, T. 16 N., R. 23 W.*

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Sandstone and conglomerate	17	17	Sandstone	9	512
Shale	8	25	Sandy shale	8	520
Shaly sandstone	3	28	Sandstone	4	524
Sandstone and shale	8	36	Sandy shale; strong flow of salt water at 609 feet; water rose within 75 feet of surface	88	612
Sandy shale	19	55	Sandstone	10	622
Shale	13	68	Sandy shale	12	634
Sandy shale	126	194	Sandstone	121	755
Shale; salt water at 100 feet	98	292	Limestone	40	795
Sandy shale	68	360	Fine gray-buff sandstone	135	930
Shale	61	421	Coarse sandstone conglomerate	25	955
Sandy shale	64	485	Fine-grained sandstone	68	1,023
Shale	8	493			
Sandy shale	10	503			

Altitude 5,527 feet. Salt water stands 121 feet below ground surface. Casing set at 745 feet and well plugged back to 950 feet. Casing burst below 121 feet. Well was pumped for 4 hours at rate of 1,500 gallons an hour and did not lower water 70 feet, which was depth of tubing into column of salt water. Water used for sanitary purposes. Drilled in 1934. Log from surface to 634 feet by Frank H. Bunnell, ranger-naturalist; from 634 feet to 1,023 feet by M. V. Walker, assistant park naturalist. Log by courtesy of National Park Service.

The following correlation of the log is supplied by M. V. Walker:

Correlation of log of Petrified Forest National Monument well

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Chinle	300	300	Moenkopi (sandstone)	143	755
Shinarump	55	355	Kaibab	40	795
Moenkopi (shale)	257	612	Coconino	228	1,023

110. *Hopi Oil Co. well 1, sec. 21, T. 15 N., R. 19 E.*[a]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Coconino sandstone:			Redwall limestone:		
Sandstone, hard, cross-bedded, gray to buff	465	465	Limestone, very hard, black on blue	63	1,788
Supai formation:			Sandstone	87	1,875
Sandstone, red	160	625	Sandstone, red, with salt in upper half	300	2,175
Limestone, sandy, red	72	697	Limestone, red, sandy, hard	180	2,355
Sandstone, gray	13	710	Sandstone, buff	45	2,400
Shale, etc., red	365	1,075	Limestone, sandy, and red sandstone	20	2,420
Shale, sandy, black	125	1,200			
Sandstone, red, with salt beds (limestone, 1,550–1,590 feet)	525	1,725			

Another record gives red sand and shale, 2,196–2,235 feet; lime and shale, 2,235–2,505 feet; and white "lime," 2,505–2,520 feet. Possibly the base of the Supai was at 1,725 feet, but red material occurs in underlying strata.

[a] Darton, N. H., A résumé of Arizona geology: Arizona Univ. Bull. 119, p. 203, 1925.

113. *Adamana Oil & Land Co. well, sec. 4, T. 14 N., R. 20 E.*

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Red shale	60	60	Soft brown shale, strips of hard brown lime	40	2,425
Hard cross-bedded sandstone	274	334	Dark-brown water sand; water now absent	13	2,438
Yellow limestone	60	394	Dark-brown lime	42	2,480
White shale	45	439	Oil sand	12	2,492
Buff sandstone	42	481	Dark-brown shale	73	2,565
Buff and red sandstone; fresh water	68	549	Brown shale	45	2,610
Red sandstone	62	611	Brown lime	8	2,618
Red sandstone and shale	69	680	Brown shale	50	2,668
Hard lime	12	692	Dark-brown shale	57	2,725
Red shale and gypsum	8	800	Fossil bed	5	2,730
Set 8-foot casing	10	810	Dark-brown shale and fossils	118	2,848
Shale, salt, and gypsum	45	855	Medium soft gray lime	17	2,865
Reddish-brown shale	150	1,005	Black hard shale and lime	5	2,870
Brown shale	35	1,040	Dark-gray hard lime	8	2,878
Blue lime	5	1,050	Dark-gray shale (?)	4	2,882
Brown shale and silt	40	1,090	Brown water sand	4	2,886
Blue shale and brown sandstone	110	1,200	Black lime	4	2,890
Blue shale and salt	540	1,740	Brown water sand	6	2,896
Blue shale; strong showing of oil	10	1,750	Gray lime	6	2,902
Lime	190	1,940	Water sand	4	2,906
Shale, strong showing of oil and gas	10	1,950	Gray-black shale	68	2,974
Blue lime	78	2,028	Gray lime	6	2,980
Water sand (white)	12	2,040	Dark shale; thin streaks of dark lime	105	3,085
Soft brown shale	110	2,150	Dolomite, very dark brownish gray	100	3,185
Blue-gray lime, thin shales	67	2,217	Thin gray lime and gray shale	90	3,275
Brown sandy shale	43	2,260	Brown sand, dry	20	3,295
Oil sand, dark brown; did not test on account of water; looks like productive stratum	40	2,300	Gray lime and shale	65	3,360
Brown shale	5	2,305	Water sand; heavy water	5	3,365
Buff water sand; salt water	15	2,320	Shale	6	3,371
Rotten red lime or shale	15	2,335	Lime	3	3,374
Soft brown shale	40	2,375	Shale	2	3,376
Sandy lime rock	5	2,380	Lime shell	2	3,378
Hard brown lime	5	2,385	Sandy lime	9	3,387

"Oil sand at 3,387 feet. Big showing, free oil and black paraffin came up at this time, also strong gas showing. 2,800 feet of water in hole; lost the well by not getting a water shut-off. Looks like big producer from the showing."

The above log, which was supplied by the University of Arizona, differs considerably from that given by Darton,[43] which shows 60 feet of red shale at the surface, underlain by 20 feet of very sandy yellow limestone. Darton's correlation is as follows: 0–60 feet, Moenkopi; 60–80 feet, Kaibab; 80–680 feet, Coconino; 680–1,745 feet, Supai; 1,745–2,345 feet, Redwall.

Record of boring east of Holbrook, Ariz.[a]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Soil	23	23	Gypsum	1	178
Quicksand	38	61	Red sandstone	51	229
Rock	8	69	White sandstone	206	435
Red mud	2	71	Light-yellow sandstone	5	440
Rock	5	76			
Red mud and some gypsum; water, no flow	101	177			

"A moderate amount of good water was found in the sandstone from 178 to 300 feet, yielding about 700 gallons an hour. The boring is to be deepened to obtain a larger supply."

[a] Darton, N. H., A reconnaissance of parts of northwestern New Mexico and northern Arizona: U. S. Geol. Survey Bull. 435, p. 79, 1910.

The next two wells were drilled in the Sitgreaves National Forest, by the United States Forest Service. The logs are given by courtesy of Robert C. Salton, acting forest supervisor, Sitgreaves National Forest, Holbrook.

126. *Well near Pinedale, SW ¼ sec. 29, T. 11 N., R. 20 E.*

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Surface soil	3	3	Coconino (?) sandstone:		
Moenkopi (?) formation:			White sandstone	62	197
Red clay	77	80	Buff-colored sandstone	45	242
Red sandy shale	13	93	Yellow sandstone	65	307
Red shale	42	135	Buff sandstone	38	345

No water was found. Drilled in February 1934.

127. *Well near Pinedale, SE¼ sec. 32, T. 11 N., R. 20 E.*

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Surface soil and boulders	16	16	Lime and sandstone streaks	12	60
Red shale	9	23	Sandstone	16	76
Yellow clay and sandstone streaks	22	45	Red shale	7	83
Water streaks or strata	3	48	Sandstone	7	90

Water was obtained at 46 feet and rose within 32 feet of the surface. The well tested 25 gallons a minute without lowering the head. Drilled in July 1934.

[43] Darton, N. H., A résumé of Arizona geology: Arizona Univ. Bull. 119, p. 203, 1925.

134. *Atchison, Topeka & Santa Fe Railway well A, at Houck, sec. 26, T. 22 N., R. 29 E.*

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Old well		28	Sand	10	76
Sand and clay in old well	7	35	Clay	4	80
Clay and gravel	13	48	Quicksand	25	105
Clay	7	55	Gravel and clay	3	108
Sand	8	63	Hard red clay	7	115
Clay	3	66			

Cased with16-inch stove pipe casing to 113 feet; perforated from 28 to 86 feet and from 105 to 108 feet. Tested 188 gallons a minute for 24 hours.

135. *Atchison, Topeka & Santa Fe Railway wells 1, 3, 6, 7, 8, and 9, at Houck, sec. 25, T. 22 N., R. 29 E.*

Well 1

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Red clay	63	63	Brown sandy clay	15	88
Sand and clay	10	73	Sandstone	8	96

Ninety-six feet of 16-inch casing. Perforated from 60 to 75 feet. Water level at 20 feet. Drilled April 1927.

Well 3

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Red clay	65	65	Sandstone and clay	7	105
Quicksand and clay	10	75	Sandstone and shale	45	150
Red sandy clay	23	98	Brown shale	50	200

Cased with 104 feet of 16-inch and 153 feet of 12-inch casing. Casing perforated from 60 to 85 feet. Water level at 17 feet. Drilled May 1927.

Well 6

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Red clay	45	45	Quicksand and clay	25	98
Blue clay	15	60	Soft sandy clay	10	108
Clay and streaks of quicksand	13	73	Sandstone	1	109

Cased with 113 feet of 16-inch casing perforated from 60 to 108 feet. Drilled August 1927.

Well 7

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Red clay	45	45	Clay and streaks of sand	13	87
Blue clay	13	58	Blue and brown clay	18	105
Clay and gravel	4	62	Sand and gravel	4	109
Sand and little clay	12	74	Sandstone	1	110

Cased with 113 feet of 16-inch casing perforated from 58 to 85 feet and 104 to 108 feet. Drilled October 1928.

135. *Atchison, Topeka & Santa Fe Railway wells 1, 3, 6, 7, 8, and 9, at Houck, sec. 25, T. 22 N., R. 29 E.*—Continued

Well 8

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Clay	66	66	Hard rock	22	157
Sand; some small gravel	50	116	Shale and red clay	28	185
Sandrock and blue shale	19	135	Sandrock	25	210

Cased with 46 feet of 20-inch, 116 feet of 12-inch, and 100 feet of 10-inch casing, perforated from 66 to 109 feet. Tested 275 gallons a minute. Water level at 32 feet and draws down 13 feet when pumped steadily. Drilled May 1928.

Well 9

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Clay	67	67	Shale	17	137
Sand, clay; some gravel in last 2 feet	51	118	Hard rock	21	158
Sandrock	2	120	Shale and red clay	29	187
			Sandrock	23	210

Cased with 63 feet of 20-inch, 135 feet of 12-inch, and 86 feet of 10-inch casing, perforated from 67 to 122 feet. Tested 275 gallons a minute. Water level at 32 feet and draws down 4 feet when pumped steadily. Drilled June 1928. In wells 8 and 9 a large amount of gravel was used between the casings and around the casing when going through quicksand. Both wells are cased to the bottom.

136. *Tegakwitha Indian Mission well, SW¼NE¼ sec. 25, T. 22 N., R. 29 E.*

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Red clay and shale (subsoil)	32	32	Moenkopi formation—Continued.		
Shinarump(?):			Blue sandy shale	11	146
Sandstone	3	35	Hard blue sandstone	2	148
Conglomerate	2	37	Blue sandstone	7	155
Moenkopi formation:			Blue shale	15	170
Red sandstone	3	40	Brown and red clay	30	200
Red clay	36	76	Hard sandstone	10	210
Hard blue sandstone	5	81	Sandy red clay	10	220
Brown shale	3	84	Coconino sandstone:		
Sandstone, brown, changing to whitish blue at 96 feet	12	96	Sandstone, alternating red and white, hard and soft spots	62	282
Water sand, hole full of water	6	102	Sandstone	24	306
Sandy shale, blue	4	106	Do	44	350
Sandstone	4	110	Water sand	10	360
Sandy shale, brown	25	135			

Last 10 feet of sandstone coarse, white with bluish cast. Started into brown sand at 360 feet. Water at 346 feet. Cased to 340 feet. Ernest Boardman, contractor, Gallup, N. Mex.; Tony Leone, driller.

143a. *Atchison, Topeka & Santa Fe Railway well 2 at Chambers, sec. 36, T. 21 N., R. 27 E.*

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Sandy clay	70	70	Clay	48	260
Clay	102	172	Limestone	28	288
Sand	40	212	Red shale	15	303

Tested 2,300 gallons an hour and lowered 107 feet. Water believed to come from the 70-foot level. 272 feet of stovepipe casing in well. By December 1907 well had sanded up to 212-foot level. Abandoned because quicksand filled the casing. Drilled November 18–23, 1935.

143b. *Atchison, Topeka & Santa Fe Railway well 1 at Chambers, sec. 25, T. 21 N., R. 27 E.*

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Sandy clay; water at 50 feet	90	90	Water sand	30	210
Blue clay	15	105	Sandy clay	110	320
Red sandstone	30	135	Sandstone; water shut off at 495 feet	195	515
Water sand	25	160	White sandstone	90	605
Blue clay	20	180			

Water level at 58 feet. Tested 2,300 gallons an hour and lowered 107 feet. On May 2, 1902, pumped 20,000 gallons in 24 hours. Cased with 110 feet of 12-inch stovepipe casing, 195 feet of 9½-inch screw casing, 285 feet of 8 inch screw casing, and 525 feet of 6-inch screw casing. Well was abandoned August 19, 1902, because quicksand filled the casing. Drilled in spring of 1902.

144. *Atchison, Topeka & Santa Fe Railway well 3 at Chambers, sec. 25(?), T. 21 N., R. 27 E.*

Depth 85 feet, diameter 26 feet. Lined with 18-inch masonry walls. Water level at 38 feet; tested by continuous pumping of 50 to 500 gallons a minute and level never lowered more than 10 feet. 90 feet of 10-inch stovepipe casing was put in the well, and this was perforated from 74 to 80 feet; a box 4½ by 5 feet was built around the 90 feet of stovepipe casing; and the well was filled up with gravel to 2 feet above the water level. Necessary to treat the water. Dug in June 1925. Courtesy of Santa Fe Railway Co.

190. *Zuñi-Arizona Oil Co. well 1, SE¼SW¼ sec. 6, T. 19 N., R. 24 E.*

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Surface soil	10	10	Soapstone	8	528
Blue shale	8	18	Shale, white, sandy	10	538
Water gravel	4	22	Pencil shale	7	545
Shale, blue	10	32	Blue shale	15	560
Sand, water	3	35	Lime, gray	58	618
Red rock	5	40	Sand or lime shells, sharp	17	635
Shale, blue	15	55	Lime, brown, with sandy streaks showing oil	35	700
Lime ("Bastard")	8	63	White lime	5	705
Red shale	7	70	Shale, brown, with lime shells	15	720
"Bastard" lime	10	80	Blue lime	5	725
Sandy shale (water)	18	98	Brown lime	13	738
Blue shale	37	135	Gray lime	9	747
Red rock	15	150	Sand, very sharp and light	16	763
Blue shale	15	165	Gray lime	12	775
Red rock	5	170	Brown shale	25	800
Lime, hard	10	180	Sandy lime	8	808
Red rock	170	350	Brown shale	32	840
Shale, blue	25	375	Gray lime	5	845
Red rock	25	400	Brown shale	20	865
Shale, white	35	435	Red shale	45	910
Shale, brown	30	465	Brown lime	5	915
Shale, blue, with lime shells	15	480	Buff shale	17	932
Red rock	20	500	White sand, salt water	13	945
Red shale	6	506	Blue sand	1	946
Lime, gray	3	509			
Red shale	11	520			

Drilled in 1921.

193. *Atchison, Topeka & Santa Fe Railway, at Pinta, sec. 1, T. 19 N., R. 25 E.*

Well 2 (old)

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Sand and gravel	20	20	Cement gravel	4	56
Cement gravel	3	23	Sand and gravel	4	60
Sand and adobe	27	50	Sand and gravel and water	2	62
Rock and adobe	2	52	Sand and water	38	100

100 feet of 12-inch screw pipe casing with 9-inch strainer 20 feet long. Tested 56 gallons a minute.

193. *Atchison, Topeka & Sante Fe Railway, at Pinta, sec. 1, T. 19 N., R. 25 E.*—Continued

Well 3 (old)

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Sand, rock, and adobe	52	52	Sand, gravel, and water	25	80
Cement and gravel	3	55			

60 feet of 10-inch screw-pipe casing with 21 feet of 8-inch strainer. Drilled October 30 to November 7, 1901. Well now sanded up; out of operation.

Wells 2 and 3 (new)

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Silt and sand	24	24	Clay	3	68
Gravel, water	6	30	Water, gravel	13	81
Quicksand	10	40	Clay	3	84
Hard pan	15	55	Quicksand	10	94
Gravel	10	65	Heavy clay	4	98

These wells were plugged back to 83 feet in clay. Unable to handle quicksand below 84 feet. Each well has 98 feet of 12½-inch casing perforated from 55 to 65 feet and 68 to 81 feet. Wells close together. Well 2 tested 7,000 gallons an hour and well 3 4,000 gallons an hour. Drilled May 1924.

208. *Artesian well at Adamana, sec. 8, T. 18 N., R. 24 E.*

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Sand and sandy clay	55	55	Moenkopi (?) formation—Con.		
Shinarump(?):			Brown shale	43	151
Sandstone	3	58	Red shale	49	200
Cement gravel	1	59	Hard brown and blue shale	5	205
Moenkopi (?) formation:			Red shale	70	275
Sandstone (slightly salt water at 88 feet)	49	108	Sandstone	10	285
			Hard brown shale	20	305

Intensely salt water at 305 feet. Flow was 25 gallons a minute, and head stated to be sufficient to raise the water 19 feet above the surface. (Darton, N. H., in U. S. Geol. Survey Bull. 435, p. 79, quoting Ward, L. F., Status of the Mesozoic floras of the United States, U. S. Geol. Survey Mon. 48, pt. 1, p. 18, 1905.) Now plugged.

209. *Atchison, Topeka & Santa Fe Railway, at Adamana, sec. 8, T. 18 N., R. 24 E.*

Well 1

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Sand and red clay	12	12	Sandy clay, gravel, and water	1	69
Water gravel; very little water	1	13	Brown sandstone	8	77
Sandy clay	20	33	Blue shale	7	84
Sand, clay, gravel, and quicksand	22	55	Red shale	7	91
Red clay	13	68			

70 feet of 16-inch casing, which is perforated at 54 feet. Tested 70 gallons a minute. Drilled July 12–26, 1927.

209. *Atchison, Topeka & Sante Fe Railway, at Adamana, sec. 8, T. 18 N., R. 24 E.*—Continued

Well 2

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Sand and sandy clay	30	30	Hard red sandstone	11	76
Quicksand	32	62	Hard red shale	4	80
Gravel, but no water	3	65			

69.5 feet of 16-inch casing, perforated to 62 feet. No test recorded. Drilled August 2–10, 1927.

254. *Flowing well at schoolhouse, at Hunt, sec. 18, T. 14 N., R. 26 E.*

	Thickness	Depth		Thickness	Depth
Moenkopi (?) formation:	*Ft. in.*	*Ft. in.*	Moenkopi (?) formation—Con.	*Ft. in.*	*Ft. in.*
Brown shale	20 4	20 4	Reddish-brown shale	59, 8	190 3
Gravel; salt water	9 5	29 9	Red-brown shale	49 9	240
Light-blue shale	50	79 9	Coconino sandstone:		
Salt-water sand	9 10	89 7	Water sand	12	262
Light-blue shale	21 5	111	Red-brown shale	16	288
Sandstone; bitter salt water	9 9	120 9	Red sandstone	6	294
Light-blue shale	9 10	130 7	Sandstone	36	330

Casing set at 288 feet, not cemented. Water at 15 feet and hole wet from that depth. Main water sand at 288 to 330 feet. Log by courtesy of Mr. Knight, Hunt, Ariz.

PUBLIC WATER SUPPLIES

COCONINO COUNTY

Leupp.—Four wells, depth 78 to 100 feet, drilled into alluvial materials of the Little Colorado River Valley. Sufficient water to supply town of 500 during school year.

NAVAJO COUNTY

Winslow (population 3,917).—Supplied with water from a reservoir 5 miles southeast of Winslow on Clear Creek. The reservoir and distribution system are owned by the Santa Fe Railway Co. Most of the water is derived from surface sources, but springs are reported to occur in the canyon of Clear Creek above the dam. Clear Creek flows in a deep gorge cut into Coconino sandstone. The stream is intermittent and is dry most of the year.

Holbrook (population 1,115).—Obtains water from wells drilled into alluvial materials of the Little Colorado River. The city wells have been abandoned temporarily, and the Holbrook Light & Power Co. at present furnishes the supply from a well drilled to a depth of 78 feet. The well owned by the city is 90 feet in depth. It has not been used since 1930. During the winter the city pumps from 37,000 to 50,000 gallons a day; in summer 80,000 to 90,000 gallons a day is used. Mr. Flannigan, superintendent of the Holbrook Water Co., reports that the average water user in Holbrook fails to use the minimum of 1,750 gallons, for which he is charged $1.75 a month. The chemical analysis of the water used in 1934 is given in the table on page 89 (no. 95). The city is reported to have purchased J. W. McLaw's artesian well in sec. 10, T. 17 N., R. 20 E., which is capable of yielding 1,300 gallons a minute of excellent water from the Coconino sandstone.

Joseph City (*unincorporated*).—Obtains a public supply of water from two privately owned wells (59 and 60 in tables). The water is reported to occur in the Coconino sandstone at a depth of 320 feet.

Snowflake (population 659).—Is furnished water by the City Utility from a well that produces water from the Coconino sandstone at a depth of 300 feet.

Woodruff (*unincorporated*).—Supplied with water from a well reported to be 41 feet in depth, drilled into the Coconino sandstone. The Woodruff Domestic Water Co. owns the system.

Lakeside (*unincorporated*).—Supplied with water from Adair Spring.

Pinetop (*unincorporated*).—Obtains water from Pinetop Springs and from privately owned wells.

APACHE COUNTY

St. Johns (county seat, population 1,386).—Obtains a public water supply from Schuster Spring and McIntosh Spring. Shallow private wells are also in use.

Springerville, Egar, Adamana, Navajo, Chambers, Lupton, Houck, and Sanders do not have public water supplies. Wells furnish citizens with water.

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